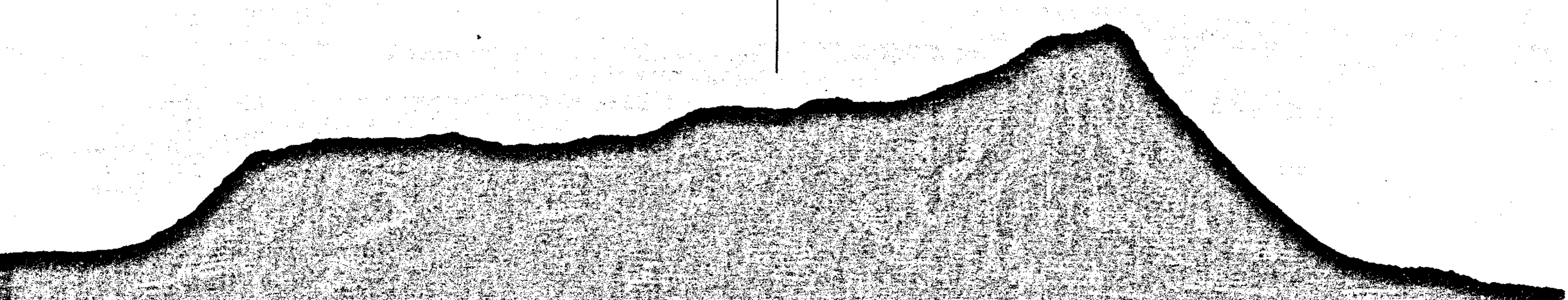
HAWAII INTEGRATED ENERGY ASSESSMENT

VOLUME I

OVERVIEW

DEPARTMENT OF PLANNING
AND ECONOMIC DEVELOPMENT

LAWRENCE BERKELEY LABORATORY
U.S. DEPARTMENT OF ENERGY



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VOLUME I
OVERVIEW

State of Hawaii
Department of Planning
and Economic Development

Lawrence Berkeley Laboratory
University of California
Berkeley, California

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PREFACE

The Hawaii Integrated Energy Assessment (HIEA) is designed to aid decision makers in Hawaii as they plan the transition from nearly total dependence upon oil to a mix of renewable, indigenous energy resources during the next 25 years. Recognition that an integrated assessment of Hawaii's energy future would be useful during this transition grew out of discussions between the State of Hawaii Department of Planning and Economic Development (DPED) and the San Francisco Operations Office of the United States Department of Energy (DOE). Subsequently commissioned by DOE with funding from its Office of Conservation and Solar Energy and the Office of Resource Applications, with further assistance from the State of Hawaii, this study was undertaken as a collaborative effort by the Lawrence Berkeley Laboratory and DPED.

This assessment is intended to be as realistic as possible in its analysis of the prospects for commercial evolution of the energy technologies that are appropriate for Hawaii and in its examination of the many-faceted implications of developing those technologies. As a result, the HIEA conclusions may be more restrained than those with a more optimistic range of opinions might expect.

This report offers a series of views of possible future events. Like any other look into the future, it becomes more tenuous the farther it reaches. It is not intended as a definitive evaluation of the alternate energy technologies it considers nor as a precise forecast of things to come. The basic analytical models used in the assessment, however, will continue to be useful tools if updated data are introduced over the years. The transition to indigenous energy resources will call for a sequence of aggressive, informed decisions as the real future unfolds. It is hoped that the information presented in the six volumes of the HIEA report will provide a sound basis for these decisions.

The many experts from diverse fields and institutions who participated in these studies are acknowledged in the appropriate volumes. We commemorate here the late Dr. Eugene M. Grabbe, former Manager of the DPED's State Center for Science Policy and Technology Assessment, for his key role in initiating the project and guiding its earliest work.

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INTRODUCTION

Hawaii's generous endowment of indigenous, renewable energy resources could deliver the state from its all but complete dependence on imported petroleum. With 92% of its energy derived from imported oil -- and 64% of that from foreign sources -- Hawaii is highly vulnerable to the full impacts of rising oil prices and the growing risk of supply disruptions. This study addresses the questions of how, when and to what extent Hawaii's abundant geothermal, wind, solar, ocean thermal and biomass energy resources can be harnessed to displace oil during the next 25 years.

In part, the answers are cast in the form of feasible "energy futures" for the evolution of these indigenous resources in each of the counties. The projections of the means by which Hawaii's future energy demands can be met were based on evaluations of technologies considered appropriate to Hawaii, estimates of their future costs, and directly relevant economic parameters projected by the state. Environmental impacts, institutional structures, the relevant body of laws and regulations, and social attitudes that may constrain resource development were also taken into account.

Three energy demand-supply projections were structured to quantify the transition to the commercial use of indigenous resources. Energy Futures 1 and 2 take form partly in response to an average 3% per year increase in the price of oil. Future 2, however, incorporates improvements in end-use energy efficiency and conservation beyond those induced by oil price alone. Future 3 is shaped by a high rate of increase in world oil price--10% per year over inflation. While a sustained price escalation at this rate would be severely disruptive to society as a whole, it serves the purpose here of providing perspective on the sensitivity of a transition to indigenous resources attributable to oil price alone.

The analysis embraces only the civilian use of energy and does not take into account US Department of Defense activities. It also excludes petroleum products refined in and exported from Hawaii. Commercial aviation, the largest consumer of petroleum products, is dealt with separately from the other demands for energy. There is no foreseeable indigenous source of jet fuel (hydrogen-fueled aircraft are not expected within the time frame of this study, if at all) and consequently, aviation fuel use would affect the transition from oil to indigenous resources only indirectly through the general economy. This linkage is taken into account but its full ramifications are not explored.

By providing an approach to integrated energy analysis for Hawaii, this assessment offers a model for decision makers in a region, state or small country who must plan to meet the need for energy in a time of growing shortfalls and rising oil prices. This report is intended to help Hawaii plan conversion to the resources it has without relying entirely on one technology or one source of energy. Only after all the feasible options have been examined can a reasonable emphasis be placed on those most likely to meet the state's energy needs. Future events will certainly alter specific details, but the method of analysis used in this study is highly adaptable and should give decision makers a basis for flexible response to changing circumstances.

The report is presented in six volumes. Volume I both summarizes and integrates the findings of the study to present a composite picture of how Hawaii's energy future could evolve. Volume II, Alternate Energy Technologies for Hawaii, and Volume III, Projecting Hawaii's Energy Future: Methodology and Results, evaluate the energy technologies and describe the analytical methodology employed in this study. Volume IV, Energy Data Handbook, provides baseline series of energy and related data essential for the development of alternate energy planning.

Volume V, Rules, Regulations, Permits and Policies Affecting the Development of Alternate Energy Sources in Hawaii, provides a comprehensive review of required permitting procedures, indexed by type of permit and technology. This volume, which is expected to be of great practical use to those interested in implementing alternate energy technologies, also outlines the major federal, state, county and other institutional regulations and policies affecting energy development in Hawaii. Volume VI, Perceptions, Barriers and Strategies Pertaining to the Development of Alternate Energy Sources in the State of Hawaii, focuses on the views expressed in a survey of a wide cross section of Hawaii residents concerning priorities in energy development, conservation, the environment, and the economy. It outlines the major social constraints perceived and suggests strategies for mitigating those constraints. A brief discussion of the major conclusions of Volume VI can be found in Volume I.

ABOUT INFLATION

Throughout the report, costs and prices are expressed in 1980 dollars unless otherwise stated. That means that price increases shown are in addition to inflation. Energy values are given in British thermal units (Btu). In the case of electricity, the term "energy value" means the primary energy input needed to generate and deliver the electricity, assuming a heat value of 11,150 Btu/KWh (kilowatt hour). Capacity, or electric power, however, is expressed as electricity output in megawatts (MW). Energy equivalents in millions of barrels of oil (Mbbl) are approximated by a heat value of 5.8 million Btu/bbl, although it must be borne in mind that petroleum products vary in heat value, and more than one barrel of crude oil is needed to make one barrel of refined product.

SUMMARY OF MAJOR CONCLUSIONS

1. Electricity. By the year 2005, Hawaii could produce as much as 90% 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 and that the rate at which indigeous resources can be exploited depends more on the rate of technological development and the availability of capital than on oil price. 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% of all the energy used in Hawaii. This is largely because there is no indigenous substitute for the jet fuel which represents 32% of Hawaii's energy use and which is central to Hawaii's economy. At least 10% 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% alcohol/90% gasoline mixture. Little liquid fuel should be needed to generate electricity by 2005.

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% of the state's electricity.

4. Economic Impacts. Replacing imported petroleum with indigenous energy sources would have a benefical 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%. The federally mandated automobile mileage standard is expected to reduce gasoline consumption by 60%.

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 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. The use of coal would pose environmental problems, particularly with air pollution and solid waste disposal,and Hawaii would still depend upon an imported fuel.

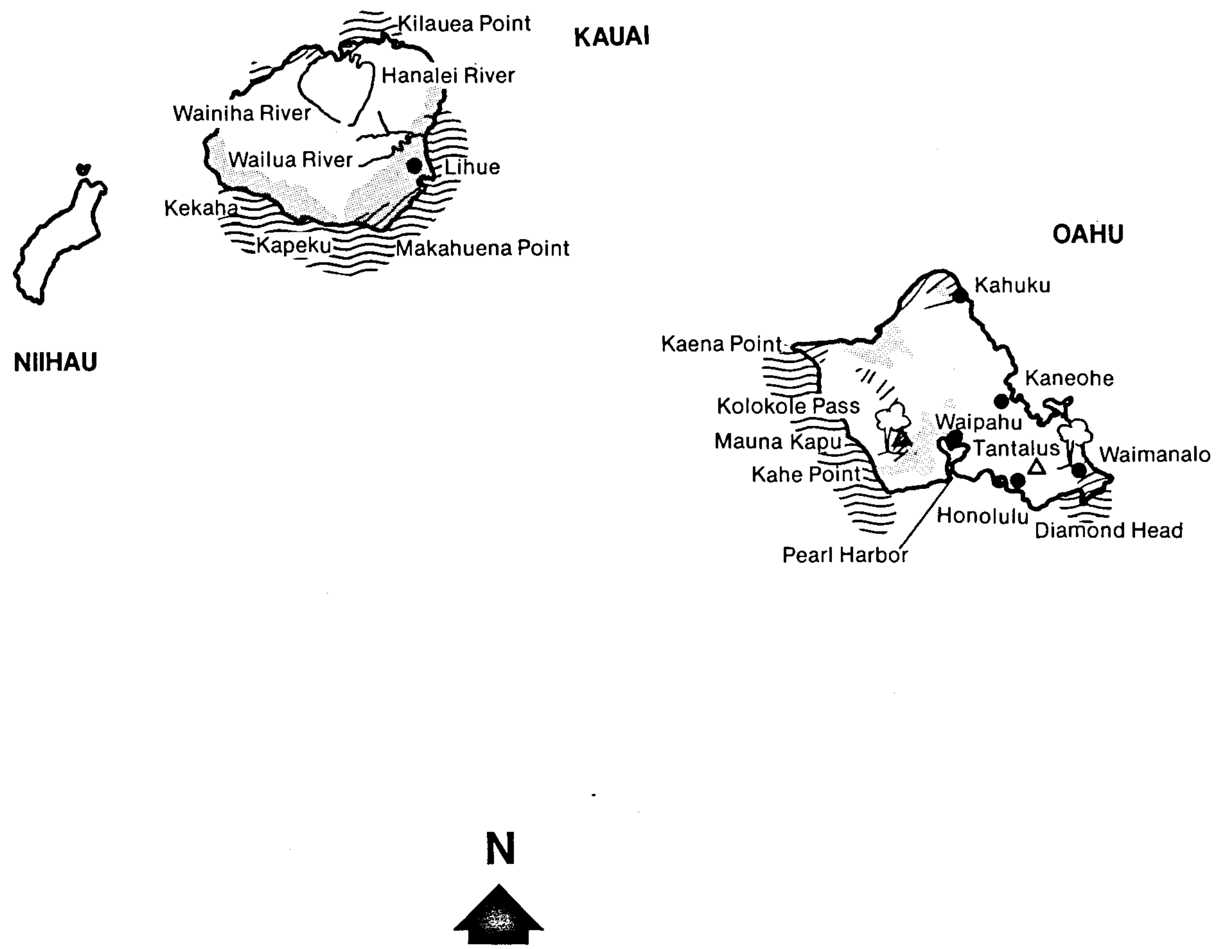
7. Public Opinion. A large majority of Hawaiian residents consider energy as serious a social issue as crime, inflation or unemployment, and public awareness of new energy technologies is high. Consumers know less about energy end uses and will not necessarily place energy savings above convenience in 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.

Chapter 1: HAWAII TODAY

From the towering and sometimes snow-tipped peak of Mauna Kea jutting 13,796 feet into the bright blue sky to the warm, golden beaches that draw millions of visitors from around the world each year, Hawaii is a state of vivid beauty and stark contrasts. White surf crashes against black sand beaches; crisply defined rainbows arch over wisps of waterfalls as they cascade down precipitous slopes; lush green forests glow with a profusion of multi-hued flowers; and the green can suddenly give way to the harsh black terrain of lava flows that vegetation cannot claim.

The Hawaiian Islands consist of eight major and 124 minor islands, giving the state a total land area of 6425 square miles, more than Connecticut, Rhode Island or Delaware. The islands arc from Ka Lae, or South Point, on the Island of Hawaii--the southernmost part of the United States--to Kure Atoll in the group called the Northwestern Hawaiian Islands. Honolulu, capital of Hawaii, lies near the center of the Pacific Ocean. It is 2397 miles southwest of San Francisco, 3847 miles southeast of Tokyo, 5070 miles from Sydney, Australia, and 4829 miles from Washington, D.C. Because of Hawaii's location, aviation fuel represents fully one-third of the energy the state uses, while it accounts for only 2.5% of the country's total energy demand.

Figure 1. Hawaii's alternate energy resources



- ● Community
- △ Mountain
- (sun symbol) Hawaii has many promising sites for solar technologies. On all the islands where solar radiation has been measured, there appears to be a potential for siting solar plants.
- (stippled box) Sugar land and pineapple fields
  In addition to the sugar cane and pineapple shown, biomass is found in the form of MSW in the cities, and wood resources are expected to be developed, mostly on Hawaii.
- (diagonal hatching) Potential wind energy areas
- (tree symbol) Potential geothermal
- (wavy lines) Potential OTEC

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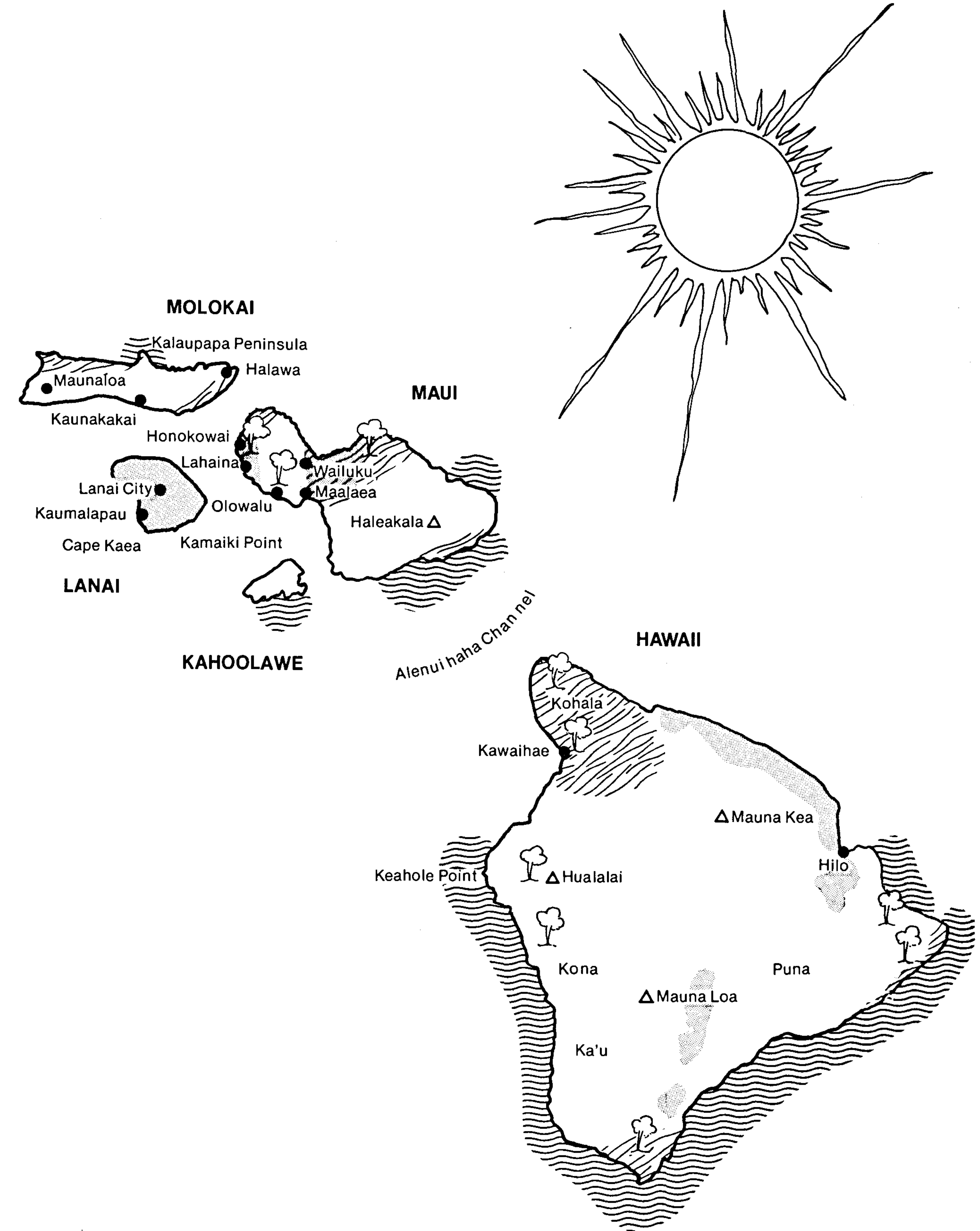

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Seven of the eight most southerly Hawaiian islands are inhabited, and these lie just below the tropic of Cancer. Climatic conditions are close to ideal. Severe storms are relatively infrequent, and while rains can be heavy, especially in windward areas, there is a wide variation in rainfall. Other differences in climate depend upon prevailing winds, the height of the land above sea level, and the effect of island elevation contours on cloud movement. The general weather pattern, however, is of cooling trade winds and moderately warm temperatures throughout the year. In the United States as a whole, 68% of residential electricity is used for space heating, but virtually no energy is used for space heating in Hawaii.

The interesting contrasts in Hawaii's physical environment are paralleled by contrasts in the social environment. Hawaii's people are a remarkable melding of cultures and traditions from many parts of the world: Hawaii, Japan, Europe, China, The Philippines, Korea, Africa, the mainland United States, Puerto Rico, Samoa, and many other places. No ethnic group in Hawaii is numerically dominant; each is a minority.

POPULATION

Official 1980 Census figures have not yet been released, but preliminary counts place the resident population at about 965,000 -- a 25% increase in the last decade. De facto population (including tourists but excluding temporarily absent residents) is nearing 1.1 million. Almost 80% of the residents live on the third largest island, Oahu, in the City and County of Honolulu. Oahu also accounts for more than 80% of the state's energy use. In the last decade, however, the population growth rate of the Neighbor Islands has outpaced the 21% growth rate of Oahu. Since 1970, Hawaii County's population has increased by 45%, Kauai County's by 31%, and Maui County's by 55% (see Table 1).

The state's population is expected to increase at an annual rate of 1.6% from 1980, and 1.3% from 1985 to 1990. This growth will have an important effect on Hawaii's future energy needs. Long-term forecasts of both resident and de facto population growth will be essential to future energy planning.

TABLE 1. -- Resident and De Facto Population by County: 1970 and 1980[a]

County	Resident Population (Thousands) 1970	1980	Percentage Increase[c]	De Facto Population[b] (Thousands) 1970	1980	Percentage Increase[c]
Honolulu	631	762	21	650	826	27
Hawaii	63	92	45	66	99	49
Maui[d]	46	71	55	49	86	75
Kauai	30	39	31	32	49	42
Total	770	965	25	797	1057	33

[a]1980 data are preliminary counts released by the US Bureau of the Census. Numbers have been rounded to the nearest thousand.

[b]Includes visitors present; excludes temporarily absent residents. Independently rounded, may not add to indicated totals.

[c]Percentages are based on unrounded data.

[d]Includes islands of Maui, Molokai and Lanai.

INCOME

The rate of growth in total personal income in Hawaii has been slightly lower than that for the nation as a whole in the last four years. Total personal income for Hawaii in 1979 amounted to $8.4 billion, an increase of $0.8 billion, or 11.3%, over 1978. Wages and other labor income totaled $6.2 billion, or 74% of total personal income in Hawaii, compared to 78% in 1970.

Income generated by industries in Hawaii differs from the US pattern because Hawaii's industrial distribution is different. For example, the ratio of government income to total labor income in Hawaii is 1.9 times the US ratio. Hawaii has 2.8% of the military income of the US and 1.0% of federal civilian income, but it has only 0.4% of total US personal income. Hawaii's relative share of total personal income is low in durable goods, manufacturing and mining, moderately low in non-durable goods, manufacturing and wholesale trade, somewhat higher than the rest of the US in the government sector.

Per capita personal income for Hawaii in 1979 was an estimated $9223 per year, which exceeds the national average of $8773. However, Hawaii's population is growing faster than the national average, and growth in total personal income is less able to keep up with the population increase. (These figures may be revised later when 1980 Census final counts are published and 1971-79 population estimates are changed.)

Real personal income growth (adjusted for inflation) will probably exceed population growth and increase 4.2% per year in the next decade. As personal income outstrips population growth, increased demand for energy--if supplies are restricted by foreign-import shortfalls--will put inflationary pressure on the prices of electricity, gasoline and aviation fuel.

ECONOMIC OVERVIEW

Hawaii's economy has been dynamic in the years since 1959, when statehood was achieved and the first jet planes arrived. Today it consists of four basic sectors: tourism, federal expenditures, agriculture, and small industry. The most vigorous and perhaps most important of these in terms of the overall economy is tourism.

Tourism

As Hawaii's number one industry in providing income and jobs, tourism stands out in any analysis of the economy. Whereas sugar, pineapple, and military spending were the most important industries from the 1940s into the early 1960s, tourist expenditures took off in the late 1960s. In 1959, only 243,000 overnight visitors came to Hawaii. By 1969, the number had reached 1.5 million. It soared to 3.96 million in 1979. This growth reflected general prosperity and rising disposable income on the Mainland. Visitors spent $2.6 billion in Hawaii in 1979, provided approximately $2 billion in additional indirect income and tax revenues and more than 111,000 jobs for residents.

Tourist activity is expected to continue to shift to the Neighbor Islands at rates comparable to those of the past 10 years. The state expects a 5% annual rate of increase in visitor arrivals from 1980 to 1985, and 4% from 1985 to 1990. If current trends continue, tourism would increase about 3.3% annually on Oahu, 5.5% on Kauai, 6.8% on Hawaii, and 6.0% on Maui. This growth rate could change if national economic conditions continue to decline.

There is a continuing need to create jobs on the Neighbor Islands, which have generally higher unemployment rates than Honolulu (see Table 2). The economies of the Neighbor Islands are less diversified than Oahu's, and sugar employment (over 80% of which is on the Neighbor Islands) is expected to continue to decline. Until potential new industries become productive on the Neighbor Islands, tourism will have to provide most of the new jobs there.

TABLE 2. -- Unemployment Rate for Hawaii: 1970-1980
(percentage of workers unemployed)

	State	C&C Honolulu	Hawaii County	Kauai County	Maui County
1970	4.9	4.8	4.4	5.2	7.0
1975	8.3	8.0	9.9	9.1	9.8
1976	9.8	9.6	11.4	9.4	10.6
1977	7.4	7.3	9.2	6.5	7.4
1978	7.8	7.6	10.1	6.9	7.5
1979	6.3	6.1	8.1	5.6	6.3
1980[a]	5.6	5.3	7.5	5.0	6.1

[a]As of third quarter 1980.

Source: Hawaii Department of Labor and Industrial Relations.

Federal Expenditures

Before 1972, federal defense expenditures were the state's most important economic sector. After 1972, tourism moved into the number one spot; and since 1977, federal non-defense spending has exceeded defense spending. Combined federal expenditures in Hawaii have recently begun to compete once again with tourism for importance in the state's economy.

Military expenditures in Hawaii totaled $1.2 billion in 1979, a 5.7% increase over 1978. On the average, total military expenditures have increased by 6.6% per year. Non-defense expenditures, which were slightly higher than military expenditures in 1979, have been increasing by an average of 15.7% per year since 1973.

It is clear that federal expenditures will continue to be an important part of Hawaii's economy, but while military spending is increasing, the rate of growth of these expenditures is declining. This trend may be reversed in years to come as a result of national legislation focused on defense spending. Federal non-defense spending may not fare so well because Congress is expected to make domestic budget cuts in an attempt to reduce the budget deficit.

Agriculture

Agriculture provides Hawaii's third largest source of income. The value of sugar and pineapple sales was $536 million in 1979, up 21% from $443 million in 1978. Together, these two crops accounted for 88% of the value of all agriculture crops grown in Hawaii in 1979.

Unprocessed sugar cane production increased from 9.3 million tons in 1978 to 9.6 million tons in 1979. Pineapple production rose from 675,000 tons in 1978 to 681,000 tons in 1979.

The outlook for more diversified agricultural production for both local consumption and export is bright. Among Hawaiian products, flowers and other nursery products, macadamia nuts and papayas seem most likely to find markets. However, because of mechanization, biological engineering and labor-saving devices, productivity will probably outpace the growth in agricultural jobs.

Construction

Construction in Hawaii continues to be a very unpredictable economic sector, mainly because of the sensitivity of housing construction to money-market conditions and, more recently, to widespread speculative buying. Although it is very important in terms of income and employment, construction has not been considered a primary economic activity in the past because it is stimulated by other factors such as tourism and federal expenditures. It is important to the economy of the state because of its large dollar-volume ($1.3 billion construction-put-in-place in 1979), large number of jobs (22,950), and impact on personal income and tax revenues.

The combined value of authorized private construction and government contracts awarded in 1979 totaled $1.373 billion, compared to $1.047 billion in 1978. Private residential construction authorizations in 1979 increased 34% above 1978, and commercial and industrial authorizations increased 18%.

The Garment Industry

The garment industry is a small but growing sector of Hawaii's economy. Although garment manufacturing now has an export value of only $50 to $60 million, it is a labor intensive industry and promises to furnish considerable employment in the future. In 1980, an estimated 4200 jobs were available in the industry. Total wholesale sales are estimated to have been $75.7 million in 1980, with $28.9 million from exports and the remainder from sales to residents and tourists. As Hawaii fashions are promoted and accepted on the Mainland, and as markets expand, more jobs will be available in the apparel trade, and more export dollars will accrue to the state. Increasing costs of fabrics due to rising energy costs, however, may challenge the industry's planned market expansion.

Employment

Of the 889,000 civilian residents in Hawaii in 1979, 399,000 were in the labor force. Most of these were working in labor intensive service industries and in government, which together provided 42% of all the jobs in the state. Tourism, which is the economic backbone of the state, provides many of these jobs, including 24,950 jobs in hotels alone in 1979. Agriculture provides a significant amount of export income but only a small number of jobs. In 1979, sugar and pineapple field work provided 7500 jobs and total agriculture only 10,800 jobs, or 2.5% of the jobs in the state. Food processing provided another 11,500 jobs in 1979. Even when food processing and all agriculture jobs are combined, they account for just 5.1% of all jobs.

The state's total unemployment was 25,000 in 1979, a decrease of 6000 from 1978. The number of civilians employed increased from 369,000 in 1978 to 374,000 in 1979. Hawaii's unemployment rate peaked at 9.8% in 1976 but dropped to 5.4% by mid-1980.

The Long-Term Economic Outlook

Beyond 1980, Hawaii's economic performance for the rest of the century will depend upon the degree to which its key industries expand. Tourism is the most important. It is the largest source of export income and jobs, and it has the largest potential among all Hawaii's major industries. The long-term forecast for the US economy calls for an average GNP growth rate of 3.5% per year resulting from improved technology, increased labor productivity, labor force growth, and capital accumulation rather than from expansionary economic policies. For Hawaii, this forecast means a favorable outlook for tourism because growth in travel from the Mainland depends on the growth of personal income, along with continued promotional efforts and improved airline service.

However, future tourism growth may be restrained by other factors, including limited energy supplies and spiraling energy costs that result in higher air fares and ground transportation costs, competition in national and worldwide tourist markets, and population pressure from increasing numbers of visitors. It is estimated that visitor arrivals will increase at an average annual rate of 5% from 1980 to 1985, and 4% from 1985 to 1990.

Other primary economic activities, including diversified agriculture, aquaculture, commercial fishing, textile manufacturing, precious coral harvesting, motion picture and television production, astronomy, alternate energy resources development and manganese nodule mining, also show promise for growth, as the State of Hawaii pursues its policy of diversifying its economic base.

ENERGY CONSUMPTION TODAY

The total annual state civilian energy consumption increased from 78 trillion Btu in 1963 to 200 trillion Btu in 1978. This represents about one-quarter of one percent of the nation's annual energy consumption. From another point of view, it is about equal to the fuel needed to run three 1000 MW thermal power plants for a year.

Because about 80% of the state's resident population, and business, government and educational facilities are located on the Island of Oahu, City and County of Honolulu, Oahu is the primary source of the state's energy demand. In 1978, this energy demand was divided among the four counties as follows: Honolulu City and County, 82.0%; Hawaii County, 7.5%; Maui County, 7.2%; and Kauai County, 3.3% (see Figure 2).

However, population and economic activities are increasing rapidly on the Neighbor Islands, with a concurrent increase in energy demand. Maui does not yet have as many residents as Hawaii; increasing numbers of energy-intensive hotels and other aspects of tourism probably account for its growing and disproportionate energy consumption.

Energy Consumption by Type of Fuel or Energy

Hawaii consumes energy in significantly different forms from those of the United States as a whole. Because Hawaii has almost no need for space heating, there is no consumption of furnace oil. On the other hand, Honolulu is the transportation hub of the Pacific with more than 4.2 million air passenger arrivals per year, so that nearly one-third of Hawaii's energy demand consists of aviation fuel. Figure 3 shows Hawaii's aviation fuel consumption in relation to all other types of energy consumption. Nationally, aviation fuel makes up only 6% of US oil consumption and only 2.5% of US energy demand. Figure 4 provides energy consumption breakdowns for the four counties, with the national breakdown shown for comparison. The 1977 figures are based on a point-in-time survey which was not repeated, and therefore the data given are the most recent available.

Energy Consumption by Type of Consumer

The major uses of energy in Hawaii are: transportation, 54.9%; electricity, 24.8%; non-transportation, 20.3%. The impact of Hawaii's two largest economic sectors on energy consumption is apparent. Tourism accounts for most of the 27% consumed by air transportation, and a significant portion of the 16% used by ground transportation. The military accounts for 19% of the state total. Energy consumption by the military is highest for transportation, followed by non-transportation direct fuel usage, and electricity. (Military energy use is not included in the later analysis of Hawaii's energy future in this report, and military consumption is noted here only as a matter of interest.)

The civilian population exhibits a significantly different consumption pattern. Electrical energy (21% of the total civilian energy consumption) is followed by transportation and non-transportation direct fuel usage.

There are significant differences in consumption patterns between Oahu and the Neighbor Islands:

* All international and most interisland aircraft and domestic overseas carriers fuel primarily at Honolulu International Airport on Oahu, although some domestic and interisland aircraft fuel at the other island airports

* Military installations, which account for a significant proportion of the demand for aviation fuels, are located primarily on Oahu

* The agricultural industry is located predominantly on the Neighbor Islands

* More than three-fourths of Hawaii's business and commercial establishments are located on Oahu

FIGURE 2. -- Total Energy Consumption by County: 1963 to 1978

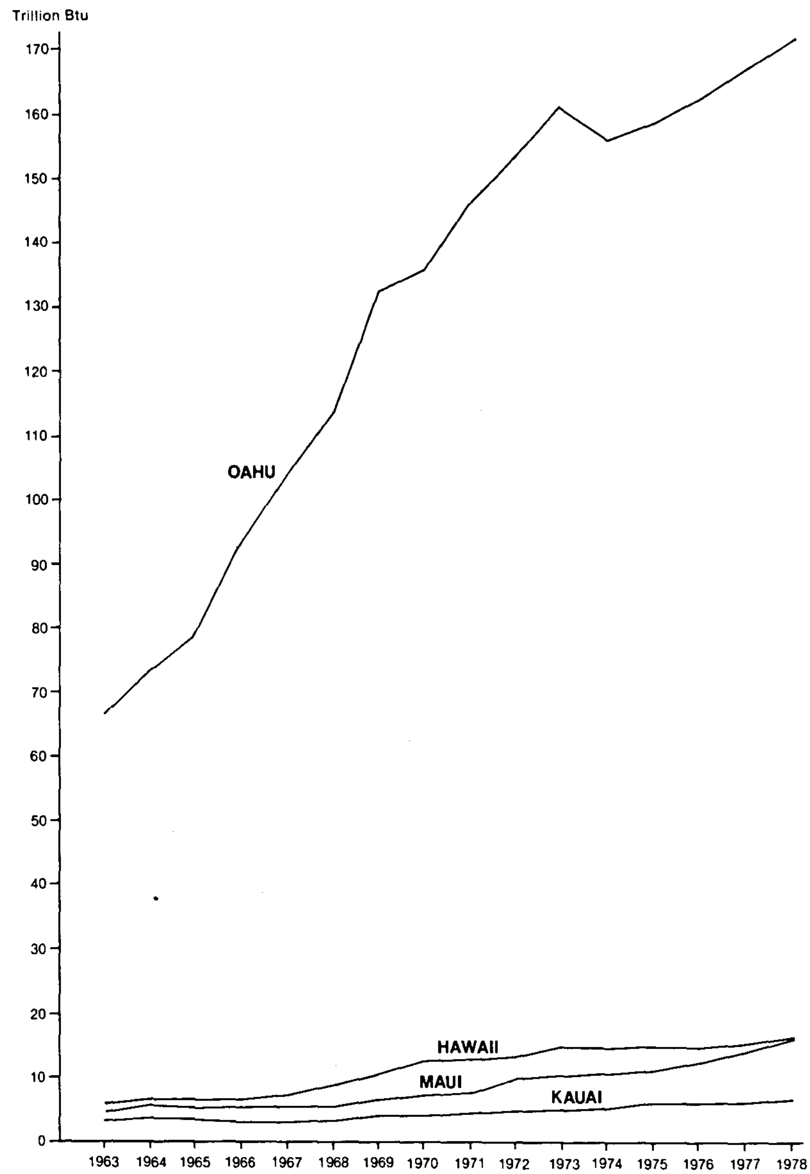

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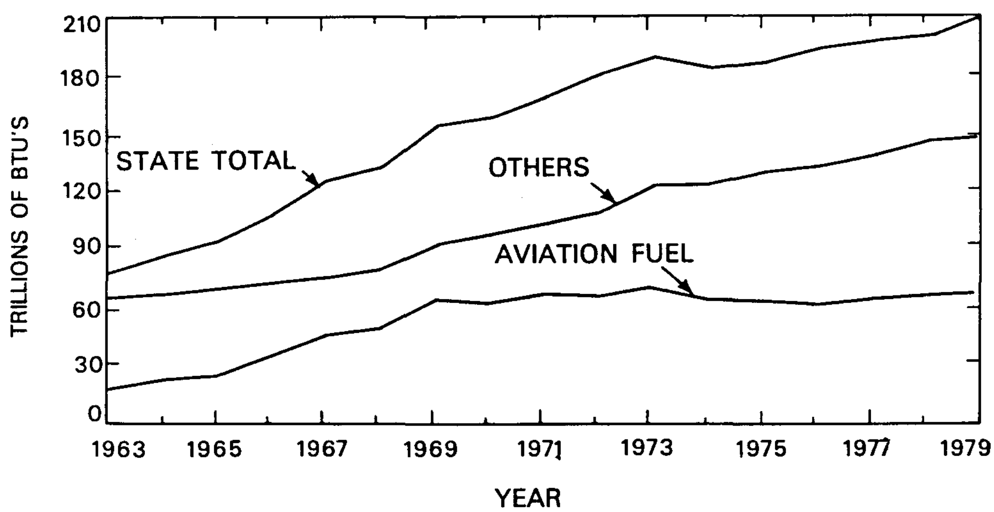
FIGURE 3. -- Energy Consumption, Aviation Fuel and Other Types: 1963 to 1978.



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Energy Consumption by End Uses

Figure 4 shows Hawaii's energy consumption by type of energy. For the most part, the end uses are clear, given the energy type. Each petroleum fuel has specific applications. Gasoline is employed in light-duty vehicles. Residual fuel is burned in industrial boilers; for example, the sugar mills use residual oil to supplement bagasse when the latter is in short supply or too wet to burn properly. Diesel fuel is consumed by heavy trucks and buses, and also by the heavy equipment employed to harvest sugar cane and pineapples. Gas, both synthetic natural gas (SNG) and liquid petroleum gas (LPG), is used mostly for water-heating, although a certain amount goes for cooking.

Electricity, with its myriad of end uses, presents a special problem in analysis. However, the Hawaiian Electric Company (HECO) has developed an ongoing program to analyze its customers' requirements. HECO serves the Island of Oahu, including Honolulu, and provides 83% of the state's electricity. Sales in 1979 totaled 5.164 million kilowatt-hours (KWh) to 213,781 customers.

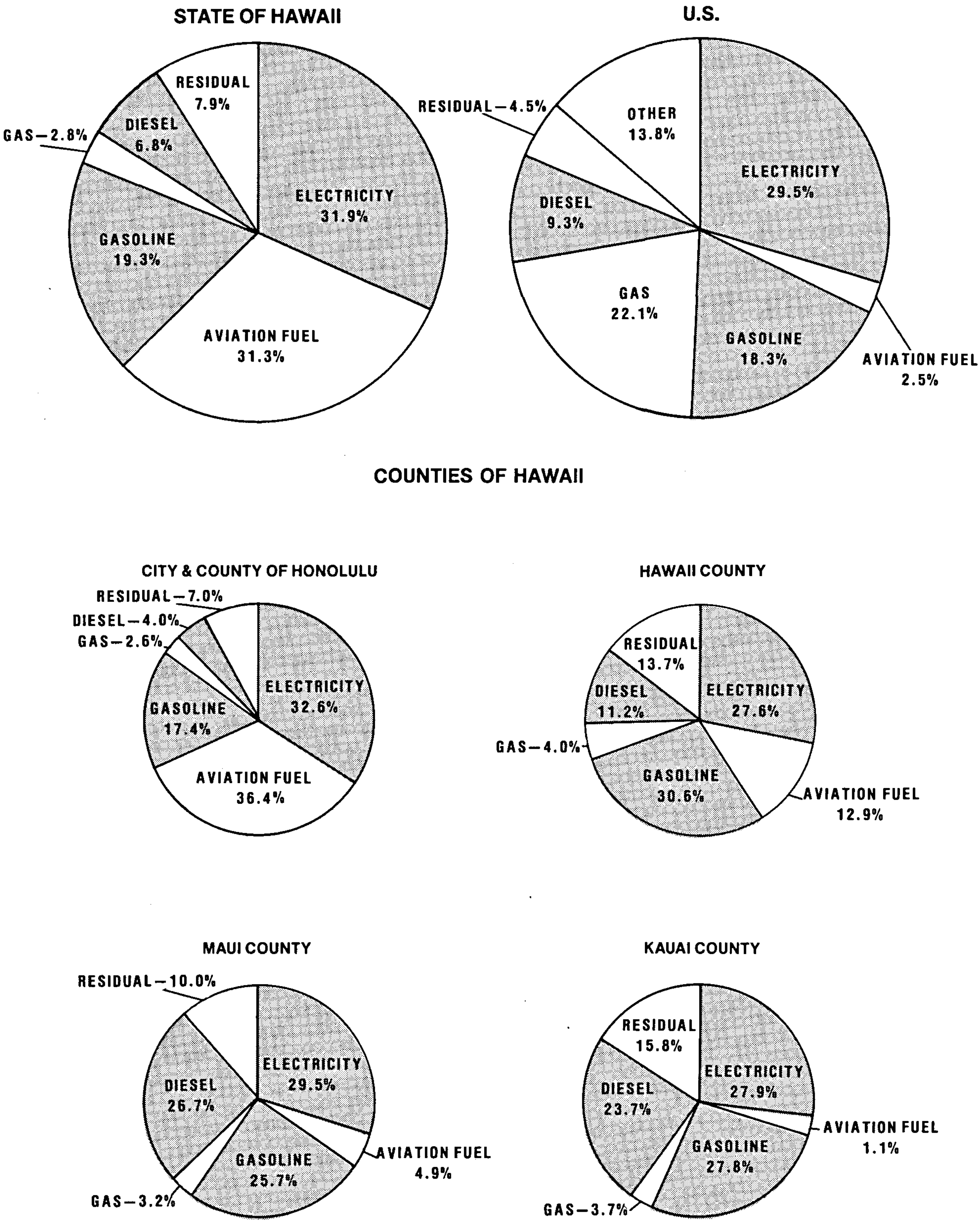
HECO identifies usage by percentage of sales under four groups of rate schedules: residential users; small commercial power users; large power users; and street lighting. There is a certain amount of overlap between rate schedules. For example, residential customers using over a certain amount of electricity each month can be classed as small commercial users. Large power rate schedules cover multi-unit apartments and military housing as well as hotels and offices, stores, manufacturing establishments, schools and hospitals.

A study done by HECO covering the 12-month period between December 1977 and November 1978 showed that large power users accounted for 50% of sales, residential users accounted for 30%, small commercial users accounted for 18%, and street lighting for slightly over 1% (see Table 3).

TABLE 3. -- Hawaiian Electric Company Sales by Rate Schedule: 1978

Rate schedule by type of customer	Percentage of sales
Large power users	50
Residential users	30
Small commercial users	18
Street lighting	1

FIGURE 4. -- Energy Consumption by Energy Type, Hawaii and the United States: 1977



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Residential electricity consumption on Oahu is actually higher than 30% of sales; an additional 7% is purchased on another schedule for consumption in master-metered apartments or condominiums, in the common-area loads of apartments and condominiums whether master-metered or not, and in military housing.

Although the building trend is toward condominiums and other multi-unit housing, single family homes are still the predominant type of residence in Hawaii. In 1978 they comprised 56.5% of the state's 274,000 dwelling units. In a typical, all-electric single-family home for a family of four, electricity consumption averages 1000 Kwh per month, broken down as follows:

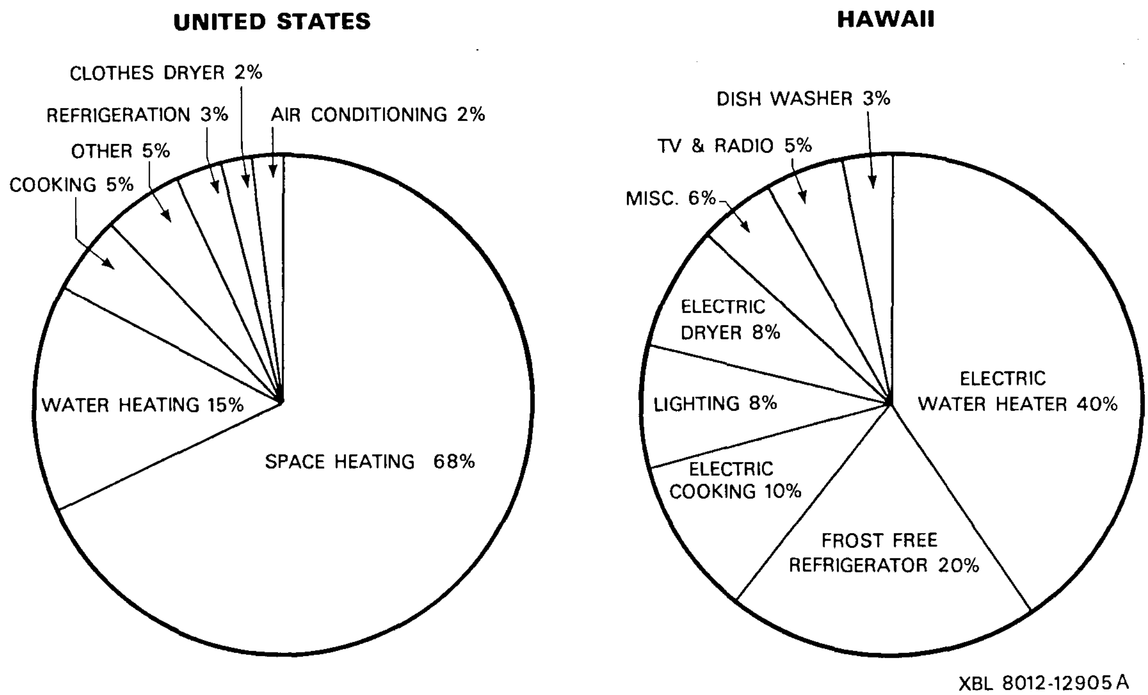
TABLE 4. -- Typical Single Family Home Electricity Use: 1978

Use	Percentage
Water Heating	40
Refrigeration	20
Cooking	10
Lighting	8
Clothes dryer	8
TV & Radio	5
Dishwasher	3
Miscellaneous	6

Energy consumption patterns in Hawaii's apartments and condominiums tend to resemble those of single family homes, with two differences. Central water heating in such units generally uses gas rather than electricity. Twenty-eight percent of all dwelling units have gas water heating. With few exceptions these dwellings are apartments and condominiums. Second, apartments and condominiums tend to have air conditioning, often more for noise control than for temperature control. Air conditioning, if operated full time, doubles the energy consumption of a dwelling in Hawaii. One kilowatt-hour of electricity is required per ton of refrigeration per cooling degree day. For example, a three ton air conditioning unit, with a load of 4000 cooling degree days per year, will consume 12,000 KWh per year. Central air conditioning causes a 55% to 60% increase in the electricity consumption of a two bedroom, all-electric apartment. For the more typical apartment that is all-electric except for gas-fired central water heating, central air conditioning entails an increase of 85% or more in electricity consumption.

A contrast between energy usage by the residential sector in Hawaii and in the US as a whole is presented in Figure 5 (again, 1977 data are the most recent available.) The disparities primarily reflect the differences in climate between the two locations. Because Hawaii has no significant need for space heating, which accounts for 68% of residential energy use nationwide, the remaining home uses all take on larger shares of the total. On a per capita basis, total electrical consumption is much lower in Hawaii than in any other state.

FIGURE 5. -- End Uses of Residential Electricity, Hawaii and the United States: 1977



Half of the total electric power consumed is purchased on the Large Power Schedule. As Table 5 indicates, there is no typical customer. Some of the sectors are well understood with respect to end-uses, others are not. It is known that lighting is the predominant end-use of electricity on the military bases and refrigeration the largest end-use of electricity in supermarkets. Electric motors as large as 2000 horsepower are the most common users in the manufacturing sector. Hotels use an average of 1000 kilowatt hours per guest-month at 80% occupancy.

TABLE 5. -- Major Users, Large Power Schedule: Dec. 1977 to Nov. 1978

User	Percentage of Usage
Military bases	22.1
Hotels and Offices	21.2
Hotels	11.7
Offices	9.5
Businesses	18.8
Supermarkets	3.6
Other retail	5.2
Service	5.1
Communication & recreation	4.9
Housing (multi-unit)	14.0
Military housing	8.7
Apartments	5.3
Manufacturing	12.3
Diversified manufacturing	8.9
Food processing	2.4
Wholesaling & storage	1.0
Other	11.6
Schools & hospitals	8.6
Pumping - sewers, etc.	3.0

ENERGY SUPPLY TODAY

The State of Hawaii is largely dependent on imported petroleum. The extent of this dependence varies, according to the method of calculation, from 91% to 94% dependence on petroleum.

Petroleum

Hawaii is part of a world-wide oil-refining and oil-consuming system. The state has two refineries that both import crude oil and export refined products.

It has already been noted that because of Hawaii's mid-Pacific location and the large air travel industry associated with tourism, jet fuel makes up nearly one-third of total oil consumption. It is not economical to produce such a large fraction of kerosene from a barrel of crude;

thus Hawaii imports about half of its jet fuel. When the other half is produced at the local refineries, an excess of residual oil results. This residual is exported to San Diego Gas and Electric Company.

The state's location also makes it the closest point of supply for other Pacific islands; Hawaii's refineries export about 5000 barrels of petroleum products per day to these consumers.

Hawaii's virtually complete dependence upon petroleum would be of less concern if the petroleum originated within the United States. In fact, 62.5% arrives directly from foreign sources--Saudi Arabia, Oman, Indonesia and Malaysia. Alaska supplies 13.5%, and the Mainland 24%. Even this last figure can be misleading because refined products from Mainland refineries may be of foreign origin. Petroleum products are brought in from California, the Caribbean and Singapore to meet the demand that cannot be met by the local refineries.

Biomass

Biomass by-products from agricultural operations currently represent the state's second largest source of energy. In 1978, the sugar industry had 221,000 acres in cane cultivation and produced about one million tons of raw sugar and about 309,000 tons of major by-product, molasses. Approximately 2.9 million tons of bagasse were produced, with a nominal moisture content of 48%, of which some 2.4 million tons were burned in the sugar factory boilers. This is roughly equivalent to 2.2 million barrels of fuel oil. In addition, over 276,000 dry tons of trash (leaves and cane tops) were removed by cane cleaners, and about 14% (38,200 dry tons) of this was burned; 2800 tons of wood chips and a small amount of macadamia nut shells were also used as fuel.

Hydropower

Hawaii now has 13 hydroelectric power plants with a total rated capacity of 17.75 MW. In 1979, they generated a total of 97 million KWh of electricity.

STATE ENERGY POLICIES AND OBJECTIVES

Hawaii's reliance upon imported foreign oil for its energy supply became especially evident with the oil embargo of 1973-74. Since that time, spiraling prices for oil and petroleum products, coupled with the growing political instability of many oil-producing nations, have intensified the interest of decision makers and the general public in the problems of Hawaii's energy supply and demand and in formulating policies to help overcome these problems.

Although the lead role in developing and commercializing alternate energy technologies will usually be taken by the private sector, the federal, state, and county governments must be involved in determining Hawaii's energy goals and in expediting the planning needed to achieve these goals.

The Hawaii State Plan

The principal planning document for the State of Hawaii is the Hawaii State Plan, which was adopted by the legislature in 1978. It sets forth the overall goals and policies which serve as guidelines for the orderly development and use of Hawaii's resources in the areas of the economy, the physical environment, and the social well-being of its people. The State Plan establishes two general goals for energy planning:

* Dependable, efficient, and economical statewide systems capable of supporting the energy needs of the people

* Increased energy self-sufficiency

Specific recommendations, called Priority Actions, are outlined for achieving these energy goals. Because of the broad scope of the Plan itself, the Priority Actions are also quite broad. They include recommendations that the state encourage the development of alternate energy resources and the development of energy-efficient transportation systems. They also ask that the state channel future urban development into more compact, easily serviceable urban areas to maximize energy conservation. Other conservation recommendations in priority actions include state encouragement of programs educating consumers on the need and means of conserving energy. The state has instituted tax incentives to encourage the use of alternate energy resources in homes and other buildings.

State Energy Functional Plan

Because of the broad nature of its coverage, the Hawaii State Plan and its Priority Actions have to deal with energy issues briefly and in fairly general terms. But because of Hawaii's extreme vulnerability, both physically and economically, to changes in energy supply, energy was identified in the State Plan as one of twelve functional areas requiring a specific Functional Plan. The State Energy Plan was developed to meed this requirement. It was published in September 1980, and will be considered by the legislature in early 1981.

The primary purpose of the state functional plans is to further define and to implement the goals of the Hawaii State Plan. The functional plans form a critical middle link between the broad policy guidelines of the State Plan and the specific implementing activities of several state and county agencies. Functional plans also establish vital linkages between different state agencies and between state and county agencies. The Energy Functional Plan is also designed to meet federal requirements for state energy plans that are expected to be mandated under the National Energy Management Partnership Act now pending before Congress.

The Energy Functional Plan offers specific directions to state agencies about implementing State Plan energy goals. It provides a basis for assigning priorities to the allocation of resources and the delivery of energy services. The Plan points out the need to coordinate the roles of state and county governments, private industry, and the general public in addressing the issues of Hawaii's energy supply and demand problems.

The State Energy Plan identifies major relationships among energy and other functional planning areas. For example, the Tourism Functional Plan interacts closely with the Energy Functional Plan in terms of the needs for aviation and ground transportation fuels and furnishing power to resort areas. In another aspect, energy conservation programs which persuade large numbers of people to use public transportation instead of private cars will require expansion of the public transportation system to accommodate the increased numbers of passengers. A significant reduction in the amount of gasoline purchased in the state would affect the amount of taxes paid into the state highway fund, creating a need for additional funding or cutbacks in expenditures.

County General Plans and Development Plans

The four counties of the state have developed their own General Plans or Development Plans. These form another element in the statewide planning system and provide the State Energy Plan with additional bases for the formulation of state energy goals and policies. County-oriented goals include:

* The provision of energy facility systems dependent upon desired county growth levels and distribution of population

* The development of alternate energy resources through expressed county positions regarding the compatibility of energy resources development and desired land use

The City and County of Honolulu General Plan sets forth energy objectives in three policy areas directed primarily toward conservation, development of near-term and long-term alternatives, and public education on energy. This approach follows closely the objectives and policies of the Hawaii State Plan, although the City and County of Honolulu places more specific emphasis on public information.

The Hawaii County General Plan has as one of its energy goals the establishment of the Island of Hawaii as a demonstration community for the development and use of natural energy resources, including biomass, ethanol, geothermal, wind, solar and ocean thermal energy conversion (STEC and OTEC). Policies include encouraging the expansion of the energy research industry, educating the public about new technologies and conservation techniques, and maintaining a balance between resource development and environmental quality.

The energy objectives of the Maui County General Plan are directed toward making the county (which includes the three inhabited islands of Maui, Molokai, and Lanai as well as the uninhabited Island of Kahoolawe) more energy self-sufficient. Energy resource development policies include maintaining an ongoing assessment of energy resources and encouraging programs to test the feasibility of alternate energy sources. Energy conservation policies call for public awareness programs, incentive programs for solar heaters and other energy-saving devices, installation of energy-saving devices in government buildings where feasible, and support for similar installations in all new private and public development.

The Kauai County General Plan as published in 1979 does not contain specific energy objectives, although these objectives will be developed when the General Plan is revised in 1981.

County Energy Self-Sufficiency Plans

Each of the state's four counties has been responsible for developing and implementing a County Energy Self-Sufficiency Plan that provides resource utilization strategies appropriate to the unique conditions and indigenous energy resources of each county. Like the State Energy Functional Plan, the County Self-Sufficiency Plans make specific recommendations for carrying out the broad guidelines expressed in the General Plans.

The Energy Self-Sufficiency Plan of the City and County of Honolulu (comprising the Island of Oahu) differs from the energy plans of the other counties in that it does not consider that energy self-sufficiency for the Island of Oahu is possible. Energy for Oahu will have to come from other islands, if not from Indonesia, Alaska, the Persian Gulf or other sources.

The City and County of Honolulu does plan, however, to make a marked improvement in Oahu's energy situation by encouraging conservation and greater efficiency in energy consumption. Bicycling and car pooling are to be encouraged and facilitated. Bus service is to be improved and an expanded mass transit system is planned. Solar water heating, waste heat reclamation, and natural ventilation are to be encouraged. Building ordinances will be revised, if necessary.

On the energy supply side, the centerpiece of the City and County's program is a proposed solid-waste recovery plant; a construction and operation contract for the plant is being completed. The City and County government also plans to support siting investigations for wind turbines and an OTEC plant.

The Energy Self Sufficiency Plan for the County of Hawaii was prepared by SRI International which acted as a consultant with the aid of a grant from the US Department of Energy. This plan calls for the increased utilization of bagasse-fired cogeneration of electricity, early deployment of wind turbine generators, immediate development of geothermal energy, and immediate conversion of molasses to motor alcohol. The first three are considered economically feasible at present; various subsidies are or might be made available to assist in the commercialization of fuel ethanol.

Hawaii County's plan includes development of a stronger economy and a 90% overall growth in population with only a 4-6% increase in fuel imports and a 13-17% increase in overall fuel use between 1978 and 1990. The percentage of indigenous energy use is expected to increase by 42-47% during the same period, assuring greater independence from imports, but not self-sufficiency, by 1990.

Maui County (including the islands of Maui, Molokai and Lanai) has an Energy Self-Sufficiency Plan which envisions electrical self-sufficiency by 2005. All feasible sources of electricity are to be developed: bagasse, geothermal, pineapple waste, solar thermal energy conversion (STEC) and wind, followed later by biomass plantations and OTEC. Virtually complete energy self-sufficiency is predicted when and if electric vehicles replace internal combustion vehicles. The total capital cost of the 25-year program is estimated at $2.4 billion (1978 dollars). The Island of Molokai, with its small population of 6000, expects electrical energy independence in a relatively short time through use of biomass electrical generation and wind turbines. Lanai Island, with its even smaller population of 2200 residents will continue to receive power from the pineapple plantation.

Kauai County's Energy Self-Sufficiency Plan recognizes that its energy situation is significantly different from the remainder of the state. Kauai is the oldest of the major Hawaiian Islands and because the subsurface residue of its volcanic origin has long since cooled there is little possibility of harnessing geothermal energy there.

Kauai has to contend with another adverse circumstance. Even if the rest of the state is eventually connected by undersea cables into a single electric grid, it is unlikely that this cable system will be extended across the 72.8-mile-wide and 10,000-foot-deep channel that separates Kauai from Oahu. The problem of connecting Kauai and Niihau, the two islands comprising Kauai County, is less severe because the channel between them is only 17 miles wide and 3600 feet deep.

Kauai County, then, has to consider energy self-sufficiency very seriously. The Self-Sufficiency Plan develops three scenarios: Business as Usual, Rapid Growth, and Controlled Growth. Each scenario contains projections of population; per capita income and petroleum prices (both in constant dollars); and expected changes in the county's economic structure.

An inventory of available energy resources provides the point of departure for the three scenarios. Kauai already obtains half of its primary energy from bagasse and hydropower, with a million barrels of oil per year making up the balance.

Energy self-sufficiency for Kauai is considered a possibility only under the Controlled Growth scenario. Kauai has the greatest hydropower potential in the state. Maximum development of hydroelectricity, together with bagasse-fired cogeneration in modern boilers, could bring the county much closer to electrical self-sufficiency. After that, emerging technologies, such as wind turbines and tree farms, will have to be considered for development.

<u>Implementing State Energy Policies</u>

The several plans dealing with state energy goals contain a generally encouraging agreement within the goals themselves and even on overall means of implementing these goals. In general terms, the State of Hawaii's policies for achieving its energy goals can be organized into five major categories of implementation:

* Statewide energy organization and program management

* Alternate energy resource development

* Energy conservation

* Management of conventional energy sources

* Land use and support facility systems planning

As a means of assisting energy organization and program management, the State Energy Plan recommends three administrative procedures:

1. Establishing a Division of Energy within the DPED to implement energy planning. Functions of the proposed Division include policy and resource allocation recommendations, and program management and evaluation.

2. An ongoing institutional mechanism to integrate county energy self-sufficiency planning with statewide efforts.

3. Establishing an energy data management system to support Energy Division activities. This system would generate current status reports of government and private sector energy activities, data analyses, and simulation of future energy scenarios. It would provide a consistent and comprehensive data base for planners and decision makers.

Future energy scenarios will model the rate of increase in the use of indigenous energy resources over time, based on resource potential and different estimates of cost and development constraints. Such analyses will assist planners in establishing measurable goals and in formulating basic strategies and priorities. This planning tool will become available upon completion of the Hawaii Integrated Energy Assessment project.

Central to the implementation of state energy policies is the need to establish clearly the appropriate roles of government, private industry and the general public in shaping Hawaii's energy future.

Private industry has the primary role in commercializing alternate energy resources and developing effective conservation measures. It takes part in research, development and demonstration activities directed toward commercializing new technologies, although in many instances this involvement is made through joint arrangements involving the cooperation and support of government. Under our economic system, private industry can engage in R&D only if eventual benefits are likely to outweigh current risks to capital invested.

The role of government is to encourage the achievement of desired social, economic, and environmental conditions related to energy. It also provides support and incentives to research and demonstration projects which have not yet become competitive with conventional energy supplies. Government manages public resources and facilitates appropriate action by other levels of government and the private sector to work towards these goals. Some of the actions taken by government in its role as a manager and facilitator of energy programs include:

* Provision of public awareness and education programs

* Removal of institutional and legal barriers

* Provision of economic and financial incentives for commercialization and development of indigenous energy resources

* Assistance to the private sector or assumption of the lead role in research, development and demonstration of alternate energy technologies

* Regulation for the wise use of public resources and establishment of public and private rights to these resources

* Formulation of plans for future implementation

The general public, as consumers and taxpayers, have an increasingly important role in formulating as well as implementing government and private energy programs. Refusal by the general public to accept any energy program will mean its eventual failure.

The State of Hawaii, through its Department of Planning and Economic Development, recognizes that coordination of its efforts with the private sector and the various county and federal government agencies is essential to achieve energy goals. An integral part of the state's strategy will be to assist in the implementation of private sector and county programs when they are consistent with state policy. The state will also encourage federal involvement which complements and accelerates implementation of local energy self-sufficiency strategies and promotes Hawaii as an energy research and demonstration center.

Setting Priorities

In Hawaii's present energy situation, priorities among program areas such as building efficiency, biomass, geothermal, OTEC and ethanol can be expressed only at a general level. More specific priorities are difficult to establish and can be misleading in light of present limited knowledge of factors affecting Hawaii's long-term energy future. The general priorities recommended for Hawaii include:

* Improving the state's energy organization and data management capability

* Developing alternate energy resources within the state

* Encouraging of energy conservation measures

Given the existing uncertainties about new energy technologies, the emphasis in alternate energy resources development is to avoid setting hard and fast priorities and to encourage all appropriate technologies to achieve commercialization and widespread application. This approach will facilitate a more diverse energy supply in the future.

General near-term (1980-85) emphasis among conservation and alternate energy development programs will be affected by these considerations:

* The largest demands are for aviation fuel, electricity, and ground transportation fuels

* Aviation fuel presents the most significant challenge because the continued viability of Hawaii's tourism industry will require high consumption levels. Indigenous resources that can replace jet fuel are not available. Residual and diesel oils can be recracked, however, to produce additional quantities of jet fuel

* Ground transportation fuel supply, on the other hand, can be more easily and immediately affected since indigenous biomass resources offer a potential for the local production of liquid

fuel. Additionally, the demand for ground transportation fuels can be reduced immediately through conservation efforts and innovative approaches to land use and transportation systems planning

* Numerous alternate energy technology and conservation options could affect electricity supply and demand. Unfortunately, they affect transportation fuels supply much less

* Energy conservation measures implemented to date have met and surpassed expected energy savings, substantiating the belief that conservation offers the most immediate, significant, and economically feasible opportunity for improving the current energy situation

* The capability for widespread application of all the alternate energy technologies exists, or will be available within the foreseeable future.

Waterfalls offer the potential for hydropower.

Chapter 2: THE ALTERNATE TECHNOLOGIES

The technologies Hawaii can use to meet its energy needs through the end of the century must be adapted to the state's special circumstances. The state is composed of a group of islands well over 2000 miles from the nearest continent; one island, Oahu, uses by far the most energy, and local resources do not include fossil fuels, natural gas or uranium. As a result, this study focuses on alternate energy technologies that rely on resources indigenous to Hawaii and which are expected to be ready for large-scale commercial use, primarily to generate electricity, within the next 25 years. Most of the technologies were examined with regard to their potential for centralized use. Decentralized use of new energy technologies should also be encouraged because it reduces overall demand, but it cannot be expected to supply all of Hawaii's energy needs.

The selection process took into account the present state of development of the technologies; projections of their technical and economic feasibility; and potential environmental, social, institutional and legal constraints on their development. With the exception of biomass-fired steam generation and a small amount of hydropower, none of the technologies has had significant commercial operating application in Hawaii, and of the others, only geothermal energy is ready for commercial deployment. Expert estimates of capital and operating costs and

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The technology summaries in this chapter are based on the technology characterization papers in Volume II of this report. The authors of those papers are credited there.

rates of commercial penetration therefore differ, sometimes widely. In recognition of a widespread tendency to underestimate costs and development times, the estimates used in this study are not the most optimistic. Table 1 lists the alternate technologies that can reasonably be expected to have a role in Hawaii's electricity supply in the next 25 years. Throughout this chapter all costs are expressed in 1980 dollars; inflation will undoubtedly make actual dollar figures considerably higher.

Hawaii's land area is limited and many uses compete for it. The state is strictly zoned to protect agricultural and recreational land from urban and industrial encroachment. Some land, called Hawaiian Home Lands, has been set aside for the use of native Hawaiians. Each of the renewable energy technologies has its own land requirements. Planning a transition to renewables should include an intensive land use survey to identify the best sites for power plants of various types. Location of the resource will have to be considered as well as the present land use patterns and laws, land costs, expected trends in population growth, the presence of other energy sources, competing uses including military uses, and environmental impacts.

All of the alternate energy technologies likely to be used in Hawaii will need some government backing to carry them through to full implementation. Even geothermal power, which is already in commercial use elsewhere, cannot bė developed to its fullest extent in Hawaii unless an undersea cable links the islands, and that cable will require subsidizing in the R&D stages. Some adjustments will also have to be made in utility rate structures and state and federal energy tax credit programs. These are not yet geared to offer maximum encouragement to utilities that are developing alternate generating facilities, particularly those such as wind and OTEC which do not have fuel costs.

TABLE 1. -- Alternate Energy Technologies

Technology	When Commercialization Expected in Hawaii[a]	Suitable for Base, Intermediate or Peak Load	Capital Cost 1980-2005 (1980 $)	Assumed Maximum Resources Potential in 2005	Major Environmental, Legal, Social and Institutional Constraints on Implementation
Geothermal	Near term	Base[b]	3,000 -1,200[c]	1,000 MW developed on Hawaii, expected to be used by Hawaii, Oahu and Maui	Toxic fumes, noise; industrial use of Hawaiian Home Lands; questions of ownership of rights to geothermal resources; industrial development of new rural areas; potential for volcanic destruction of facilities
OTEC	Mid term- to long term	Base	8,000 - 2,600	440 MW for each county	Construction stage requirements for large land area near beaches and marine facilities already in short supply, possible influx of workers; operating stage interference with underwater fuel lines and other cables and with surfing and swimming sites; water pollution from accidental discharge of working fluid; possible adverse effects from changes in thermal gradients or ocean temperatures
Wind	Near term	All three	2,500 - 700	20% of installed generating capacity for each county; 432 MW for Oahu	Visual impact of large arrays, subsonic or audible noise disturbing humans and animals; possible danger from broken or thrown blades; possible interference with flight operations and TV reception
Biomass	Near term	All three	1,500 - 1,500	164 MW for all four counties combined	Visual and noise pollution; competing land uses; potential for erosion; loss of recreational forest and open lands and other archaeological sites; toxic stillage discharge; competing markets for biomass resources
MSW	Near term	All three	2,200 - 2,200	45 MW for Oahu	Air and water pollution; increased noise and traffic from municipal solid waste trucking operations
STEC	Mid term	Intermediate	3,000 - 2,000	440 MW for each county	Considerable site disturbance; danger from misdirected high temperature radiation; glare interfering with flight operations; uncertainties concerning solar rights; land use issues
Photovoltaics	Long term	Intermediate	18,000 - 2,600	116 MW for each county	Pollution and health and safety problems with manufacturing and decommissioning toxic semiconductor materials, site disturbance and land use issued for central systems arrays; uncertainties concerning solar rights
Hydroelectric	Near term	All three	800 - 800	100 MW for all four counties combined; significantly expanded development is not expected, although the potential for nearly 250% expansion exists.	Danger of flash floods and downstream damage if dams fail, disturbance of impoundment site; legal questions concerning ownership of water and water use rights
Pumped storage	Near term	Peak	1,000 - 1,000	100 MW potential for all four counties combined	Danger of flash floods, environmental impacts at impoundment site, potential for salt water intrusion into fresh water supplies if salt water is used; legal questions concerning ownership of water and water use rights
Submarine High Voltage DC Transmission Cable	Mid term	Not Applicable	800 - 800	No theoretical limit; to be used to transmit power from island to island	Visual impact and possible damage to swimming and surfing sites where cables come on shore; navigational hazards during cable laying and repair; laws of international waters and navigation rights; little or no damage to deep marine environment expected

[a]Near term, present to 1985; mid term 1985-1995; long term 1995-2005 or later.

[b]Baseload power sources run 24 hours a day; intermediate load, 17 hours a day; and peak load, two to three hours. Wind, hydroelectric power, biomass, and its subset, municipal solid waste, can power baseload facilities only when supplies are uninterrupted by seasonal or daily variations.

[c]The range of capital costs indicates a decline in costs as commercialization takes place. No range is shown for technologies that have been commercialized for a number of years because cost in constant dollars is not expected to decline further.

The alternate energy technologies will also have some environmental and social impacts. Most of them cause less pollution than conventional power plants, but construction always involves considerable site disturbance; noise; increased transportation, especially trucking; and often, the creation of new access roads. Even when the final plant is relatively inoffensive, access roads remain and transmission lines become a new feature of the landscape.

Among potential changes in the end uses of energy, only the electric vehicle and solar water heating were considered. Other end uses are amenable to improved efficiency and conservation without major shifts in technology.

A number of other alternate technologies were examined and rejected as being inappropriate for Hawaii. Nuclear power is discussed later in this chapter and at greater length in Volume II. Other technologies, such as hydrogen-fueled aircraft and harnessing tidal energy to produce electricity have potential but are unlikely to be developed within the 25-year time frame of this study. Several energy storage technologies were also examined, but only pumped hydro storage is now economically feasible and sufficiently developed to merit serious consideration.

BASELOAD TECHNOLOGIES

One way to categorize energy facilities is by the character of load, or demand for electricity, they are best suited to supply. Baseload generating facilities meet the major part of electricity demand and must operate continuously at a high capacity and relatively low cost. Baseload technologies indigenous to Hawaii include geothermal, ocean thermal energy conversion (OTEC), and biomass-fired steam plants.

GEOTHERMAL ENERGY

The Hawaiian Islands are volcanic cones that rise from the floor of the Pacific Ocean. The islands exist because of geothermal energy. Millions of years ago that energy extruded magma in submarine lava flows. On some of the islands, volcanos have been active in recent times, suggesting that large quantities of geothermal energy may still be available relatively near the earth's surface. The key question is: How much economically recoverable heat remains within drilling distance (a maximum of 3 kilometers) from the surface of each of the islands?

Hawaii's Geothermal Resources

More than 20 geothermal sites have been identified on the Islands, but their potential for development is still unknown. Complete geothermal surveys of all the islands have not yet been made, although research is underway. Only two deep wells, including the productive HGP-A well in Puna, have been drilled so far. By early 1981, permits had been issued for drilling at over 20 more sites.

The existing information on eight of the 20 known areas which show promise of geothermal resources is summarized in Table 2. Only one is situated on the island of Oahu. Four others are located on the Big Island, and three are on Maui.

The one relatively well-defined reserve in the Islands is near the Kilauea East Rift zone in the Puna District in the southeastern part of the Big Island. The Puna site is believed to have the potential to produce enormous amounts of power relative to the state's electrical demand. The Rift zone may contain enough heat to produce from 100 to 3000 MW-centuries of electrical energy. Hawaii County has a peak demand of about 80 MW; the entire state generating capacity is now aproximately 1700 MW. Thus, the Puna area could provide electrical power to meet a large portion of state demand for many centuries if the islands were connected into a single electrical grid.

Basic Geothermal Technology

Geothermal energy is found in nature in three basic forms: as hot dry rock; as a hydrothermal reservoir; and as a geopressurized reservoir. A well is drilled into the earth to bring the energy to surface. The only form of geothermal energy of current commercial interest is the hydrothermal reservoir, which may be vapor- or water-dominated. Vapor-dominated sources are the most commercially desirable because the steam can be used to power the plant's turbine without resort to a secondary heat-exchange fluid. Water-dominated sources, however, are 20 times more common in nature, and these are the type so far discovered in Hawaii.

TABLE 2. -- Recognized Geothermal Resources of Hawaii

Name of Site	Location	Knowledge of Resource	Likelihood for Development if Resource Proved
Kilauea East Rift Zone	S.E. area of Island of Hawaii	Various geophysical and geochemical surveys and well drillings (as deep as 6000 ft., 358°C max. temp.) support conclusion that large hot resource exists; may contain 100-3000 MW centuries of electric energy	Excellent. Site also known locally as Puna and Kapoho Reservoir
Kawaihae	N.W. tip of Island of Hawaii	Low to moderate temperatures resource evidenced by radon, mercury & cl/mg ratios; near to highly resistive body on North (possible 80,000 year-old intrusive)	Excellent. No estimate of size or temperature. Located at western edge of a large cattle ranch that would control development.
Hualalai	Central West area of Island of Hawaii	Presently available geochemical and geophysical data do not provide convincing evidence of geothermal resource, but eruption in 1801 suggests some unconfirmed potential	Excellent. No estimate of size or temperature.
Kailua-Kona	Central West coast of Island of Hawaii	Geochemical surveys suggest thermal anomoly possibly related to Haualalai volcano	Excellent. No estimate of size or temperature
Lahaina-Kaanapali	Western end of Maui	Cl/mg ratios and radon/mercury data suggest that lower order anomalous temperatures may be associated with the post-erosional Lahaina volcanic system	Excellent. No estimate of size or temperature
Olowalu-Ukumehame	West area of Maui	The presence of anomalous groundwater chemistry and resistives suggest the presence of a low temperature resource	Good. No estimate of size or temperature
Haiku-Paia	North Central coast of Maui	Strong geochemical anomalies suggest thermal source	Fair. Relatively low rating not clear
Lualualei	West coast of Oahu	Available data indicate presence of a low-temperature fracture-controlled thermal anomaly	Excellent. No estimate of size or temperature. Excellent location relative to energy load centers.

Wells drilled into a water-dominated reservoir can produce hot water, steam, or a mixture of both. The liquid-vapor phase composition of a geothermal field's output depends on the resource's temperature, and on the distance from point of resource extraction to a wellhead. The pressure within most geothermal wells is usually insufficient to lift the hot water through the wellbore to the surface, so wells are started by reducing pressure at the bottom. This allows the fluid there to change phase to steam and rush up. At the surface, the well is capped by pipes that lead the effluent to a steam separator and then to a turbine, which spins a generator to produce electricity. The steam from the turbine is then recondensed and turbine offgasses are sent to a hydrogen sulfide (H_2S) abatement system.

In addition to the electricity produced by a geothermal plant, hot water and steam from the reservoir can furnish industrial process heat and district heating to nearby communities. In the case of the geothermal resources in the Puna District, the heat could be used for sugar processing, ethanol production or other industries.

Technical Problems

Outside the Hawaiian Islands, electricity has been produced from geothermal sources for a long time. The first geothermal electricity was generated in Italy in 1904, and geothermal power has been developed commercially since then in Italy, New Zealand, and the United States. Sixteen geothermal wells are currently producing commercial electricity for three US utilities in California at the highly competitive average cost of $273/KW.

The major technical and scientific problem facing geothermal development on Hawaii is defining the state's geothermal reserves and resources accurately enough for further development to begin. As much as five years and $3.5 million may be required to "prove" a single prospective geothermal well. The work involves magnetic, gravity, and electrical surveys, as well as microearthquake surveillance, water geochemistry studies, and seismic refraction analysis.

The HGP-A geothermal well on the Island of Hawaii.

The pace of commercialization of geothermal energy resources will be limited by the rates at which supply and demand can be matched at different locations, by the availability of a cable to create an inter-island grid, and the time frame in which economic, environmental, legal, and social concerns can be resolved.

Work is now underway to define the geothermal resources of Oahu, and results may be available during the next few years. The Koolau area of Oahu has shown signs of geologically recent volcanic activity, and certain anomolies have been found which are regarded as hopeful signs of a viable resource. Additional geophysical surveying is needed to map the potential resource and to gather heat flow data for a model that could be used to predict the size and longevity of the Koolau resource. Some deep wells (2-3 km in depth) are regarded as essential. A geothermal resource on Oahu would have great value because Oahu uses so much of the state's electricity.

Costs of Geothermal Power

Measurements in the deep well drilled at Kilauea revealed that the well bottom is 676°F (358°C), making it one of the hottest geothermal wells in the world. The hotter the steam is on a pound-mass basis, the more fossil fuel it can displace. Thus, the Kilauea site is very valuable.

A 3 MW wellhead generator plant is now being installed at the Puna well site under the terms of a four-year contract signed in 1978 by the US Department of Energy and the HPG-A Development Group. The plant is expected to be on-line by May 1981. The Hawaii Electric Light Company (HELCO) has already contracted for the plant's first two years of electric output. HELCO has agreed to purchase electric power at rates estimated at 43.6 mills/KWh for the first year of operation and 47.5 mills/KWh for the second year.

Environmental Problems

Typical problems associated with the operation of a geothermal field in other parts of the world are physical disturbance of the site, noise, water or brine disposal (from the plant's separator), land subsidence, earthquakes, groundwater contamination, and air pollution. Differences in terrain and in characteristics of the steam and underground fluids and gases of the resource will mean that environmental problems found in Hawaii's geothermal development will differ from those of California or New Zealand.

Reinjection of used geothermal fluids can solve a plant's wastewater disposal problems and mitigate or eliminate problems of subsidence and seismic disturbance. Reinjection can also prolong the life of a geothermal field.

The Puna plant is equipped to abate 92% of the H_2S that the plant could produce. The gas, which has the odor of rotten eggs, is probably the most troublesome of air pollutants associated with geothermal development. Other emissions have been slight. Typically, emissions from a geothermal plant may include ammonia, carbon dioxide, methane, and trace quantities of heavy metals and radioactivity. Noise abatement equipment has been installed at the Puna plant to reduce noise levels from about 90 dba (the sound of a motorcycle at 25 feet) to 60 dba (the sound of ordinary conversation). Access roads built for geothermal development can cause erosion in some areas, and drilling activities can pollute surface water with drilling muds; care also needs to be taken that drilling does not contaminate fresh-water aquifers, if any are located near the geothermal walls.

Social, Legal and Cultural Barriers

To project the impact of a major geothermal development on a Hawaiian site, site-specific data are necessary. The Puna district, for example, is remote, and sparsely settled with small farms and a few subdivisions. Some families in the area have been living on their lands for five or six generations. The local residents treasure the land and the tranquility of rural life. New settlers have come to escape from the crowding, noise, and pollution of urban centers. The immediate effect of present geothermal development has been small. Substantial geothermal development and the availability of large amounts of surplus electrical power could attract heavy industry such as chemical processing and smelting. Industrial activity would cause major increases in population and that, in turn, would require additional investment in the social and commercial services necessary to support an expanded population. New roads, housing, schools, medical facilities, and police and fire protection, are some of the services and amenities that would have to be provided. As the above developments occurred, native wildlife and local access to unspoiled outdoor recreational activities would suffer.

On the positive side, new jobs would be created. However, residents are asking specifically what kinds of jobs these would be, and whether they would go to local people who must bear the burdens of development, or to outsiders. Land values can also be expected to increase with development--another mixed blessing because it often increases property taxes. That increases government revenues, but it may make it impossible for current residents to retain their property and for low income people in general to buy or rent homes in the development zone.

Viewed from a societal perspective, geothermal development will contribute to the state's goal of reduced dependence on imported fuel, and it could result in reduced electrical rates for consumers. Over the long term, if geothermal electricity is transmitted to Oahu to meet baseload electricity requirements, it will alleviate the state's balance of payments problems and its dependence on imported oil. Geothermal development also stimulates the economy by adding to local personal incomes through expenditures for labor and materials.

The body of law establishing legal ownership of geothermal resources in Hawaii is complex and dates back to the distribution of royal lands by King Kamehameha in 1843. Additional statutes have since been superimposed on this legislation--during the annexation of Hawaii, the territorial period, and statehood. It is therefore now unclear whether ownership of geothermal resources is vested in the state, the surface property owner, or the native Hawaiians. A study has been proposed to help resolve the ownership question.

SUBMARINE POWER TRANSMISSION CABLES

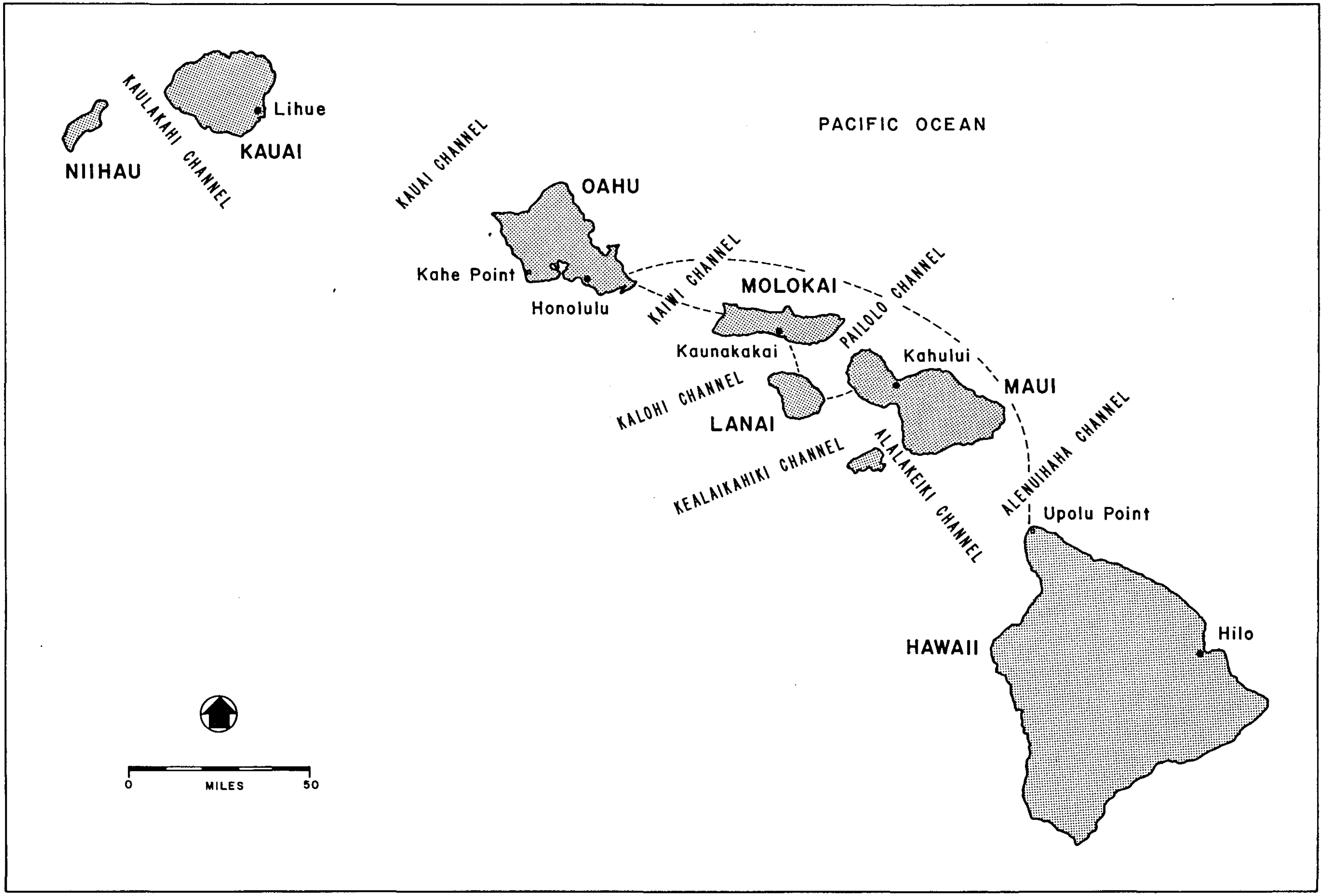
An interisland transmission cable is the keystone of any plan for a statewide electrical grid. Without such a grid, Oahu will be less able to reduce its dependence on imported oil, and all but minor development of the Big Island's geothermal resources will be economically unsound.

Submarine cables have been used since the latter half of the 19th century, but no undersea power transmission cable has operated at depths greater than 1800 feet or over distances of more than 80 miles. The proposed Hawaii cable system will have to cross the 7000-foot-deep (2100 meters) Alenuihaha Channel that separates Hawaii from the other islands to reach Oahu 150 miles away.

The US Department of Energy has recently accepted a proposal from HECO, which is acting in association with research, design and manufacturing firms, for a demonstration program which could lead to a network of submarine power transmission cables among the Hawaiian Islands. The primary link in the cable system would connect the sites of energy production on the Big Island with the population and commercial centers on Oahu. Further links would connect Oahu with Molokai, Molokai with Lanai, and Lanai with Maui. Kauai is separated from the other islands by a 10,000-foot-deep channel and is not expected to be connected to a statewide electrical grid (see Figure 1).

The proposed demonstration program is expected to take three and a half to four years to complete. If it is successful, and if public or private funds for construction are available, HECO estimates the major link between Hawaii and Oahu could become commercially operable within three years after work began. This study assumes completion of the first link between Hawaii and Oahu in the mid-1990s.

FIGURE 1. -- Proposed Submarine Electric Cable Routes for Hawaiian Islands



XBL 812-271

Technical Problems

While the final routing of the proposed Hawaiian cable system is contingent on cost-benefit studies, routing surveys, and at-sea testing, it is known that the system will have to reach depths and distances unprecedented for a cable system of this type. This raises special problems of cable design, deployment and retrieval.

To avoid the current losses that occur in AC cables over distances greater than 32 kilometers (km), high voltage direct current (HVDC) cables will be employed in the two longest links, Hawaii-Oahu and Oahu-Molokai. Even so, the extent of current losses with HVDC cables over distances greater than 125 km are unknown at present. Effects of pressures exerted on the cable at a depth of 2100 meters are also unknown. In addition, technical evidence suggests that recently developed torque-balanced, contra-helically armored cables pose problems of their own. Extremely sensitive to torsional forces, these cables require new techniques of manufacture, deployment, retrieval and repair.

The present plan is to manufacture the cable in continuous lengths of approximately 93 km. No cable manufacturer currently has the capacity to make such continuous lengths. Once they are made, three splices will be necessary to complete the Hawaii-Oahu link, and each splice represents a difficult maneuver in light of the sensitivity of the armored cable and the requirement that the splice bear the full weight of the cable during deployment. The weight is considerable: 7000 feet of cable weigh roughly 123,000 pounds. A new generation of cable-handling ships and equipment will have to be designed and built before the cable can be deployed or taken up and repaired when necessary.

Successful completion of the cable demonstration program will therefore require that state-of-the-art knowledge advance in four critical areas: manufacturing product quality control; cable handling systems; design of repair splices; and techniques used to deploy and retrieve the cable.

In addition, any submarine cable system faces associated problems of possible seismic activity; potential damage from ships' anchors or fishing equipment; potential damage by marine growth or large organisms such as fish or whales; corrosion caused by chafing movements of the cable or H_2S gas escaping from bottom sediments; and overextending bend radii due to poor cable placement.

Costs

Present estimates, which are necessarily highly speculative, place the total cost of a deep water, high voltage DC cable system for Hawaii at approximately $1 million per mile. If the cable system were routed from island to island rather than from Hawaii directly to Oahu, costs would differ according to the cost of land. Estimates of the costs of shore termination equipment and facilities to convert the current to AC range from $13 million to over $62.5 million per termination point. Costs may decrease if DC conversion technology is advanced in the course of the project, but unforeseen problems may increase costs in other areas.

Environmental Barriers

The environmental impacts of the cable would occur mostly during the construction and deployment phase. Once in place, the cable would have little effect on the marine environment. The point at which the cable crosses the surf line and the sites of termination facilities will have to be chosen to avoid negative effects on scenic and recreational areas, or interference with shipping, fishing or other forms of navigation.

OCEAN THERMAL ENERGY CONVERSION

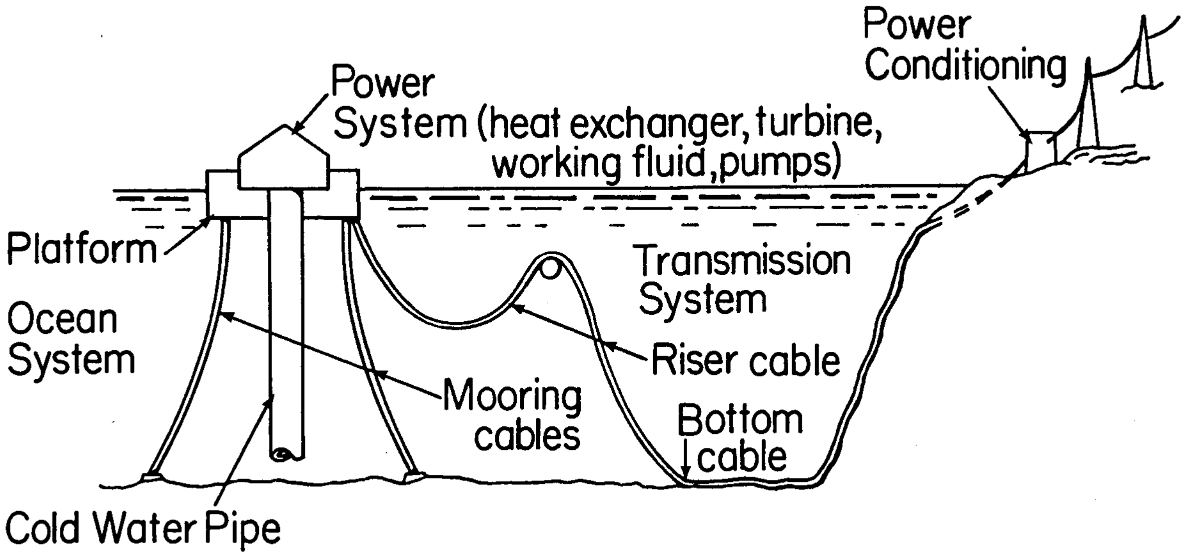
Ocean thermal energy conversion (OTEC) is an emerging technology well suited to Hawaii because the state is located in the northern reaches of the tropical oceanic belt. OTEC generates electricity by tapping the large energy potential created by the temperature difference between sun-warmed surface water and deep, polar-fed bottom currents. Theoretically, the resource is almost inexhaustible. More practically, Hawaii has enough near-shore sites where the sea floor rapidly descends to the required depth to meet the projected demand for OTEC plant sites during the time frame of this study. OTEC plants can be sited on or near each island, making OTEC development independent of interisland cable development. In the past two years, research on Mini-OTEC, Hawaii's experimental platform, has shown OTEC to be technologically feasible. Depending upon the solution of several key technical problems and the commitment of development capital, OTEC could fulfill a major portion of Hawaii's energy needs by 1995.

How Otec Works

OTEC works on the principle of heat exchange. Warm water drawn from the ocean's surface provides heat which is transferred through a heat exchanger to a working fluid. The working fluid, enclosed in a partial vacuum, is evaporated by the heat and the resultant high pressure steam drives a steam turbine to produce electricity. Cold water is pumped up from the ocean's depths to recondense the working fluid, and the cycle repeats itself (see Figure 2).

The main components of an OTEC plant are: the platform (which may be a floating, semi-submerged hull or barge, an onshore building or a jacket tower); the station-keeping system (mooring, anchoring, tower legs for onshore site); cold water pipe; warm water pipe; the power system (turbines, pumps, working fluid, and heat exchangers); and transmission system to cable the power to the power grid). Onshore, nearshore and offshore plants offer different advantages and disadvantages in the technical and cost requirements. Some of the necessary components are well developed and ready for use while others are still in the design stages. However, all of the technical problems appear to be soluble by 1986-88, and a 100 MW OTEC plant could perhaps be fully designed by the mid-1980s and deployed for operation by the end of the decade.

FIGURE 2. -- Closed-Cycle OTEC Plant Components



XBL 811-151

Technical Problems

With the exception of heat exchangers, most of the subcomponents of the power system are ready for use. The steam turbines are the same as those currently used for utility and industrial applications. While various working fluids have been tested, ammonia appears to be favored for its superior heat conductivity and its higher capacity for work per pound than other fluids.

Both the material and the choice of design of the heat exchangers are still in the experimental state. Because of the vast surface area of heat exchanger required for adequate extraction of heat from the ocean water (approximately one acre/MW of capacity), the heat exchangers may well account for one-third to one-half of the total plant cost. It is therefore crucial that the material used be as inexpensive as possible. Titanium has been used in the experimental tests because of its good heat transfer properties, its resistance to biofouling, and its durability. However, the supply of titanium is small relative to the amount required for large-scale use; its price may rise prohibitively with increased demand. Stainless steels and aluminum alloys appear to have the requisite heat transfer properties, but aluminum alloys, while cheap, have yet to thoroughly be tested in an ocean environment, and stainless steels may prove too expensive.

The size and design of the heat exchangers are still undergoing modification. In the past, researchers favored shell-and-tube exchangers, but recent experiments indicate that exchangers with a roughened plate surface are most efficient. Research is underway to determine what size of heat exchanger is maximally efficient. The larger the exchanger surface, the more heat is available and the larger the gross output of electricity. But large warm water flows increase the amount of energy used to power the pumps, thus reducing the net output of electricity.

The OTEC platforms or plantships can be moveable or fixed. They can be sited on- or offshore, perhaps as much as 30 to 50 miles, where seas are rough and the water deep. Thus, certain components must be built to withstand tremendous forces. For instance, the cold water pipe, which brings water up from depths of 3000 feet, is subject to very large lateral and tension forces. It is estimated that a solid pipe 3000 feet long and 50 feet in diameter would be subject to a total lateral force of 1.15×10^6 lbs. in a 2 foot/second current. In addition, the junction of the pipe with the hull of the plant would be particularly vulnerable to large torque forces. No design to counter these forces for a commercial-scale cold water pipe has yet been tested, although an experimental-sized cold water pipe consisting of a cluster of three 48" diameter pipes is deployed and operating on OTEC-1 as of this writing.

The mooring and anchoring system must be capable of withstanding steady-state current forces as well as storms and the buffeting of high seas. Researchers have investigated two different solutions to the problem of stationing: dynamic positioning and static anchoring. In the first system, portions of the cold and warm water flows would be used to power water jets and thrusters that constantly adjust the position of the platform. One drawback of dynamic positioning is that it siphons energy from the plant to operate. Static mooring and anchoring systems consisting of anchors and cables consume no energy; however, the cost of multiple anchors and tens of thousands of feet of cable may well be excessive. Jacket tower and onshore OTEC plants would eliminate some of these problems.

The major problem with the transmission cable is the design of the riser section between the ocean floor and the OTEC plant. This section is subject to heavy loads and must be durable over the long term. One proposed design would make use of a submerged buoy that would help bear the weight and strain of tugging on the cable. Hawaii has the advantage that floating or jacket tower OTEC plants could easily be located close to shore and could therefore use AC lines compatible with the shore-based power grid.

In addition to the technical problems listed above, some operational problems appeared during the tests conducted in 1979 at Mini-OTEC, the experimental platform located at Keahole Point off Hawaii. The action of high seas against the platform retarded heat exchange, disrupted pumping, and disturbed the turbine oil supply. These problems may have resulted from the small size of the platform. Tiny bubbles of nitrogen in the cold water discharge prevented it from dispersing adequately into the deeper waters. However, Mini-OTEC also demonstrated considerable technical success. Designed to generate 50 KW of electricity (18 KW net), Mini-OTEC produced more net power than expected. In addition, the performances of the various systems were commensurate with their predicted values.

Depending on the combination of technical solutions, governmental support, and the absence of major social or institutional barriers, the maximum rate at which development could proceed would result in commercial production of OTEC power by the late 1980s. A more realistic "best guess" scenario predicts limited commercial production before 1990 with development accelerating after that date. If engineering problems prove more difficult than expected, they could delay development of OTEC through the mid-1990s. After that time, however, the crucial factors affecting OTEC rate of growth would be capital availability and demand.

Cost of OTEC

One important advantage of OTEC is that the energy source is not only unlimited but free. Hence, costs are confined to the design, construction, and operation of the conversion plant and transmission system. There is a considerable difference in costs between a prototype plant and a mature plant. This study assumes an initial cost of \$8000/KW declining to around \$2600/KW by 2005 as the technology develops and some components are mass produced. The Department of Energy estimates a 15% reduction in capital costs from the first to the eighth plant.

The operating and managing costs of such a plant are estimated to be between 5 mills and 10 mills/KWh. The total cost of energy based on a 15% fixed charge and an 80% capacity varies from 70 to 80 mills/KWh. These rates do not include favorable tax incentives or reduced construction periods. It is estimated that reductions in the construction period from five years to four and in the fixed charge rate to below 15% could lower the cost of energy to 60 to 65 mills/KWh.

Another factor that must be considered in capital costs is the overall temperature differential between the cold and warm water flows at a particular plant. The greater and more stable the differential, the higher the net plant output of energy and the lower its cost. The choice of plant site is important in ensuring that the temperature differential available at the site is sufficiently large and stable to support the heat exchanger design for that site. In addition, the longer the life of the heat exchangers and the more resistant they are to corrosion and biofouling, the greater the savings in cost.

The cost of materials and various designs must be considered. The impact of demand on the price of titanium for heat exchangers has already been mentioned. Final designs for the three major subsystems (the cold water pipe, the mooring and anchoring system, and the underwater transmission cable) can be expected to change cost estimates.

Environmental and Social Barriers to OTEC

One of the attractive features of OTEC is that once the construction phase is over it has a low potential for environmental and social disruption. It is a clean, non-polluting energy resource, produced at sea, and in some cases out of sight from shore. The chief environmental concern associated with the operation of OTEC is the possibility of changes in thermal gradients in the ocean and consequent adverse effects on marine life. There is also the possibility of the accidental release of working fluid and other discharges.

The location of the underwater cable and its onshore connections is important since fishing and shipping routes must be considered as well as the impact of transmission lines on the aesthetic quality of onshore recreational areas.

The construction phase, which takes place mainly on land, may cause some temporary environmental disruptions. Large storage and assembly areas are needed for the numerous large section of pipe. Construction creates noise and dust, and ocean and beach views may be somewhat cluttered and obstructed. In addition, temporary construction workers may require more housing than is available at the site. The influx of workers would add pressure to local services and public facilities. Again, the choice of construction site is an important mitigating measure. Large-scale opposition is not expected, however, because of the relatively benign character of the technology.

BIOMASS ENERGY CONVERSION

Hawaii's biomass resources have the potential to supply the state with 15% of its total energy requirements by the year 2000. The sugar industry now burns agricultural wastes to generate roughly 12% of Hawaii's electricity supply. Each year, state utilities purchase some 200,000 MWh of this supply for public use. Biomass fuels now provide 51% of the electricity for Kauai County, 45% for Hawaii County, and 23% for Maui County.

In addition, there is a significant potential for a biomass-supplied liquid fuels industry. Hawaii produces enough molasses for fermentation into ethanol to displace roughly 10% of the state's gasoline consumption. Ethanol production from molasses has not yet been attempted on a commercial scale, but research indicates the process could be economical if ethanol markets were guaranteed.

Burning cane waste and fermenting molasses are likely to be the two major contributions of biomass resources to Hawaii's energy supply in the near term. Other biomass resources, and there are many, may be exploited on a smaller scale.

Most of the constraints on the commercialization of biomass in Hawaii are economic rather than sociological or technological. Many biomass resources are already valuable for other uses, and it would take a drastic shift in market values or government incentives to redirect existing biomass resources entirely into an energy-producing program. If a significant amount of new biomass crops were cultivated specifically for their energy-producing potential, this new use of Hawaii's limited land would have to compete with other agricultural, conservation, urban and recreational interests.

Current Biomass Use

Hawaiian sugar mills have burned bagasse, a fibrous sugar cane waste, for fuel for more than a century, but their role in producing power for public consumption is a recent phenomenon. In the late 1960s, environmental legislation was passed prohibiting ocean disposal of sugar cane trash. As mills enlarged their boiler capacity to burn the trash they had been dumping into the Pacific, the amount of power generated outpaced industry demand. The state utilities offered the mills a convenient, if not particularly profitable, market. Until 1980, the negotiated price of mill power ranged between $0.04 and $0.012 per KWh, depending upon the mill. Utilities placed a low value on the electricity because its supply was not reliable. Power generation was routinely interrupted when harvesting ceased. When power was generated, it was impossible for utilities to predict how much would be available to them or at what time.

The economics of bagasse-derived electricity changed drastically in early 1980 with the creation of the Public Utility Regulatory Policies Act of 1978. This legislation requires that any power generated from diverse sources such as sugar mill boilers must be accepted by the public utilities. Second, the price paid for any power generated from units installed after 1980 must be commensurate with the utilities' avoided cost, the cost the utilities would incur were they to produce the power themselves. Because Hawaiian utilities depend on low-sulfur fuel oil for power generation, avoided costs could approach several cents per KWh. Finally, Hawaii's Public Utilities Commission has the option to revise the price schedule for power produced in pre-1980 facilities.

Near-Term Potential

Nearly three million tons of bagasse are collected annually during sugar cane harvest; each ton contains an oil-equivalent heating value of roughly one barrel of residual fuel oil. (Moisture content is typically 50%.) The price incentives resulting from the 1980 legislation should augment this supply by encouraging improvements in boiler efficiencies and stimulating more effective harvesting and cleaning techniques. Bagasse dryers, which exploit stack exhaust, can raise bagasse's heat yield by 17%. Conceivably, cane growers could cultivate new genetic strains of sugar cane with high fiber content on marginal land now retired from sugar production. The net impact of these options, if they were economically feasible, could increase the amount of bagasse-derived electricity available for sale to the utilities four-fold from the present 25 MW to 100 MW of capacity by the year 2000.

Leafy Cane Trash, Macadamia Nut Shells, Wood Chips

Leafy cane trash, macadamia nut shells and wood chips are attractive subsitute feedstocks for bagasse in sugar mill boilers. All three resources are now burned alone or in combination with bagasse on a very small scale, depending upon individual mill boiler characteristics and availability. Full exploitation of leafy trash or wood would require changes in current agricultural practices; use of leafy trash or macadamia shells would require redesign of mill boilers.

Leafy cane trash is available in abundant supply. Roughly two million tons are produced annually. Two-thirds of the trash is burned in the field immediately before harvest to make it easier to transport the sugar-containing material to the mill. About 260,000 dry tons of trash are ultimately harvested, and only a small amount is cleaned of soil and gravel and burned in mill boilers. Most of the harvested trash is simply dumped in land fills or discarded according to relative economics of the alternatives. Trash has not been considered a profitable feedstock because of its high moisture content and the cost of removing the soil and gravel before burning. Mills are developing harvesting machinery which would dispense with pre-harvest burning and allow all the trash to be recovered, an annual amount equivalent to roughly 1.8 million barrels of oil. The fundamental problems of moisture and expensive pre-cleaning have not been resolved.

Roughly 94 million pounds of macadamia nut shells are now produced on the Island of Hawaii each year, and the acreage devoted to the orchards is increasing. The macadamia nut industry burns some of the shells, but few sugar mills can accept them for fuel in their existing power plants.

Wood chips are the most attractive substitute feedstock for bagasse because existing boilers will readily accept them for fuel. However, supplies are limited. Experimental farms of eucalyptus and giant koa haole trees are gathering more evidence regarding the relative economics of cultivating wood in Hawaii for energy purposes, but at this point the farms depend on government funding. A significant impediment appears to be the competing market for wood in the Japanese paper pulp industry. Wood chips cost roughly $28/dry ton to produce and bring in a return of $41/dry ton when exported to Japan for use in that country's paper industry. However, with government subsidies, the successful cultivation of 200,000 acres of Hawaii's commercial forest land could generate a maximum of 10% of the state's total electrical demand by the year 2000.

Municipal Solid Waste

Municipal solid waste (MSW) may be burned alone or in combination with bagasse, coal or gas. In 1980, Oahu produced roughly 1800 tons of MSW per day. The City of Honolulu is now negotiating with private industry to construct facilities to burn the waste for electrical generation. City projections suggest that MSW could support 45 MW of power capacity on Oahu by 1985 and 70 MW of capacity by the year 2000. The islands of Hawaii and Maui generate 173 and 134 tons of MSW per day, respectively, and co-combustion of refuse and bagasse is a realistic alternative source of fuel for electricity. The potential capacity for MSW-fueled plants on all islands other than Oahu is expected to reach 10 MW in the next 20 years.

Other Biomass Resources

Molokai Electric intends to take advantage of the 18,000 tons of hay available annually from Molokai Ranch to burn in combination with pineapple trash to meet 50% to 60% of its current demands. Mineral depletion in the soil could be avoided if the resulting ash were returned to the fields.

Liquid Fuel From Biomass

High demand for gasoline from Hawaii's transportation sector has focused attention on the possibility of using some of Hawaii's sugar cane, pineapple and wood to produce alcohol. Technical and economic constraints narrow the liquid fuel options to the production of the two simplest alcohols, methanol and ethanol.

Ethanol has some technical advantages over methanol as a fuel. When added to gasoline in a ratio of 1:9, conventional gasoline engines can use it with only minor adjustments. Ethanol blends well with cheaper, low-octane, unleaded gasoline. Empirical evidence indicates that 10% ethanol-based gasohol may reduce automobile fuel consumption by 5%. In addition, ethanol facilities appear to be cheaper to construct, and ethanol feedstock costs appear to be lower than those for methanol.

Most methanol production relies on coal or natural gas as feedstock, but wood can be used. The economics of methanol production from wood are uncertain, but they are certainly less favorable than production from natural gas. Wood supplies for methanol production in Hawaii are restricted by competing markets in the Japanese paper pulp industry and in electrical power generation.

In contrast, sugar cane juice, molasses and pineapple can be converted to ethanol by direct fermentation with very little pre-treatment, and adequate supplies are available. They are, however, very valuable in other markets.

Near-Term Ethanol Potential

Molasses

Molasses, a by-product of sugar cane processing, is the most attractive feedstock for ethanol production. In 1978, Hawaii generated 310,000 tons of molasses. One ton of molasses will produce roughly 80 gallons of ethanol; 310,000 tons is enough molasses to displace 8% of Hawaii's 1978 level of gasoline consumption.

Although molasses is now sold commercially for animal feed and beverage and industrial ethanol, its 1980 market value of $70 to $100 per ton was low enough to keep ethanol production at the break-even point. One study of 28 ethanol distilleries concluded that probable production costs, including the cost of molasses, would range between $140 and $200 per ton, or $1.68 to $2.40 per gallon of ethanol produced. Capital costs are assumed to represent roughly 10% to 20% of total costs. However, private industry has stated its reluctance to assume the initial capital cost of setting up ethanol production without secure guarantees of long-term government supports in either the market for energy crop molasses or in ethanol production.

Sugar Cane Juice

Fermenting sugar cane juice to produce ethanol is simple and very efficient. Over 90% of the energy originally contained in the cane juice is concentrated into half the weight in ethanol; 13 pounds of sugar will yield one gallon of ethanol.

Supply problems will probably preclude using sugar cane juice as feedstock. The world price of sugar would have to fall to 4 cents a pound before cane destined for sugar production could be attracted into markets for energy production, given the current price of ethanol.

The economic picture improves slightly if two distinct sugar crops are considered. Unlike cane destined for sugar production, cane raised as an energy crop requires no ripening period and less sophisticated processing. The Hawaiian Sugar Planters Association estimates that

10,000 to 20,000 hectares of land are no longer used in sugar production because shallow soils, steep slopes and insufficient water make it only marginally productive. Reductions in cultivation costs, more frequent harvests, and significant price incentives could bring some of this land into use to raise sugar cane as a energy crop.

Pineapple, Bagasse and Algae

Pineapple's high sugar concentration yields more ethanol per acre than sugar cane juice, but its alternative value as food ($3000/ton) removes it from consideration as a feedstock.

Processing bagasse into ethanol would most likely require strong acid hydrolysis, weak acid hydrolysis or enzymatic hydrolysis, all of which are too expensive to be likely alternatives in the near term.

Kelp and other algae are capable of producing methane to replace natural gas through anaerobic digestion, but they are not viable energy sources in the near term. Technical problems encountered in algae production and harvesting are not expected to be solved within the economic or time constraints of this study.

Environmental and Social Barriers to Biomass Use

In some instances, using biomass to produce energy will have a beneficial environmental effect. Waste products that are burned in energy systems do not have to be disposed of by dumping, burying or open burning. There is, however, a potential for environmental damage.

One environmental hazard posed by the large-scale use of biomass products to produce ethanol is stillage discharge. Stillage has a very high biological oxygen demand, and in locations where it has been released directly into waterways, aquatic life has been all but destroyed. If this toxic stillage were allowed to intrude into Hawaii's underground water system, the results could be catastropic. Intrusion of large quantities into ocean water could damage the state's commercial and sport fishing industries. Processing stillage into fertilizer or cattle feed could eliminate these problems. If bagasse is used as a feedstock for conversion into alcohol fuels, acid or enzymatic hydrolysis can generate toxic substances which also must be disposed of carefully.

Secondary impacts from harvesting and transporting agricultural products and wastes include erosion from dirt roads built for access, truck traffic and the noise of heavy harvesting equipment and chain saws. Another concern may be the freedom of private landowners to clear lands of vegetation without obligation to provide for new planting. Some observers have voiced opposition to road building or tree removal in heavily forested mountain areas without first providing for surveys and preservation of archaeological remains.

NUCLEAR POWER

Nuclear power is one baseload technology that does not appear to be an option for Hawaii within the next 15 to 20 years, and for that reason it was not included in this study in detail. US utilities tend to limit the size of their largest generating units to about 10% of the total system capacity to ensure reliability. Even on Oahu, which has a grid capacity of 1800 MW, the prudent size of a nuclear-powered unit would be under 200 MW, and not more than 250 MW by 1990. Small, 200 MW reactors, the largest that could be used even if Oahu's distribution system incorporated the most advanced load-shedding capability, are not now available.

Small reactors will probably not be available for purchase in the United States for at least 15 years or longer, and marketing and regulatory barriers could delay them even further. The availability of small reactors will depend largely on the development of a market for them in the third world. The growth of this market is uncertain. Vendor estimates of development times for small reactors range from nine to 12 years, but this must be considered a lower bound in the absence of an adequate market. When and if a small reactor is purchasable, manufacture and plant construction may add another five to ten years for early models.

Cost of Nuclear Power for Hawaii

Cost estimates for small reactors are highly uncertain. Rolls Royce, Ltd., has estimated a cost of $2700/KW for complete installation of its proposed 200 MW barge mounted, pressurized water reactor. Taking into account the costliness of regulatory delays, public protest, environmental constraints, and the tendency of vendors to underestimate costs, such estimates must be viewed with caution.

Barriers to Commercialization

Nuclear power would encounter strong legal and institutional barriers in Hawaii. An amendment to the Hawaii State Constitution, approved in the General Election of 1978, expressly prohibits the construction of any nuclear power plant or any disposal of radioactive materials in the state without prior approval of a two-thirds vote of each house of the state legislature.

Even if this hurdle were overcome, there are other barriers. The present Generating Station Emergency Plan of the Nuclear Regulatory Commission (NRC) requires an evacuation plan for persons living within a 10-mile radius of the reactor. Pressure is mounting on the NRC and state legislature to provide contingency plans for an area within a 50-mile radius. Considering Oahu's relatively small size and concentrated population, a workable evacuation plan would be extremely difficult to devise. If the 50-mile radius rule passed, plans would have to be made to evacuate the entire island.

Fulfilling licensing requirements, especially for small reactors of new design, and possibly foreign origin, would be time-consuming. This would be compounded by the likelihood that safety testing done in another country would not be wholly accepted in the United States. The entire licensing process would be slowed by public hearings, protests, and delaying litigation.

INTERMITTENT SOURCES

Some of the most promising sites in the world for implementing wind and solar technologies are found in Hawaii. However, wind and solar technologies, with the exception of OTEC, are intermittent power sources, and peak power generation does not often correspond with peak demand. Present energy storage technology is not yet adequate to allow Hawaii to meet its electricity needs with intermittent sources alone.

ENERGY STORAGE

In planning energy storage systems, utilities must take into account space requirements, siting flexibility, initial costs, operating and maintenance costs, the life of the system, replacement costs, and public acceptability. In Hawaii, suitability for use with renewable resources must be added to the list. Most Mainland utilities now consider energy storage for peak power, rather than load leveling, in conjunction with large coal or nuclear baseload plants. Hawaii, because it has limited pumped storage sites and because it plans to rely on intermittent sources as much as possible, represents a potential market for energy storage systems of several kinds. However, the state's energy needs are not large enough to inspire haste in the development of a product for a market manufacturers regard as emerging rather than established. When and if adequate storage systems become available, their costs will be added to the initial capital costs of intermittent generating facilities.

Pumped hydro storage, which will be discussed in more detail later, is the oldest and best developed energy storage technique for utilities. The sites available are not numerous, large or fortuitously sited enough to make a significant contribution to Hawaii's energy picture. Underground pumped storage, a concept which is being investigated by utilities across the country, is likely to present many problems in Hawaii, where almost all rock is highly porous.

Lead-acid batteries represent the next best storage potential, but the economics of utility battery storage will have to improve considerably to interest utilities. At a first cost of $125/KWh, lead-acid batteries are prohibitively expensive (planners suggest 8000 KWh of storage for each 200 KW of generating capacity); they have a relatively short life span compared to the required investment; and the quantity of storage a utility would need would require a large amount of space. Advanced batteries--for example, zinc chlorine or lithium metal sulfide batteries, as well as advanced lead-acid batteries--are now being developed, but a commercially mature utility battery suitable for Hawaii's energy storage needs is not expected within the time frame of this study.

Thermal storage systems, such as molten salt used in conjunction with solar thermal energy conversion, may become feasible by the end of the century. The problems with such systems now are more economic than technical. Consumer use of thermal systems for water heating and space cooling are the most likely near-term applications. However, even without storage, wind is already competitive with oil in Hawaii, and other intermittent energy sources will become so later in this century.

WIND

Wind generators could contribute significantly to Hawaii's electricity supply in the next 25 years. Many excellent wind power sites have been identified in the state, and the technology is advanced enough to be practical and economical. Wind is an indirect form of solar energy with several advantages over other renewable energy sources. The power is already in mechanical form, no water is required for cooling, and material requirements for energy extraction are lower than for direct solar energy conversion. The major problem with wind power is that the power source is intermittent and cannot be controlled or matched to load requirements.

From an energy point of view, 1 MW of wind capacity running at typical Mainland conditions of 30% plant capacity factor would save 5000 barrels of oil per year. In the most optimistic plausible case of 60% PCF, the savings would double. At least 84 MW of wind generating capacity is planned for Hawaii by 1984.

Wind turbines will produce power from Hawaii's trade winds.

Current Level Of Wind Generation

Technical experience has been gained in Hawaii from both large and small wind machines. Several projects which involve wind machines connected to Hawaii's electric power system are underway or scheduled.

A DOE-funded 200 KW, 125-foot, horizontal axis wind generator has already been installed at a HECO site at Kahuku, Oahu, and it is connected to the grid. This MOD-O-A is the fourth and probably the last in the series built under the auspices of NASA. The MOD-O-A's are medium-scale machines which produce high-cost electricity, even with the most optimistic assumptions about lifetime, wind speed, and operation and maintenance costs. Even so, electric utility engineers have gained experience on the machine, and the MOD-O-A has demonstrated safety, low environmental impact, reliability and simplicity.

The USMC station of Kaneohe, Oahu has a 15 KW Grumman Windstream in operation, and the University of Hawaii is installing a 2 KW Dunlite generator at Kahuku to supply demands of a marine aquaculture facility. A 6 to 8 KW wind machine funded by HUD is scheduled for installation at a senior citizens' housing project at Honokaa on the Island of Hawaii.

The small wind generators are of interest in assessing their potential for supplying electricity to locations which are not grid-connected. The amount of oil saved by small machines will probably not be significant on a state or national level.

Future Potential for Wind Generation

It is assumed that Hawaii's electrical system will grow fairly slowly for the next three decades. Wind technologies are modular, so installation and electrical production could be realized incrementally. A policy of installing large wind generators sequentially, at the rate of 5 MW per year on Oahu, for example, could be implemented without completely planning the program in advance. Building wind generators requires a relatively short lead time--two to three years, compared to eight to twelve years for conventional plants. Installation could stop when the value of the electricity produced was no longer sufficient to pay the incremental cost of producing it. In addition, wind generators can be installed on each island and do not require a statewide grid.

The problem of predicting how much wind capacity will actually be installed in the near term becomes a matter of predicting future government policies and changing attitudes concerning wind technology itself. Both are predicated on future costs of oil, demand and revenue growth in the utility system, development of competing alternatives, and the future cost of wind equipment from private manufacturers. The potential of wind contribution is limited by the ability of the electric utility system to absorb the output rather than the availability of suitable windy sites. More sites with a long-term average wind speed of 20 mph (rated "excellent") have been identified in Hawaii than in any other state.

Environmental and Social Barriers to Wind Generation

The problems of raising capital to build wind generators, rather than wind availability and technical considerations, pose the most significant barriers to rapid development of wind resources. Wind generation, like OTEC, STEC and geothermal generation, still faces the paradoxical rate structure pass-through problems that afflict all energy-generating technologies which do not use fuel. Utility economists note that wind is also penalized by federal and state income tax structures which exempt utilities from the 15% federal energy tax credit for purchases of energy equipment. As a consequence, it is possible for an outside company to purchase and erect wind generators and sell electricity to the utility company for less than it would cost the utility to produce it from its own generators. In recognition of this, HECO has a contract with Windfarms, Ltd., a private firm based in San Francisco, under which Windfarms will install a cluster of 20 large wind generators on Oahu by the mid-1980s and sell the electricity to HECO.

Once the generators are purchased, the economics of wind generation are extremely favorable. Hawaii's electric supply system possesses all the elements necessary to make wind generation feasible economically, except for overall size. At the moment, there are no low fuel cost baseload units in the state's supply system, so the fuel saved by wind generation would be high-cost, low-sulfur oil. All units in the system can be throttled back to take advantage of wind when available. The system can quickly adjust to accommodate time-varying wind generation.

Utilities have had very little experience with long-term, large-scale, grid-connected wind generation, and problems with grid operation and reliability will doubtless arise. Some utility engineers fear that the small size of Hawaii's grid will create problems if wind is introduced to any large extent. Most utility system planners hold that to preserve system stability wind should not represent more than 20% of installed generating capacity. This study projects 432 MW of wind generation (or 20% of installed capacity, whichever is less) on Oahu by 2005. The costs of wind generation are expected to drop from $2500/KW now to $700/KW in 2005, making wind highly competitive with other indigenous energy sources.

Wind generation scores extremely well in the area of environmental impacts. Bird kills, insect kills, and climate modifications have all been searched for but not found. The generators require little land and need no cooling water. Noise can be a problem. Safety is not expected to be a problem if wind machines are located away from population centers.

Opinion differs on the question of visual impact. Some observers predict significant local opposition to wind generators which mar island mountain and ocean vistas. Again, remote siting could help solve the problem. Television interference is significant only within a kilometer or two and where it occurs, may be dealt with by providing cable television.

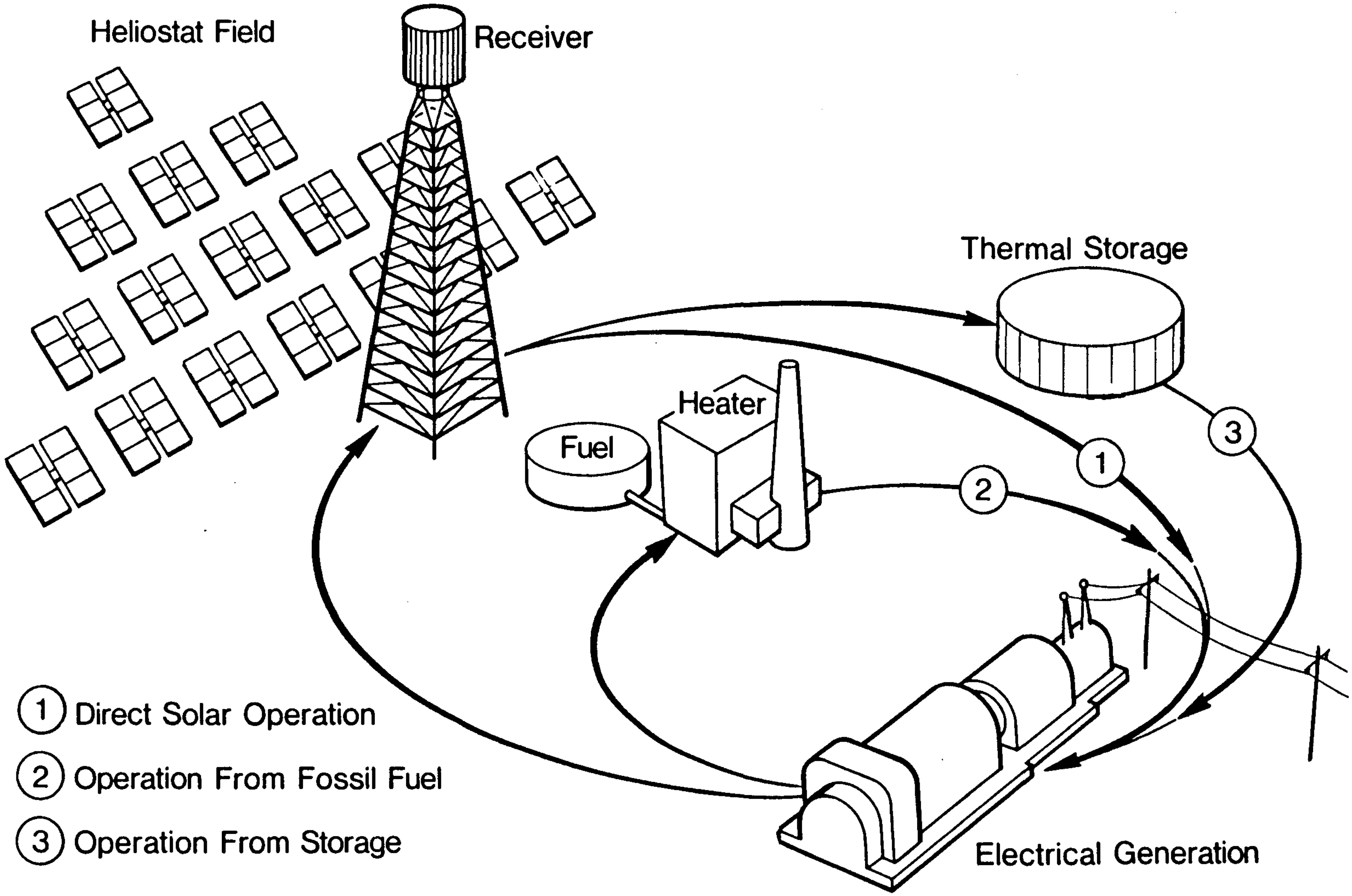
Secondary impacts can be expected from roads and transmission lines constructed to connect the machines with the supply system grid. Operation and maintenance will create some jobs, although not many.

SOLAR THERMAL ENERGY CONVERSION

Solar thermal energy conversion (STEC) is a promising renewable energy resource for Hawaii. STEC uses mirrors, lenses and other focusing devices to concentrate solar energy to produce heat which can then be used for industrial process heat or in a conventional power plant to produce electricity. Much of the research and development of major components of both large- and small-scale solar thermal power systems have already been completed, and commercial demonstration projects for several kinds of STEC systems are already in progress.

STEC technology is versatile and has a broad range of applications--from powering remote irrigation pumps to large (100 MWe) commercial electricity plants. In large-scale electrical generation, STEC systems may be used alone, in combination with conventional fossil-fuel systems to supplement fossil and other fuels at existing plants (repowering), and to produce both electricity and process heat at one installation (cogeneration). In repowering, an existing gas or oil-fired boiler is modified by the addition of a solar thermal receiver and conversion system. Investment costs for the STEC plant are reduced because investment credit can be taken for the existing electric power generating system. A study of a cogeneration development is underway in Hawaii at a sugar processing mill on Maui. Solar energy will replace the oil-fired fuel source when insolation is sufficient. Fuel oil savings to the mill are expected to be 82%, although no dollar savings are expected.

FIGURE 3. -- Central Receiver STEC System



How STEC Works

The principal component of STEC technology is its receiver. All STEC receivers employ a reflective surface to collect and concentrate solar radiation on a heat-absorbent surface. This intercepted sunlight then heats (either directly or through a heat exchanger) the working fluid which powers a turbine or industrial process (see Figure 3).

Two types of receiver have been developed. The first, for smaller-scale applications in the 10 KWe to 10 MWe range, is the distributed receiver. It takes the form of a reflective trough, dish or bowl, with the receiver element at its focal point. Distributed receivers are modular and can be clustered to increase power output. Some basic receiver designs include parabolic troughs, parabolic dishes and hemispheric dishes.

Parabolic troughs can provide industrial process heat at temperatures below 1000^{o}F and can meet comprehensive energy needs (e.g., lighting, air conditioning, water heating, possibly mechanical power) in the 0.5-10 MWe range for institutions and industrial plants. They are now used in Arizona and New Mexico to power large irrigation systems. In producing process heat, parabolic troughs offer greater than 60% efficiency in the mid-temperature (less than 1000^{o}F) range. Such temperatures are adequate for 45% of US process heat requirements. STEC energy production for individual plants and institutions could reduce the demands of the US industrial sector on utility grids by as much as 50%.

Parabolic dishes may be used to generate electrical power in the 1 to 10 MWe range for municipal utilities, communities, and major installations. Hemispheric dishes may be the most suitable design for generating small amounts of power in the 10 to 250 KWe range for irrigation, shaft horsepower, and isolated heat process needs.

Central receiver STEC, in contrast, is being developed to produce high-temperature, large-scale industrial process heat, and large amounts of electricity. In central receiver STEC, sunlight is reflected from a field (or fields) of tracking mirrors, or heliostats, to the receiver in a centrally located tower. Heat may be absorbed in the receiver and transported from it by any of a number of liquids and gases, including water/steam, liquid sodium, molten salts, air, or helium.

Central receiver STEC is compatible with conventional Rankine-cycle turbines, which operate at slightly above 1000°F, and at higher temperatures--up to 2000°F--with Brayton-cycle turbines.

Because solar radiation is intermittent, STEC systems need some form of storage. Both latent and sensible heat storage are sufficient for Rankine-cycle STEC. Brayton-cycle turbines, because of the high temperatures involved, require electrical, pumped hydro, and more advanced types of storage. Rankine-cycle is the more commercially feasible of the two turbines and will be employed in most of STEC's early uses. It can be powered by water/steam, liquid sodium, and molten salt transporters each of which has advantages and drawbacks.

Water/steam does not require a secondary working fluid, but is only moderately efficient. Furthermore, its specific heat is too low to permit extended storage, and the high-pressure containment (up to 2000 psi) required is expensive. Existing water/steam receivers are being used to power industrial processes at several southwestern locations. A stand-alone 1 MWe pilot plant project for a Southern California utility, also using existing technology, will begin operation in 1981.

Sodium has been used as a heat-transporter in nuclear plants, and its advantages and disadvantages in such applications are well known. Sodium has an extremely high heat capacity, but it is too expensive to be used for thermal storage, and thus a secondary working fluid is required. Sodium is potentially explosive and requires strict safety precautions.

Molten salt used as a heat transporter is inexpensive, and like water/steam, it can be used in thermal storage as well as in the receiver itself, without the need for a heat-exchanging secondary fluid. Although molten salt systems are in commercial use, their applications for STEC have not been as widely studied as those for water/steam and sodium.

The Economics of STEC

It is difficult to make overall cost estimates for STEC. Efficiency of conversion is highly variable, depending upon the design of the receiver or heliostatic system and the generators used. There is no commercial production of STEC components at the moment, so prototype plant costs necessarily include the cost of research and development. This study uses a $3000/KW beginning capital cost, dropping to $2000/KW by 2005. Some studies place the cost at a significantly lower figure.

Up to 50% or more of the cost of a central receiver STEC plant is the heliostat field. It is expected however that the cost of manufacturing heliostats will be reduced dramatically when they are mass produced, and that the needs of the Southwest and Hawaii will create sufficient manufacturing volume to reduce costs. Once heliostat costs drop, solar thermal energy will be competitive with both petroleum and other renewable energy resources.

One note of caution should be sounded. STEC, like OTEC, is both capital- and material-intensive, and cost analysis depends on accurate forecasting of long-term financial conditions, including interest and capital recovery rates. Minor errors in or changes of assumptions can dramatically change economic forecasts for STEC.

Social and Environmental Barriers to STEC

A major limitation to implementing STEC in Hawaii is the need for sufficient amounts of suitable land at affordable prices. Land unavailability could present the largest barrier to STEC, particularly on Oahu. STEC requires two square miles of land for each 100 MW of capacity. This is a land use requirement on the same order of magnitude per unit of delivered energy as eastern strip mined coal plants. Hawaii has not yet carried out the intensive survey of potential solar sites that will be needed before large-scale solar generating facilities can be planned.

STEC produces little air- or water pollution, and harm to the environment will be limited largely to the immediate site, which may be paved or sprayed with herbicides in some cases. Some problems could be posed by waste disposal, misdirected solar radiation, and adverse changes in the ecosystem and microclimate of the site.

If Oahu, Maui and the Big Island are connected by an undersea cable, STEC sites serving Oahu could be built on either of the two less populous islands. Prospects for siting STEC facilities on the Big Island are more favorable because of its extensive barren lands. Whether those lands could be leased for this purpose from private landholders is another question.

SOLAR PHOTOVOLTAIC POWER SYSTEMS

Solar photovoltaic power systems, now undergoing intense research and development, are another promising evolving solar technology. Photovoltaic systems, which convert sunlight directly to electricity, have been used extensively and reliably in the US space program and for other small, off-grid applications. Expanding this technology to large scale, low-cost electric power production presents many technological, economic and environmental challenges. If, however, development progresses according to the DOE's projections, photovoltaic arrays could cost $0.70 per peak watt by 1986, dropping to $0.15 to $0.50 per peak watt between 1990 and 2000, and could contribute as much as 10% of Hawaii's electricity demand by the turn of the century.

How Photovoltaic Cells Work

The photovoltaic effect was first observed in electrolytic cells by the French physicist Edward Becquerel in 1839. More than a century passed before researchers at Bell Laboratories invented, in 1954, a photovoltaic cell using ultra-thin, crystalline "wafers" of the abundant element silicon. The effect itself takes place when photons strike certain semiconductor materials, solids that can act as either electrical insulators or conductors. These materials characteristically contain bands of electronic charge. When excited by impinging electromagentic radiation of appropriate wave length, charge carriers are generated and can diffuse through the material. An electric current can then be conducted into an external circuit to do useful work. Strings of individual photovoltaic cells can be connected into modules and these, in turn, can be assembled into arrays to produce photovoltaic generators of any desired voltage. A large system could also include power conditioning and control devices to regulate the flow of alternating and direct current, and coolant systems to reduce the intense heat at the surface of the collector array.

Technical Barriers

More than 20 semiconductor materials are being studied at present for possible large-scale photovoltaic power generation, and many potential solar collector designs are being considered. Three technologies are closest to commercial maturity: single-crystal silicon solar cells, thin-film cadmium-sulfide cells, and gallium-arsenide heterojunction cells.

Nearly all photovoltaic devices produced to date have employed very thin (200 to 250 micron-wide) slices of purified silicon, wired together to collect direct current electricity. They display a 10% to 14% efficiency at converting sunlight to electricity and last about 10 years. (The average insolation at a good terrestrial site is about 0.250 KW per square meter). Researchers hope that during the next five years, conversion efficiencies can be increased to 15-18%, and the lifetime of these devices doubled to 20 years.

Silicon solar cells have been used extensively in the exploration of outer space, generating power for more than 90% of space satellites. Reliability rather than cost was the main objective for such remote power sources, and the individual custom designs used are not suited to large-scale power production. Silicon solar cells have also been used in remote terrestrial areas to power microwave repeater stations, weather stations, seismic monitoring equipment, and a radar station.

Despite their proven reliability for these small-scale applications, the high cost of producing silicon solar cells and their relatively low efficiency levels have led researchers to investigate other semiconductor materials. Photovoltaic cells made with thin slices of crystallized gallium-arsenide (GaAs) have achieved conversion efficiencies of more than 23% and operate better at high temperatures than silicon cells. The cost of GaAs cells is currently very high (up to $20,000 per square meter), but advocates maintain that smaller, more efficient arrays could be used to collect concentrated sunlight (as much as 500 times normal intensity). Conversion efficiencies of 18-22% and 20-year lifetimes are likely to be achieved by 1985. Large scale use of GaAs cells, however, will require advances in the production of stable, high-performance thin films and reliable methods for cooling the intensely hot collector surfaces. A loss-of-coolant accident could result in the irreversible degradation of the GaAs cells as well as the release of highly toxic fumes.

Cadmium-sulfide (CdS) photovoltaic cells combine layers of CdS with layers of cuprous sulfide to generate direct current electricity. Existing commercial cells achieve routine efficiencies of only 3.2%; the maximum theoretical efficiency for this semiconductor material is 15%. CdS cells, however, have one decided advantage: Thin films can be produced by spray, sputter, or chemical vapor deposition techniques in a continuous (rather than batch-type) manufacturing process. This type of processing would allow more economical production of the large, low-efficiency CdS arrays that would be needed to produce consumer electricity. As with GaAs collectors, however, certain technological problems must be overcome first: CdS cells deteriorate if they are not hermetically sealed off from air and humidity. Current lifetimes are thus low and would have to be improved. Cadmium, like arsenic, is toxic at high concentrations and could present health hazards to workers and the public.

Two basic types of photovoltaic collectors, flat-plate and concentrating systems, have been undergoing intensive development. Flat-plate collectors are simple, rugged devices with no moving parts that use planar surfaces and unconcentrated sunlight. The collectors are mounted at a fixed angle to the sun, and by absorbing direct and diffuse sunlight, can generate power on both clear and overcast days. Concentrating systems employ reflective or refractive optics to focus sunlight on a small receiver area covered with photovoltaic cells. Since they use only direct sunlight, concentrators must move to track the sun's path. They can receive as much as 20% more energy annually than flat-plate collectors, but on rainy or overcast days, they may receive no useful insolation at all.

Two newer design concepts are in the very early stages of development. Thermophotovoltaic collectors are very high concentration devices (more than 200 suns) that use silicon cells and could conceivably produce both electricity and industrial process heat. Collection efficiencies of 30% of more may be achieved within 10 years. Luminescent concentrators use fluorescence and total internal reflection to trap and concentrate absorbed photons at one edge of the collector plate. These could be installed as integral building materials, but so far, they have short lifetimes and have achieved efficiencies of less than 5%.

Besides the above-mentioned technological problems, photovoltaic systems will require other advances before large scale application is possible. Cooling systems must be reliable enough to prevent loss-of-coolant accidents and subsequent collector damage or health threats. Power conditioning and control devices must be tailored to the photovoltaic application in question (off-grid, on-grid, grid-connected and synchronized with utility line voltages). For applications requiring energy storage, advanced batteries with characteristics superior to the present lead-acid batteries will be necessary.

Photovoltaic Potential in Hawaii

The engineering problems that confront photovoltaic systems are significant. As they are solved, the price of photovoltaic arrays should drop dramatically. Reductions are likely in the coming decade and could allow photovoltaics to play an increasing role during the 1990s. By the turn of the century, these systems could contribute as much as 10% of Hawaii's electricity.

One possible off-grid application of photovoltaic power systems during the 1980s is likely to be in drip and trickle irrigation systems, a method that helps conserve water but requires a continuous low-level power source. Photovoltaics could be used to help irrigate pineapple crops as well as flowers and vegetables. Off-grid photovoltaic systems could also be used to power microwave repeater stations, operated by general common carriers such as AT&T, and special common carriers such as Western Union and the Department of Defense.

Grid-connected photovoltaic power systems may be competitive with conventional forms of electric generation before 1990 in isolated areas that now rely on costly diesel fuel to produce electric power. Two excellent examples are the islands of Molokai and Lanai, with their small-sized, high-cost power grids. In 1980, the average cost of electricity was about $0.15 per KWh on Molokai, the third highest rate in the United States. If the DOE's price goals are met, dispersed photovoltaics will be cost competitive with such diesel-generated electricity before 1986 and could eventually contribute up to 15% of Molokai's electricity requirements.

Although the early use of photovoltaics on Molokai or Lanai would save only modest amounts of diesel fuel, the design and operating experience gained would be of value to Hawaii and the Mainland. So, too, could the operation of other economically non-competitive projects involving residential and commercial-scale configurations. Photovoltaic demonstration projects currently planned or underway in Hawaii include a remote weather station at South Point, seismic sensors operated by the US Geological Survey, and floating navigational aids. The largest planned demonstration is the hybrid thermal-electric system designed to supply hot water and 35 KW (peak) power for the G.N. Wilcox Hospital on Kauai. In May 1980, DOE awarded a $280,000 contract to design and build three residences in Hawaii, each using flat-plate silicon cell arrays to generate up to 10 KW per house. Several large photovoltaic projects on the Mainland will provide additional information and operating experience.

Cost of Photovoltaic Systems

Cost is the single most important factor in determining when and to what extent photovoltaic systems contribute to Hawaii's energy needs. Thus far, costs have fallen dramatically as world production of photovoltaic cells has grown from a few hundred kilowatts of peak capacity in the early 1970s to nearly 2 MW in 1979 and an estimated 3 to 4 MW in 1980. Wholesale prices have dropped from $25 per peak watt in 1976, to $12 per peak watt in 1978, and as low as $6 per peak watt in early 1980. Current capital costs can be as high as $18,000/KW of generating capacity, but the technology is evolving rapidly and it is expected that costs will have dropped to $2600/KW by 2005.

Progressive development of photovoltaic technology will depend on continual DOE support, on the availability of venture capital to underwrite new generations of production machinery, and on advances in safety, efficiency and reliability. Actual prices for arrays may be much higher if a competing technology--wind-energy conversion systems for example--surges forward and captures some early applications.

The costs of power conditioning and control equipment and storage batteries must also be considered. Since conditioning and control technology is relatively mature, its cost will decline less rapidly than that of the photovoltaic arrays themselves. This additional equipment could eventually represent more than 50% of the total cost for off-grid applications. Currently, for small photovoltaic systems (under 10 peak KW, all DC loads), the additional cost is $500 to $2000 per KW. That is expected to fall below $500 per KW. Off-grid applications requiring both AC and DC must use a self-commutated inverter, costing $400 to $2700 per peak KW for systems producing less than 100 peak KW. This could drop to $180 to $250 per KW.

Grid-connected systems require less complicated power conditioning systems, such as line-commutated inverters now available at prices ranging from $40 per KW for industrial scale systems to $400 per peak KW for residential-scale systems. Harmonic noise filters may add as much as 30% to the cost of the power conditioning equipment in these grid-connected systems.

Environmental and Social Barriers

While costs are certainly the major factors in the deployment of photovoltaic systems, environmental risks pose additional problems. These environmental risks, however, are expected to be less severe than those associated with generating equivalent amounts of energy from any fossil fuel technology.

Environmental insults and occupational hazards may arise during semiconductor refining, device fabrication, decommissioning and disposal of photovoltaic equipment. During the refining of semiconductor materials, workers are exposed to toxic and carcinogenic particulates of very small diameter. During manufacture of photovoltaic devices themselves, workers may suffer long-term, low-level exposure to toxic vapors, acid fumes and aerosols containing heavy metal particulates. When photovoltaic systems are decommissioned and disposed of, some toxic compounds may leach into soil and ground water, creating a small but significant public health risk. Silicon is believed to be harmless biologically, but cadmium-sulfide and gallium-arsenide are toxins and suspected carcinogens. Use of the silicon-cell technology, is therefore likely to pose fewer environmental risks.

Other possible environmental consequences include the disruption of ecosystems at the site of power plant construction, and the potential release of toxic compounds during fire or loss-of-coolant accidents. Centralized power plants are much more likely to generate significant ecosystem disruptions than are dispersed networks.

Centralized plants also raise the issue of land availability. Dispersed deployment allows photovoltaic arrays to be built into the buildings they serve, but land requirements for central station receivers are expected to be similar to those for solar thermal power: about two square miles per 100 MW of capacity.

Improved production processes and lower-cost, more efficient use of semiconductor materials must be achieved in order to allow large-volume operation and to attract serious investors. The supply of semiconductor materials, skilled labor and industrial sites will also affect development of the industry. Ultimately, the rate of photovoltaic deployment will be governed by the ability of the photovoltaic industry itself to expand production--an expansion, in turn, controlled to a great degree by the availability of technology, capital and receptive attitudes.

HYDROELECTRIC POWER

Hydroelectric power has been in use in Hawaii for over three quarters of a century, largely on the agricultural plantations of Kauai, Hawaii and Maui. The future for hydropower in Hawaii is not grandiose, especially because so little potential is found on Oahu where it is most needed, but it may play a modest but important role in supplying localized needs for electricity on the Neighbor Islands. Over the years, some plants have been decommissioned as they aged and as more reliable sources of power became available to the plantations they served. Recent engineering studies suggest, however, that the total, economically feasible hydropower potential in the state ranges from 221.7 gigawatt hours per year to 237.7 GWh/year, compared to the 91.6 GWh/year presently generated. The 19 hydropower facilities now in operation in Hawaii produce less than 0.5% of the state's total energy, and if the state's hydropower potential were fully developed, it would still account for only 1%. Table 3 lists the state's existing hydropower facilities, and Table 4 shows potential hydropower sites which are now undeveloped.

TABLE 3. -- Summary of Existing Hydroelectric Plants: December 1980

Island & Location	Number Generators	Stream	Owner	Installed Capacity (KW)	Avg. Annual Energy (GWH)	Upgrade Plans
Hawaii						
Puueo	2	Wailuku	HELCO	1,500 750	14.0	
Waiau	2	Wailuku	HELCO	350 750	6.5	
				3,350	20.5	Under study
Haina (Honokaa)	1	Lower Hamakua Ditch	Davies Hamakua Sugar Co.	800	0.75	Under study
Total Hawaii	5			4,150	21.25	
Maui[a]						
Kauaula	1	Kauaula	Pioneer	500	0.75	Under study
Paia	1	Wailoa D.	H C & S	800	3.0	Up-grade plans
Kaheka	3	Wailoa D.	H C & S	1,333 1,333 1,333	18.0	
Total Maui	5			5,300	21.75	
Kauai						
Waiawa	1	Kekaha D.	Kekaha Sugar Co.	500	1.9	Under study
Waimea	2	Waimea	" "	1,000	5.0	Under study
Wainiha	2	Wainiha	McBryde Sugar	1,800 1,800	26.0	New pipe, increase generation 10%
Kaumakani	1	Makaweli	Olokele Sugar Co.	500	3.1	Replace w/ 1,250 KW, generate 6 GWh, 1981
Alexander Res.	1	-	McBryde Sugar Co.	1,000	4.5	Under study
Lower Lihue	1	North Wailua & Iliiliula D.	Lihue Sugar Co.	800	5.0	Under study
Upper Lihue	1	" "	" "	500	3.1	
Total Kauai	9			7,900	48.6	
Total State	19			17,350	91.6	

[a]500 KW generator on Hamakua Ditch scheduled for completion in 1981

TABLE 4. -- Summary List of Prospective Hydropower Sites

Site	Installed Capacity (KW)	Estimated Annual Energy Production (KWh)
KAUAI		
Wailua River	1,800 - 17,600	4,250,000 - 25,490,000[a]
Wainiha River	3,700	14,400,000
Lumahai River	2,050	10,950,000
Hanalei River	2,150	10,500,000
Puu Lua Reservoir	1,650	9,260,000
Hanalei Tunnel	1,400	8,200,000
OAHU		
Wahiawa Reservoir	300	1,650,000
MOLOKAI		
Halawa Stream	2,100	9,920,000
Pelekunu Stream	860	3,800,000
Kualapuu Reservoir	70	3,000,000
MAUI		
East and West Wailuaiki Str.	2,750	15,080,000
Waihee River	1,860	8,490,000
Hanawi Stream	1,000	5,030,000
Kolea	1,100	4,460,000
Hoopoi Chute	2,000	3,000,000[b]
Nailiilihaele Stream	470	3,000,000
Kahakuloa Stream	230	1,590,000
Honolua Ditch (Kapalua)	130	830,000
HAWAII		
Honolii Stream	3,900	17,600,000
Wailuku River	1,970	11,070,000
Wailoa River	1,850	10,290,000
Awini Falls	1,500	7,680,000
Honokane Nui Stream	1,100	6,190,000
Union Mill	500	4,100,000[a]
Pohakupuka Stream	600	2,300,000
Keaiwa-Meyer Reservoirs	280	1,650,000
Alia Stream	330	1,540,000
Papaikou Mill	130	1,000,000[a]

[a]US Army Corps of Engineers estimate.
[b]Estimate by Mr. Sachiyuki Masumoto, Alexander & Baldwin, Inc., Honolulu.

Technical Barriers

Hydroelectric power on the small scale possible in Hawaii is not likely to undergo a technical revolution, nor are the economics of this form of generation likely to change. Several problems relating to small scale hydro plants connected to small distribution systems do need to be solved. One involves the electrical stability of the system with the starting and stopping of multi-units on the transmission line. Another concerns the safety of workers maintaining transmission lines in the vicinity of small units which may go on and off automatically. Both problems are now under study.

Another difficulty is that the costs of developing small scale hydropower from high head, low capacity flows of the sort available in Hawaii are quite sensitive to the cost of equipment and installation as well as to the value of the energy generated. At the moment, no manufacturer provides a standarized package suitable for such plants, although they are available for low head units. At least one manufacturer has plans to offer a package for high head plants this year, and this could improve the economic picture for future hydropower development in Hawaii.

Environmental and Social Barriers

In Hawaii, the major social barriers to commercialization of hydroelectric power include the legal question of ownership of water and water user rights. A landmark case involving these questions is currently going through the court system. Most of the existing hydroelectric plants and irrigation systems in the state were built many years ago by sugar plantations and are operated privately by the plantations, which may further complicate these legal questions. Investment of large sums in capital equipment could be hampered by legal uncertainties. In addition, the permitting processes for building dams, water diversion channels and other hydroelectric facilities are extensive, involving all three levels of government.

In areas where water supply is low or intermittent, conflicting needs for water may be a problem if large plantations, small farms, county water systems and a hydroelectric plant have to compete for a supply which is not large enough.

Some of the reservoirs and streams in Hawaii have been stocked with fish and are used for recreational sport fishing. Boating uses are minor because of the small size of most reservoirs and streams. Use of water for hydroelectric power should not be incompatible with current recreational uses.

If dams are built or expanded, there will be concern for the safety of people living downstream, especially because the extremely heavy rains and flash flooding that occur in many areas of the state can subject dams to periods of unusual stress.

Most of the areas which have hydroelectric potential are remote and little used, but they should be checked carefully to make sure use will not destroy sites of historic or religious significance, or endanger Hawaiian species of plant, bird or animal life.

Although hydroelectric development of Hawaii's water sources would probably not produce major disruptions of the environment because of its small scale, there are nonetheless potential impacts that could prevent or impede its use. Many of the streams offer scenic beauty, and to alter or impound their flows would ruin their aesthetic value as well as destroy those ecological communities now dependent upon them. The chief consideration that will influence the development of hydropower, however, is whether it is economically viable.

PUMPED STORAGE

Pumped storage produces hydroelectric power by moving water between reservoirs at different elevations. It is usually used to level off peak demands on primary generating capacity. A pumped storage facility pumps water to the upper reservoir when energy is produced in excess of demand and releases the water to produce hydroelectric power when needed. While not yet economically attractive enough to displace power from oil-fired plants, pumped storage may well be profitable by the 1990s if the price of oil continues to rise.

A preliminary study of 12 sites on Oahu, Molokai, Maui, Hawaii, and Kauai found that some 100 MW of potential power could be tapped as a back-up for utilities. Although costs are likely to be the major barrier to the development of these sites, there are environmental impacts and questions of public safety associated with specific sites that may prove difficult to address.

How Pumped Storage Works

Producing power at a constant level is more efficient than trying to meet fluctuating demands. However, the normal pattern of electricity use on any given day shows peaks of high demand at certain hours and troughs of lower demand at others. A pumped hydroelectric storage system allows a utility to baseload its most efficient generating units. When power is produced in excess of the demand at a given time, it is stored for release when demand exceeds power production in the baseload plant. In a similar manner, power can be stored to smooth out the fluctuations in energy production that accompany intermittent sources such as wind and solar power.

The transfer of energy takes place between two bodies of water at different elevations connected by a penstock (sluice). Excess energy is used to pump the water from the lower to the upper reservoir. When power is needed, the water is released from the upper reservoir to flow through the turbines into the lower reservoir, producing hydroelectric power. The amount of energy that can be generated depends upon reservoir size and the difference in elevation between the two reservoirs.

Hawaii's Pumped Storage Potential

Every utility system in the state has its own unique pattern of energy supply and demand. Some utilities, such as those on Kauai and Molokai, experience very slight load peaks on particular days. Thus, each pumped storage facility must be tailored to fit the needs of the utility system it serves. The maximum practical size of storage units for each island is estimated to be: 150 MW on Oahu, 15 MW on Hawaii, 15 MW on Maui, 5 MW on Kauai, and 1.5 MW on Molokai.

In the preliminary study, the 12 sites chosen for investigation were selected according to a number of criteria. First, pairs of reservoirs within three miles of each other were chosen if the difference in elevation between them was a minimum of 200 feet, preferably 500 to 2000 feet. The low-head sites had to have a capacity of at least 300 million gallons. Second, sites that had only one reservoir were acceptable if the reservoir had a large storage capacity or the available head was extremely favorable. Third, some sites with no existing reservoirs were chosen if the available head was exceptionally large (500 to 2000 feet). Other criteria included accessibility to the site, a low degree of anticipated difficulty in construction, availability of make-up water, proximity to utility transmission lines and load centers, and location in sparsely populated areas.

The power potential of a given site was evaluated according to the size of the head, water supply, and reservoir space; the length of penstock required, the need for peaking power in the area; and the source of the pumping power. This last characteristic is particularly important. If the source of pumping power is a baseload plant, the supply of power is more reliable than a variable energy source (wind or solar). In the latter case, extra storage space must be included in the reservoirs to cover short-term shortages of pumping power.

Two of the sites chosen would make use of the sea as the lower reservoir (Diamond Head Crater on Oahu and Kapale/Mimino Gulches on Molokai). Thus, salt water, not fresh water, would be pumped up to the reservoir. The advantages of such a system are that only one reservoir must be built, and the supply of water is unlimited. On the other hand, sea water is more corrosive to turbomachinery materials than fresh water. Furthermore, the environmental impacts of leakage from the upper reservoir are likely to be more severe, especially to fresh groundwater supplies. These disadvantages could be mitigated somewhat by using corrosion-resistant materials and by lining the reservoir; however, mitigation measures add to the cost of the project.

Costs of Pumped Storage

A cost analysis was done for five of the 12 sites. All but one have reservoirs, so that construction costs and environmental impacts were more easily defined. Construction costs of the facility were broken down to include the power plant, penstock, reservoirs, embankments, and intakes and outlets. The costs of access roads and transmission lines were assumed to be 20% of the equipment costs, and engineering and overhead were estimated using 15% of the cost of the project. A 7% interest rate was assumed over a two-year construction period, and the construction cost was assumed to be amortized over 50 years at 7% interest. Annual operating and maintenance costs were estimated to be $0.003/KWh of hydroelectric energy produced. Finally, though the source of pumping power was not explicitly defined, it was estimated to be a reliable source, with electricity available at $0.05/KWh.

Pumped storage hydroelectric costs varied considerably among sites, ranging from $0.016/KWh to $0.23/KWh. The current cost of peaking power from oil-fired plants is $0.07-0.09/KWh (The combined cost of $0.05-0.06/KWh for fuel costs and $0.02-0.03/KWh for operating and maintenance costs). Thus, energy from a pumped storage system would currently cost twice what peaking power costs today. Should oil prices rise to $90/barrel by 1990, pumped storage would become economical.

Environmental and Social Barriers to Pumped Storage

The environmental consequences of building and utilizing pumped storage units differ with the degree of previous development of the site. Those sites with existing reservoirs would obviously not face the same effects as sites where fresh water flows would be impounded for the first time. Some areas, such as the Koolau Range on Oahu, are pristine, and any form of development might be considered undesirable. Leakage from reservoirs or penstocks could also cause problems, especially at those sites using sea water rather than fresh water.

In some cases where agricultural reservoirs would be used, there may be competition for the water for irrigation purposes. In addition, several of the sites chosen have dams that are considered to be "high hazard" by the Army Corps of Engineers. Threats to public safety from possible flooding would have to be removed by rebuilding or repairing the dams.

CHANGES IN END USE

Developing renewable energy technologies is not the only way Hawaii can reduce its dependence on imported oil. Changing the ways in which energy is used can also help. Conservation, both through consumer awareness and improved design efficiencies, is the most immediately obvious means of reducing energy use and thus dependence on oil (see Chapter 3 for a more detailed discussion of conservation). This study examined two other changes in end use: solar water heating and electric vehicles. In both cases, the results contradicted conventional wisdom in several respects.

SOLAR WATER HEATING

Climatic conditions in Hawaii are extremely favorable for the efficient use of solar water heaters. Low latitudes and clear skies provide good insolation. High average ambient temperatures minimize collector heat loss; only a few regions with high elevations experience low temperatures.

In Hawaii, 40% of single family home electricity consumption typically goes for water heating. Less than 10% of residential customers have solar water heaters. Of single family homes, roughly 90% use electricity to heat water; and 77% of all residential utility customers have electric water heaters. A good solar system will carry 80 to 85% of the total water heating load. It follows that solar water heating could reduce residential kilowatt-hour usage by roughly one-third.

A consensus of sources places the number of solar water heaters in use in Hawaii at the end of 1979 at 8000 to 12,000 units. Roughly 200 building permit applications for solar installations are received each month, although it is impossible to say whether all permits granted are used. The average solar system has 50 to 60 square feet of panels, a storage tank of 110 gallons, and costs $3700 before tax credits. After tax credits, the device will cost the consumer $1850. Interest on the $1850 is tax deductible. The heater's value is likely to increase over time as both fuel savings and replacement costs rise with inflation.

A 1978 DPED study estimated that by the year 2000, solar water heating would provide 85% of the hot water demands of all single family residences, 75% of the demands of all multi-unit residences, and 50% of the hot water demands of all non-residential water users. Other studies suggest it is possible that the DPED estimate is over-optimistic, even though the State of Hawaii now subsidizes solar water heaters through state tax credits.

A realistic projection of maximum market penetration for the next 10 to 15 years puts roughly 90,000 to 100,000 solar units, or 50% of all water heaters, in operation by 1995. This would represent a 30% to 60% reduction in the amount of electricity used for water heating, which translates into a 1% to 2% cut in oil imports to Hawaii.

Heat Pumps

Further political actions in the form of increased tax credits, preferential housing permit processing, and specific mandates, could speed the penetration rate of solar devices. However, the increasing acceptance of large, industrial scale heat pumps and the rapid development of small residential heat pumps may affect the rate and quantity of solar heating devices installed in the next 15 to 20 years in surprising ways.

While a solar water heater uses solar insolation directly to heat water, a heat pump works something like a refrigerator in reverse. It uses a working fluid to collect heat from the air, or some other heat source if one is available, and deliver it to the water. The power required is used to run the pump and compressor which moves the working fluid.

Small heat pumps are not yet a widely used product, but they are making rapid inroads. They appear to be more cost-effective than solar devices, and they exhibit greater potential for reducing gas and electricity demands on utilities than do solar water heaters. Existing models of residential heat pumps can achieve a 60% reduction in electricity use over electric water heaters. While this is inferior to the 80% to 85% savings attained by solar heaters, heat pumps have two strong advantages over solar technology. First, in conditions of peak demand, heat pumps require only 700-800 watts compared to a few kilowatts required by electric/solar heater combinations. Large-scale use of domestic heat pumps rather than solar water heaters could save local utilities substantial additional peak generation requirements. The second recommendation for heat pumps is cost. Even with the substantial federal and state subsidies which now reduce the market price of solar systems to $1850, existing heat pump models are cheaper. Small heat pumps now on the market list at $1050. If federal and state energy conservation tax credits were extended to include heat pumps, the cost advantage would be even more dramatic.

To date, more than 1000 residential heat pumps have been sold in Hawaii. These pumps retrofit to an existing electric water heater. HECO is testing and evaluating another pump which would be used as a replacement for an existing water heater, the pump being integral with the tank. Two other manufacturers are reportedly ready to begin active marketing of their own retrofit pumps. All of these activities may begin to affect solar sales in the near term.

Barriers to Solar Water Heating

Few of the common social barriers hinder the commercialization of solar water heaters in Hawaii. Their use requires little or no change in life style. There is no active group opposition to this form of energy use, nor are there adverse health and safety concerns. However, most solar heaters in Hawaii have been added to existing housing, and the visual impact can be a deterrent to their acceptance. Most solar heaters seem to be designed more for efficiency and cost containment than for aesthetics. The metal and plastic equipment often looks incongruous perched on the roof of a house, and it is sometimes banned from the multi-unit condominiums which dominate new housing in Hawaii.

Some legal considerations continue to serve as constraints. The legal principle involved in "solar rights," the right of a property owner to prevent a neighbor from erecting a building that will cut off his access to direct sunlight, has not yet been resolved in the courts.

Pressure from increased housing costs and limited land area has resulted in more and more high-rise construction, and this affects the amount of direct sunlight available to neighboring buildings.

Although architectural schools now emphasize the design of energy-efficient housing, many architects now in practice received their training before energy conservation was considered important and therefore their designs do not usually include solar hot water heaters. In the design of large residential developments, the question of adequate supplies of component parts for multiple installations could also be a barrier.

ELECTRIC VEHICLES

Ground transportation consumes more than 25% of the oil Hawaii imports each year, and switching to electric vehicles has been suggested as one means by which the state could reduce its heavy dependence on imported oil. Whether electric vehicles will be used in Hawaii in significant numbers depends upon the future prices of electricity and gasoline; how much electricity production from renewable resources exceeds non-vehicular demand; the size of the mass market nationwide for electric vehicles; and future developments in automobile technology, particularly battery technology.

In the near term, while almost 90% of Hawaii's electricity is still generated by oil-fired power plants, electric vehicles would use petroleum indirectly, and less efficiently than gasoline powered cars. Once indigenous energy sources begin to supply most of Hawaii's electricity in the mid-1990s, electric vehicles could, in principle, reduce oil demand, although their effect on subsequent demand for oil-fired peaking power would have to be examined and possibly regulated.

The most optimistic forecasts suggest that by 2005, 65% of Hawaii's automobiles and light trucks could be powered by electricity. A more probable, but nonetheless optimistic, forecast puts the proportion at about 10% electric vehicles in Hawaii in 2005. Unless unforeseen technological breakthroughs occur in the very near future, privately-owned electric vehicles are not likely to displace the internal combustion engine (ICE) car in Hawaii within the next 25 years.

Technical Problems of Electric Vehicles

Electric vehicles share certain component systems with conventional vehicles, but their source of power is direct current electricity derived from some form of on-board storage. The present generation of electric vehicles is limited to a range of about 50 miles and speeds under 50 miles per hour except in special designs. Acceleration and performance on grades are poor, and deteriorate still more near the end of the battery charge. Advances in batteries however are expected to greatly improve the range and performance of electric vehicles within 15 years. The chief characteristics associated with mass-produced electric vehicles will probably be:

* A purchase price roughly comparable to or somewhat higher than the price of conventional vehicles of similar size and quality
* Durability comparable to and maintenance costs somewhat higher than those of conventional vehicles
* A range of about 100 miles between charges
* Definitely limited performance, especially in hill climbing
* Operating costs (based on petroleum-derived electricity) somewhat higher than those of conventional vehicles
* An infrastructure for replacement and charging of batteries

The single, critical component for future electric vehicles is a small, lightweight battery that could provide improved acceleration, driving speed and range. At present, gasoline has about 1000 times the energy density of the best lead-acid battery. Consequently, present electric vehicles must carry a relatively heavy and bulky battery, which further impairs performance. An electric vehicle with a 200-mile range and acceptable performance based on today's lead-acid battery would require about 300 cubic feet of batteries.

Of the more than 30 potential candidates for use in electric vehicles, six batteries stand out as most promising; three for the near term and three for the longer term.

Lead-acid batteries are already available with 40 Wh/kg specific energy. The eventual goal is 60 Wh/kg and a lifetime of 1000 deep cycles (nearly complete discharge and recharges). Lead-acid will be the only car battery available by 1982 at an initial capital cost of less than $100/KWh. A technological breakthrough reaching the goal of 60 Wh/kg and 1000 cycles would have a major impact, but is not expected before 1990.

Nickel-zinc batteries currently attain specific energies of 65 Wh/kg, and this is expected to increase to about 80 Wh/kg by the year 2000. The battery's energy density is high, as is its capacity for peak and sustained power. The battery, however, presently costs more than $100/KWh and has a lifetime of only 200 to 300 deep cycles. The nickel-iron battery can now store 50 to 55 Wh/kg, a figure that doubtless can be improved to 60 Wh/kg. It remains expensive, and bulky and produces hydrogen gas during the charging cycle. It is seen as a better potential candidate for trucks and buses than for passenger cars.

Lithium-metal sulfide, zinc-chloride, and sodium-sulfur batteries all offer significant advantages over these near-term candidates but are unlikely to be commercialized before about 1995. Still others--the nickel-hydrogen, iron-air, zinc-bromide and aluminum-air batteries--face such difficult technological barriers that they are unlikely to be commercially available before the year 2000.

Electric hybrid vehicles, expected within 25 years or more, will combine various types of batteries; batteries with heat engines; or the latter two with flywheels or other inertial storage devices. Improvements are also expected in portable fuel vehicles, including better fuel efficiency, down-sizing and the use of synthetic fuels.

Market Potential

Whether or not electric vehicles make a significant impact on Hawaii's use of imported oil depends on more than just technological improvements in the vehicles and their batteries. It will also depend on a sufficient mass-produced supply of and consumer demand for these updated vehicles; and a reliable, economical source of alternative fuels for producing abundant electricity.

Even with strong consumer interest, the Hawaiian market alone would be too small to stimulate the mass production and marketing of relatively low-cost vehicles. The precise size of the necessary nationwide demand is not known, but it will depend on both technological advances and on fuel prices in states with a mixture of energy resources.

In the near term, 1980-95, electric vehicles based on advanced batteries will be available with a range of 100 miles, improved-but-still-limited performance, lower operating costs and higher initial purchase price. As long as Hawaii's electricity prices continue to be tied to the price of petroleum, demand for electric vehicles is likely to be negligible and to make a correspondingly low contribution to electricity demand.

In the long term, 1995-2005, electric vehicle sales could remain negligible if electricity produced from local resources is still insufficient to meet non-vehicular demand. A more optimistic view, however, is that: domestic sources of electricity can contribute to transportation; improved ICE's would help reduce oil demand, and improved electric vehicles will be available with better range and performance. If these factors occur, there are then three possibilities:

1. If improved electric vehicles have a range of 200 miles or more, if their initial price is comparable to that of conventional vehicles, and if their operation cost is lower, then total electrically-propelled transportation would increase more or less linearly from a negligible proportion in 1995, to 60 to 70% by 2005.

2. If electric vehicles have a range of 200 miles and cost less to run, but have a higher initial price than conventional vehicles, the proportion of electric-powered transportation could reach 33% by 2005.

3. If electric vehicles cost less to run, but more to buy and also have a range of only 150 miles, their proportion in the transportation sector would reach only about 10% by 2005.

Barriers that remain to the deployment of electric vehicles thus center on vehicle technology and electricity supply and price. Other impediments include 1) competition from improved ICE and hybrid vehicles; 2) consumer resistance to decreased vehicle range and performance; 3) the small size of the Hawaiian market; and 4) problems of practical integration, i.e., development of battery charging facilities and the training of mechanics.

Electric vehicles could offer Hawaii a means of cutting petroleum consumption, considering the state's mild climate, relatively short driving distances, and receptivity to new systems of transportation. This is not a likely near-term solution, however, and will ultimately depend on the generation of electricity from renewable resources and on greatly improved electric vehicles.

COAL

Coal cannot be classified as a new or alternative source of energy, but even though it is a costly option today, it is a resource that could be used in Hawaii as a contingency or interim fuel. Hawaii's dependence on imported petroleum makes it vulnerable to interruptions in oil supply or to large increases in price. In addition, the timetable for transition to indigenous resources is not assured. In the event that the oil supply becomes threatened or too expensive before indigenous resources and the undersea cable are fully capable of fulfilling Hawaii's energy needs, coal could be a feasible alternative energy source. By the mid-1990s, two to three million tons per year of coal could supply two-thirds of the energy needed for electricity generation, which currently accounts for 31.9% of the state's energy budget. As an interim fuel, coal could gradually wean Hawaii from oil, moderate the rising price of electricity, and assure a continuous supply of electricity for the foreseeable future.

Worldwide, there is an abundance of coal. About 640 billion tons of coal are judged recoverable under present economic conditions, enough to cover the current world demand for 250 years. This figure represents only 6% of an estimated 10,000 billion tons of coal believed to be the total amount in the earth. As energy prices rise, the percentage of reserve considered recoverable will rise as well.

While the abundance of coal poses no problem, immediate availability to Hawaii does, since Hawaii has no coal and no appropriate infrastructure for handling it. Because coal is not an indigenous resource, it shares some of the problems of oil with respect to Hawaii. First, Hawaii would have to compete in the open market for coal with other importing areas, especially Japan and Western Europe. Second, crucial parts of the delivery system are not under the state's control. However, electricity generation from coal, like oil, has the advantage over other energy sources of being technologically developed, though mitigating the pollution problems associated with its use requires further refinement. Thus, it appears that the major barriers to the use of coal in Hawaii are the absence of a shipping and unloading infrastructure; uncertainty as to the best supply source, pollution problems and the cost of mitigating them; and the potentially prohibitive costs of retrofitting plants to use coal and down-time while retrofitting is in progress.

TYPES OF COAL FUELS

Coal can be transformed and used in a variety of forms. The most common method is conventional direct burning of solid coal, but other forms have some advantages. For instance, slurries (mixtures of coal with a liquid) are easier to handle and transport than solid coal. Slurries require no large bulk unloading facilities and can be piped to shore from offshore buoy pipelines or unloaded directly at dock side. Table 5 summarizes the costs, advantages, and disadvantages of a number of different solid and slurry coal fuels. All the costs have been increased 10% to allow for higher fuel and construction costs in Hawaii. Each of the fuels is briefly described below.

Solids

Conventional direct burning of solid coal is a long-established technology. Its capital costs and operating costs are relatively low, but the larger amount of pollutants it produces requires extra treatment and therefore, additional costs.

Solvent-refined (SRC-I) coal is a new fuel produced by treating solid coal with solvents to reduce the sulfur and ash content. The resultant fuel has a higher energy content (approximately 16,250 Btu/lb) and produces less waste when burned than untreated solid coal. However, the refining process creates a waste disposal problem at the treatment plant (which would not be located in Hawaii). SRC-I is a doubtful option for Hawaii because it costs more than ordinary solid coal, might require further sulfur removal when burned and the technology is still uncertain. Conventional petroleum burning plants can be retrofitted to use either ordinary coal or SRC-I but at considerable cost.

Fluidized bed combustion (FBC) involves burning a bed of crushed coal in an upward moving stream of air. Limestone or dolomite is added to react with the sulfur to produce inert solid sulfates and sulfites. This process eliminates the problem of cleaning stack gas but leaves a residue of unburned fines that requires additional burning and treatment. Furthermore, three to four times the amount of limestone must be used to remove the SO_2 as would be required to clean stack gas in a conventional plant, creating a large solid waste problem. The advantages of FBC are higher overall heat-transfer rates that allow for smaller boilers and lower capital costs. This method could be widely available in five to ten years.

Slurries

A possible slurry is a mixture of coal and water. Although this form is easy to transport, it has an associated energy penalty because it is diluted. Furthermore, the slurry uses large amounts of fresh water which then must be removed and disposed of at the plant. One possible solution to the disposal problem is a 70/30 coal-water slurry that is fired directly, using the water in the process, but this method is still experimental.

A second type of slurry is a mixture of coal and oil. It has no associated energy penalty but is more expensive because of the oil. The mixture cannot be used in conventional oil-fired plants. It is unlikely that this form would be used in Hawaii.

TABLE 5. -- A Comparison of Costs and Characteristics of Various Coal Fuels (1980 dollars)

Type of Coal Fuel	Capital Costs	O & M Costs	Date Available	Environmental Problems or Advantages	Other Advantages of Disadvantages
Solids					
Conventional Direct Burning	$2,000/KW	10 cents/KWh	now	Particulates, stack gas, ash, and waste disposal	Removal of particulates costs 0.5% of output. Scrubbing of stacks takes 5-10% of output. Ash and waste disposal also may boost cost. Technology available now. Unloading is difficult.
Solvent-Refined Coal	$3.3/MMbtu	Slightly higher than above	1990s	With sulfur reduced is cleaner burning, though pollution laws may require sulfur removal at point of burning.	Higher energy content (16,250 Btu/lb). Waste disposal at refining plant, not in Hawaii. Can't retrofit conventional plant.
Fluidized Bed Combustion	$1050-1200/KW	10 cents/KWh	1985-90	No stack gas clean-up. Large solid waste disposal problem. Can produce inert landfill. Unburned fines require further clean-up and combustion.	Higher heat transfer rates permit use of smaller boilers and consequent smaller capital costs.
Slurries					
Coal-water	N/A	N/A	now	Waste disposal problem of water decanted from slurry at point of use. Use of large amounts of fresh water (250 million gals. to slurry 2-3 million tons of coal).	Easy transportation and flexible unloading. Loss of energy per load because of dilution.
Coal-oil	N/A	N/A	now	More land required for waste disposal than for petroleum fuels, less waste than with pure coal.	Coal-oil mixture can erode tubes, clog burners, and produce slag. These problems appear manageable, but only in special systems. No loss of energy. 10%-13% cheaper than equivalent unit of petroleum fuels, but still more expensive than pure coal. Continues dependence on oil.
Coal-methanol	N/A	N/A	now	Stack gas must be cleaned for particulates NO_x, and sulfur. Ash must be disposed of.	Easy handling, long storage, and lower liquid content/lb of coal than coal-oil slurry. Some coal ash also removed. No loss of energy/load. Methanol costs more than oil.

Coal and methanol can be combined using 30-50% methanol. This slurry can be stored for a long time and has the advantage of a lower liquid content per pound of coal than coal-oil mixtures. However, now methanol costs more than oil, and coal-methanol slurries also produce particulates, NO_x, and sulfur in the stack gas as well as a fair amount of ash.

The cost of switching to coal would include the initial capital costs of replacing furnaces and boilers in present oil-fired plants with units that could handle coal or building new facilities. Continuing costs would include the price of coal and shipping.

Shipping and Associated Costs

Shipping and port costs vary with the source and type of coal and the size of the transport vessel. The mid-1960s saw a trend toward shipping coal in larger vessels for long routes. By 1976, only 25% of the carriers were under 25,000 DWT and over 14% were over 100,000 DWT. Related to the increase in vessel size is the need for larger port facilities. Few ports today can offer berths and unloading facilities large enough to accommodate the largest vessels carrying bulk coal (150,000 DWT). In Hawaii, the offloading of solid coal would require expansion of port facilities at Honolulu to accommodate large vessels and the bulk cargo. Two possibilities would be to employ either self-loading bulk carriers or barge-carrying ships. The latter would give greater flexibility in transporting smaller amounts of coal to other areas beside the port. Currently, there are no data available on costs for expansion of the port.

SOURCES OF COAL FOR HAWAII

The ten countries with the largest known recoverable reserves of coal are: the United States, the USSR, China, the United Kingdom, Germany, India, South Africa, Australia, Poland and Canada.

The two major importers of coal are Western Europe and Japan. Hawaii's projected consumption of two to three million tons of coal per year is only a small fraction of the 190 million tons traded each year in the world (1976). The most likely sources of coal for Hawaii are other states in the US, Canada, Australia, and South Africa.

The United States

Although the US has enough coal to satisfy its own needs for over a century, supplying coal to Hawaii would be complicated by shipping difficulties. Bringing coal from the eastern US is expensive because of the long distances involved. There are large coal deposits in the West, but no western ports can handle bulk coal carriers of 50,000 DWT or more, none have adequate rail access from coal supply regions, and environmental restrictions may inhibit the expansion of facilities there.

Alaska has very large coal fields, not all of which are currently under production. Those fields located near Cook Inlet have the greatest year-round potential for mining. Another advantage of this area is that the inlet can accommodate ships of 100,000 to 130,000 DWT at any season of the year.

Canada

Canada has large coal reserves in the western provinces of British Columbia, Alberta, and Saskatchewan. One Japanese study showed that western coal could be delivered to Japan at costs equal to those of coal from the US and sightly higher than delivered costs of Australian coal. The three provinces have new coal policies which permit exports only if a domestic surplus exists. Because of the large size of the deposits, this policy should not interfere with exports in the near future. Shipping facilities at Vancouver and Roberts Bank in western Canada can handle 100,000 DWT ships.

Australia

Australia is one of the world's largest coal exporters and ships 75% of its production to Japan. The Australian government is promoting long-term contracts that would permit escalations in prices between periods of negotiation. This policy may dampen foreign interest in buying large qualities of coal. Modern shipping facilities at Hay Point in Queensland can handle vessels of 120,000 DWT.

Other Possible Sources

The opening of a new coal terminal at Richards Bay has boosted South Africa to fifth place among world exporters of coal. The port can handle 150,000 DWT vessels. The South African government fixes coal prices and they are relatively low.

Another, geographically closer, potential source of coal is China. Since the late 1970s, China has shown an interest in acquiring hard currencies through foreign trade. The country has extensive coal deposits which are now in production, and lower labor costs could make Chinese coal cost competitive with coal from the United States or Canada.

ENVIRONMENTAL AND SOCIAL BARRIERS TO COAL USE

One of the most important considerations for Hawaii with respect to using coal as a major energy source is to determine what effects coal burning will have upon the environment. In Hawaii, clear air and water have an economic as well as a social value. Tourists are a chief source of revenue for the state, and most are attracted not only to the warm climate but to the pristine quality of the air and water. Of all the alternatives to oil posed in this report, coal has the greatest potential for damaging the air and water quality in Hawaii. As new sources, coal-burning facilities would come under the jurisdiction of a number of federal environmental protection laws and regulations. The Clean Air Act requires states to enforce primary standards affecting public health and empowers them to set secondary standards to protect the public welfare. The three main pollutants emitted from coal burning facilities are oxides of sulfur and nitrogen (SO_x and NO_x) and particulates. Coal storage facilities also produce large amounts of particulates in the form of coal dust. The ash residue from a coal plant presents a sizeable solid waste problem.

Current regulations require a percentage reduction in SO_x emissions regardless of the original sulfur content. Hawaii forbids the sale of fuels containing more than 2.0% sulfur and prohibits the use of fuels containing more than 0.5% sulfur in power plants generating more than 20 MW.

Current technology can meet the maximum emission rates for NO_x with 65% reduction, but the government is expected to set more stringent standards in the future. Available technology can also satisfy federal particulate standards. Under the Clean Air Act, states must make plans that show how they will comply with federal standards. The plans must contain three elements: a program to prevent deterioration of air quality, provisions to attain national ambient air-quality standards, and a program for pre-construction review of new sources of air pollution. Siting coal burning plants in Hawaii would be contingent upon compliance with these standards and regulations. In some cases a trade-off might have to be made in which an oil plant is eliminated to allow the operation of a coal plant.

The Federal Water Pollution Control Act would also pertain to the construction and operation of coal plants in Hawaii. New water pollution sources are required to use the best available control technology and to meet the effluent guidelines and standards which have been set for all of the nation's waterways. These standards may be changed in the future, and effluent pretreatment standards require that plant designs have the flexibility to accommodate increased stringency over time.

Environmental protection laws also require a plant owner to monitor and record the disposal of solid wastes. Wastes cannot be dumped into the ocean. In view of the significant quantities of solid waste that coal plants produce, waste disposal sites on land would have to be found, and this could be difficult in Hawaii.

Finally, the Occupational Safety and Health Act covers the health of employees in the work place. Specific standards pertaining to noise, heat, machinery hazards, and toxic emissions would apply to the operation of coal plants. While some of these laws and regulations protecting the health of workers and the environment would add considerable expense to the design and operation of coal plants, they would also facilitate public acceptance of the use of coal fuels in the event that it became expedient or necessary to use them.

Chapter 3: ISSUES IN ENERGY USE AND CONSERVATION IN HAWAII

Hawaii has barely begun to benefit from the energy savings available to it through conservation. By the year 2005, the combined effects of technical innovation, increased energy prices, and consumer efforts will change not only the amount of energy that Hawaii's people expend, but more important, the way in which they use it. Precise estimates of these energy savings are difficult to calculate on the basis of the data now available, but econometric modeling based on various sets of economic assumptions (see Chapter 6) makes it possible to forecast basic trends in the reduction of energy consumption. It is clear that the potential for conservation in Hawaii is very large, and that the bulk of energy savings lies in the future.

Energy prices and availability shape the evolution of energy demand. Energy demand appears to be as or more responsive to market forces as it is to social programs and public education about energy use. The econometric models described in Chapter 6, "Hawaii's Energy Future," show that sustained steep increases in the price of energy reduce demand about the same or slightly more than aggressive conservation programs on the part of consumers and government. It is quite likely that these market forces will persist for some time in Hawaii as world oil prices continue to rise. After the mid-1990s when the state begins to rely more on renewable resources for electricity generation, electricity prices will be less tied to the price of oil, but Hawaii is likely to face high gasoline prices, along with the rest of the nation, throughout this century.

Contributed by Lee Schipper, Lawrence Berkeley Laboratory

ENERGY USE IN HAWAII

Hawaii's energy use pattern differs in several important respects from that of the Mainland, and as a result, a conservation program for Hawaii must be carefully tailored to the specific conditions of the state. Hawaii's energy use is dominated by three sectors: jet airplane fuel (33% of total state energy use); electricity generation (30%); and ground transportation (15.6%). Together, these account for almost 80% of the state's energy use. In contrast, only 2.5% of primary energy use on the Mainland is used for jet travel, 27% for electricity generation, and 12% for cars. Nearly half of Mainland electricity is consumed by industry, while in Hawaii, industry is actually a net energy producer. The country as a whole uses 40% of its energy for space heating; Hawaii puts almost no energy to that use. (See Figure 4, Chapter 1 for a breakdown on Hawaii's energy use patterns.)

In addition to shaping a conservation program to its own energy use patterns, Hawaii must direct its efforts to those sectors over which the state has some influence or control: homes, buildings and cars. Trucks are important energy consumers, but their technical characteristics are little influenced by buying habits in Hawaii. The same is true of aircraft; even though jets use a third of the state's energy, aircraft energy conservation is influenced mostly by events on the Mainland. Indeed, Hawaii's economy is so tightly coupled to jet air traffic, it would not be in the state's interest to encourage jet fuel conservation through reduced air travel. Finally, military activities represent the second largest economic sector in the state, but military energy use in Hawaii (19% of the state total) is a matter under federal control.

Hawaii's conservation efforts will have to take into account other factors that are certain to affect the absolute amounts of energy to be consumed in the future. The first is increasing population, which will consequently swell the number of energy consumers. If the present trend toward smaller families continues, the number of households will increase out of proportion to the growth in population, increasing the number of one-to-a-household items such as refrigerators. If personal income in Hawaii continues to rise, more residential consumers will be able to buy labor-saving and luxury appliances and vehicles. Another important part of Hawaii's energy picture is the large number (almost 4 million in 1980) of tourists who pass through the state each year. People on vacation tend to be less conscious of conservation than residents. Because tourists never see the utility bills, even though they pay for them indirectly, consumer education is very difficult.

WHAT IS CONSERVATION?

Conservation occurs because people and firms want to reduce costs. Hotels in Hawaii, working on low margins per guest, want to reduce the cost per guest of heating water, cooling buildings and cooking meals. Homeowners want to reduce the costs of cooking and refrigerating food. People have always adjusted their preferences as relative costs changed. They drive less than otherwise if real (as opposed to inflationary) costs increase. Thus, conservation is an economic response to rising energy costs.

Energy use can be broken into two components: activities and energy use per unit of activity. Miles driven and gallons per mile represent two such breakdowns. Conservation usually means reductions in the gallons consumed per mile through technical changes or maintenance. In the long run, conservation may also result as people switch from energy-intensive activities, such as flying and driving, to less energy-intensive activities, such as vacationing closer to home or driving less and using communications instead.

Conservation is perhaps more important to Hawaii than it is to the Mainland because virtually all of Hawaii's energy comes from imported oil. Electricity prices are among the highest in the nation. Pre-embargo prices, however, were not nearly as high as they are today, and the cost of importing oil was very manageable. As a result, the price shock to Hawaii has been considerable. Overall response to such a shock is difficult to measure in as little as five or ten years both because data are difficult to collect and because a change to more energy-efficient housing, commercial buildings, vehicles and appliances takes capital and time. Since the 1974-75 oil embargo, only a small part of the building and appliance stock has turned over. A larger proportion of the automobile stock has been renewed, but energy-efficient, domestically produced cars have begun to appear only since 1978. Therefore, it is believed that most of the conservation possibilities in Hawaii are yet to be realized.

ENERGY AND THE STATE ECONOMY

The affects of energy on the state economy are important to understanding future energy demands because all parts of the economy are interdependent. For example, commercial floor space increases with upswings in commercial activity, influencing electricity use directly. Auto travel, and therefore gasoline consumption, is a function of land use planning--where new housing is built--and auto ownership. Both factors depend on population, which in turn depends on the strength of the economy and its resultant attractiveness to in-migration, and on the level of income, which helps determine the level of automobile ownership. Jet airplane travel, to take another example, is itself an indicator of the health of the tourist industry, Hawaii's lifeblood. There was a downturn in tourism in 1980, in part because of a jump in air fares caused by rising fuel costs. This slowed growth in other parts of the economy which spend the income from tourism.

Great changes in the structure or growth of the Hawaiian economy would have effects which are impossible to predict. It is necessary to assume a certain amount of continuity when attempting to forecast or analyze future trends. This discussion is necessarily limited to the principal options for reducing energy intensities as well as to a few of the minor belt-tightening changes in energy use that occur in a healthy economy when energy prices rise or supplies are uncertain.

Widespread information about investment in conservation strategies and the rate of return on such investment would be a useful part of any conservation program. For the homeowner in Hawaii, for example, it means buying a slightly more expensive refrigerator with good insulation. The extra investment would be paid back in a few years in the form of significantly lower utility bills. A comparison of the size of the investment with the amount of energy saved shows that saving energy costs far less than generating electricity from existing or new sources. Similarly, an investment in sunshades to remove the main source of heat from air conditioned rooms and offices is typically paid back in a few years in reduced cooling costs. Because there are generally high returns on conservation investments, this form of conservation helps the economy as a whole by freeing capital and other resources that otherwise would have gone for expensive new generating facilities or imported oil. Because Hawaii faces very high capital demands over the next 25 years as it switches to indigenous energy resources, the interaction of conservation with the economy has special implications for the state.

MAJOR CONSERVATION POSSIBILITIES

The most comprehensive reviews of conservation possibilities (1) point toward reductions in the energy intensity of most activities in the economy ranging from 25% to 80%, depending on the use and the price of energy. Unfortunately, it is not possible to predict actual energy use levels for the future based on a percentage reduction from present use per person or activity. Too little is known about the energy use per area in large commercial buildings in Hawaii, energy use per occupant ratio in other large buildings, or even the miles per gallon consumed on the road by Hawaii's autos and trucks. It is necessary, therefore, to discuss the relative reductions that are possible and likely.

In the possible energy futures discussed in Chapter 6, we posit energy price rises that range from a factor of two to a factor of ten by the year 2005. For purposes of this discussion, the assumption is that energy prices will quadruple over 1975 prices by the year 2005. The assumption that energy prices will continue to rise in real terms is based on the fact that US price controls have recently been removed from oil products. Another reason is that long-term growth in the world economy will push demand for oil in developing countries even as developed countries begin to conserve effectively (2).

It may be helpful here to define energy intensity as the amount of energy used per unit of activity (gallons of gasoline/passenger miles driven, or KWh/hot showers taken). Energy intensity takes into account the efficiency of both the appliance or vehicle and its user. For example, a manufacturer can make a car more fuel efficient by raising its MPG rating, thus decreasing its energy intensity. A driver can decrease the energy intensity even more by taking other passengers along in the car.

The conservation possibilities that energy prices make attractive in key sectors permit the assumption that the energy intensity of industry will decline at about 1.5% per year (3). Light or heavy trucks are expected to use 25% to 40% less energy per ton-mile in the year 2000, both because of technical improvements in rolling stock and through important changes in operations that will become economical as fuel prices rise. More important, passenger jet aircraft are expected to continue to decline in energy intensity, already 25% below its pre-embargo value per passenger-mile, by another 25% by 2005. But as noted above, these three energy use sectors are either less important in Hawaii than they are in the rest of the nation, or they are out of the reach of state policies and programs. Three areas in which the state can be expected to have considerably more influence are energy use in the home, in commercial buildings, and in automobiles.

Residential Energy Use

Residential energy use in Hawaii is characterized by an almost complete reliance upon electricity. It accounts for 8.5% of total state energy use. Since there is virtually no space heating and little air conditioning, residential electricity is used for water heating (40%), refrigeration (20%), cooking (10%), washing (3%), drying (8%), lighting (8%) and TV and radio (5%).

Fortunately, conservation possibilities are becoming commonplace in all these areas as new appliances appear on the market. Both federal and state appliance efficiency standards, along with consumer desire to reduce utility bills, are contributing to the pressure for more energy-efficient appliances. Table 1 shows the potential conservation savings by the year 2005 for the major residential energy uses.

TABLE 1. -- Residential Energy Use Conservation Potential in Hawaii

Use	Potential Electricity Savings by 2005
Water heating	70%
Stoves	33%
Refrigerators	50%
Freezers	50%
Lighting	50%
Dishwashers	35%
TV	25%
Washers	25%
Dryers	25%

Source: (5)

Note that the assumption underlying the savings shown in Table 1 is that by the year 2000, the market for major appliances will be fully saturated at virtually all income levels. The result gives about a 50% reduction in energy use per household.

Because water heating takes the place of space heating in Hawaii as the main user of energy in the home, it is important that the prospects are good for solar hot water systems or electric heat pumps to completely replace the present electric systems. It is estimated that by the year 2000, 10% of all homes will use the more expensive solar systems to supply 80% of their hot water needs. The other 90% of homes will use electric heat pumps. In addition, rising energy prices are expected to reduce per capita water use by 20%. These factors, combined with other shifts in household size, number and water use rates could produce a per capita decline in hot water energy use of 75% to 80%.

A number of factors complicate the home energy use picture, and while it is not possible to predict their exact effects, over several decades they will shape energy growth patterns. For example, it is reasonably certain that energy prices will rise, forcing down the absolute level of energy use per home, and that could balance the increase in the number of households and appliances. New appliances may become smaller. Less certain trends in population structure could create new patterns of energy use. For instance, if Hawaii continues to be a favorite retirement spot, the number of older people will grow out of proportion to the population, probably increasing the demand for multi-unit apartment buildings that have an important air conditioning demand not found in single-story dwellings. Land use planning and changing living patterns can also influence the way in which automobiles are used. If higher gasoline prices keep people at home more, they will tend to use somewhat more energy for appliances, although the kinds of appliances that keep people busy at home use very little energy per hour compared to cars. The dominant trend, however, will be toward less energy use in the residential sector.

Commercial Buildings

It is more difficult to break down energy consumption by use in commercial buildings than it is for homes. Certainly, the division of labor among lights, fans, air conditioners, other motors (i.e., for elevators) and water heaters has been studied in literally thousands of buildings, but no single characterization can be developed because the functions of commercial buildings differ so much. In Hawaii, commercial buildings, like homes, rely predominantly on electricity for energy. In some buildings, such as laundries and hotels, water heating by either gas or electricity is very important.

A report for the Department of Energy (4) indicates that significant reductions in the lighting, cooling and ventilation energy requirements of 35% in buildings designed before 1975 are both practical and economical. Pre-embargo energy use has already been halved in many schools and office buildings (5), and even greater reductions are possible in new buildings.

Technical, behavioral and institutional factors combine to affect the level of conservation achieved in any given building. Technical factors include the design of the building as well as of the equipment which cools, ventilates and lights it. This is crucial to understanding the energy problems in buildings built when energy was cheap and energy costs were not a major concern to designers, builders, landlords or tenants. Behavioral factors influence the probability that building occupants will take measures to save energy. This has already been noted in connection with the difficulties of directing conservation education programs toward tourists. Institutional factors determine whether those responsible for the building will or can take any action. This can be affected by something as simple as making the party--tenant or landlord--who controls most of the energy use in the building, responsible for utility bills.

The cost of energy is one of the single most powerful incentives for conservation. It is estimated that, for the entire services sector, gross savings corresponding to a reduction in energy use per unit of output of 25% would accompany an increase of energy prices to 9 cents/KWh in 2005, or 40% with an increase in prices to 12 cents/KWh (3).

Air conditioning has not been a major factor in Hawaiian energy use. However, it is sometimes used in high rise buildings as much for noise control as for temperature control, and it is becoming an important energy consumer in Hawaii as high-density housing and high-rise hotels and other commercial buildings become more common. Hawaii has generally mild temperatures and steady trade winds. Careful building design, window shading, and ventilation systems that take advantage of the trade winds can reduce or eliminate the need for air conditioning in many cases. Improved sound insulation would be a better solution for noise control than air conditioning.

Prevailing opinion among those engaged in conservation analysis suggests that, for Hawaii, the following savings per unit of output are possible: in retail trade where cooling is used, 25%; where no cooling is used, 20% (better lighting); in schools and hospitals, 30%; in older commercial buildings with operable windows and low cooling loads, 15%; in sealed buildings with appreciable cooling loads and typical lighting loads, 35%. Hotels could save 15% in cooking gas, or 33% in cooking electricity; 50% in energy use for hot water; and 25% in cooling energy use. It is difficult to make estimates for service buildings (laundries, repair shops), but a 20% reduction in energy use per unit of activity seems reasonable. Overall, it is not unreasonable to expect energy use in the commercial building sector to be about 45% lower than 1975 use levels by the year 2000.

Present HECO estimates hold that operating a hotel room in Waikiki for one month at 80% occupancy requires about 1000 KWh, which costs around $120 a month, or $4 a day (6). This is an appreciable sum taken in the context of operating margins and justifies far greater attention to energy use than has been given in the past. Similarly, energy costs raise costs per square foot of commercial floor space, eating into profit margins and giving building owners and tenants the incentive to modify operating technologies. It is reasonable to expect that cost pressures will, given time, bring about large savings in energy use in Hawaii's commercial buildings.

Automobiles

In spite of the importance of automobiles in the state energy picture, little is known about the distances cars are driven in Hawaii, the driving cycle, or their energy intensity in gallons per mile. The Hawaii State Energy Factbook assumes a performance of roughly 15 miles per gallon, consistent with Mainland experience, given the somewhat smaller average weight of cars in Hawaii and the somewhat more urban and congested driving cycle. This figure was used to derive the average driving distance; it is only an estimate. By 1990, most new cars will probably achieve better than 30 MPG, and 40 to 50 MPG could be reasonably expected by the year 2000 (7).

The 30 MPG goal, which many foreign manufacturers are now meeting (7), will make cars considerably more competitive with mass transit in Hawaii than is usually realized. Unless gasoline prices continue to rise precipitously, mass transit seems unlikely to attract many auto commuters on the basis of energy economics alone. If Oahu's bus system, which has been plagued by equipment shortages improves service to commuters as freeways grow more crowded, it may be able to compete in terms of convenience. Overall, the automobile will continue to dominate personal land travel.

Energy use also depends on the way in which autos are used. There is little open highway driving on Oahu, where most of the automobile traffic occurs. Demographic changes and land use planning--whether new housing is concentrated west of Honolulu or on the windward side, for instance--will also affect automobile use. Thinning traffic and increases in the average trip length would boost actual MPG considerably.

The force behind gasoline conservation is expected to be rising prices. Even though market saturation of high MPG cars is expected to take some time, overall MPG is expected to increase faster than the number of cars, and the number of miles driven per car per year to decrease somewhat. This has been observed on the Mainland during the past several years, and the major oil companies and the DOE are now forecasting a continuation of this decline through most of the century (8). One counterweight to this trend is the increasing number of light trucks, vans and recreational vehicles purchased by private households, possibly as a replacement for the large, luxury cars Detroit is now phasing out. Overall truck and car MPG may not rise as fast as otherwise expected if these vehicles remain popular.

At present, then, it can be assumed that the number of miles per car driven today may continue to decrease slightly with increased gasoline prices. These prices increased in real terms, as opposed to inflationary terms, during only two periods--1973 to 1974, and 1979 to 1981. In both periods, there was a national drop in miles driven per car. Moreover, the trend toward small, fuel-efficient cars continues. It appears that America, including Hawaii, is finally on its way to the 40 MPG car.

POLICY ISSUES

Hawaiian energy use data have not yet been collected in enough detail to plan a complete conservation program for the state. Even so, it seems that for nearly 60% of Hawaiian energy flows (counting the oil used to generate electricity), a conservation reduction of roughly 50% per unit of activity, averaged over all the buildings and transportation energy uses, is possible and likely from an economic viewpoint in a near-perfect marketplace. It is important to realize, however, that the marketplace is not perfect. There are many areas where conservation policies related to pricing, regulation, or other areas only indirectly connected to energy can have significant impacts on energy use. The well-recognized social and institutional barriers to conservation are often described as market failures (9).

Social Barriers to Widespread Conservation Programs in Hawaii*

Many kinds of energy programs encounter general social barriers, such as skepticism about institutional and government policies, refusal to believe that an energy crisis still exists, and resistance to change from known practices to new and different ways of doing things. Often, public support for a program is high, but only as long as the inconveniences it may cause or changes in behavior it may necessitate are carried out by someone else in some other place.

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*This section was contributed by the Hawaii Department of Planning and Economic Development.

Certain conservation measures, such as the use of car pools or public transportation, encounter the "status symbol" barrier. The young executive, for example, might feel that his or her successful image would be damaged by taking the bus or a carpool to work. A senior company officer may thoroughly enjoy the mark of success signaled by driving a large, luxurious, energy-inefficient car.

Other conservation measures encounter the very practical barrier of lack of time on the part of the two-wage earner families that are so prevalent today. Hanging the family laundry outdoors takes more time than putting it into a dryer. Often, laundry can be done only at night when drying clothes outdoors is not feasible. Similarly, the tight scheduling required by working adults, especially those with children, often precludes taking the extra time involved in using public transportation or bicycling or walking to work. Carrying home a week's supply of groceries is difficult on public transportation.

Centralized air conditioning and heating in large buildings often requires temperatures to be averaged to meet mandated levels. The result is usually that some areas are too hot and others too cold for comfort. Individual response to temperatures makes it impossible for everyone to be comfortable. In addition, some rugged individualists invariably resist mandated temperature levels on the grounds that government determination of ambient temperatures, or indeed of any energy use, is an unwarranted interference with personal rights.

Price

Energy prices in Hawaii are high by US standards, but even so, all US gasoline prices are low by world standards and probably inconsistent with a transition to a 30 MPG fleet of cars (7). It is doubtful that today's gasoline prices will bring about a massive shift to public transit, particularly in non-rush hour periods when load factors are low. If prices reach levels that do bring large numbers of people to use mass transit, the lead time for providing additional equipment must be considered. State officials concerned about the pace of conservation in this and other energy use sectors should recognize the interaction of policy and prices (3); neither alone will assure achievement of conservation goals, and the goals themselves should be consistent with price levels.

An additional consideration should be borne in mind. If market prices are to reflect the total social costs of energy supplies, they should then include costs such as those of pollution and import risks. This may not be politically feasible, and the time scale for full response to these social costs may be long. Under such conditions, government intervention beyond the usual scope of funding research and development, regulating prices, and offering public information may be called for. Such intervention sometimes takes the form of mandatory conservation programs even though these are unpopular and difficult to enforce. Griffin (10) has shown that taxation as a way of internalizing costs produces the most economically efficient allocation of resources in the long run, but he assumes that society is moving from one economic equilibrium to another. This may not be the case, particularly if demand markets are imperfect, a case Griffin does not treat. Hence, it seems there is a limited role for regulation on the demand side.

Standards

When it is believed that market forces are imperfect--rental housing is a good example because building owners, managers and tenants all have different economic interests in buying and maintaining energy-efficient equipment--society may act through regulation to improve the workings of the marketplace (7). The US government-imposed temperature limitations in commercial buildings generated much ill-feeling in Hawaii because it was felt that they were inappropriate for local conditions. Yet unless all public buildings restrict their use of energy for heating and cooling to some extent, those that do so voluntarily risk penalties from customers and tenants. No single building is apt to move toward new comfort settings unless all do. The 55 mile per hour speed limit, which appears to save more in lives than in gasoline, is a similar case because driving more slowly works well only if all drivers slow down.

The actual mandated temperatures may have been incorrect for Hawaii, but the principle behind regulating all buildings in a class still holds. There is ample scope in Hawaii for energy savings in the building sector from temperature regulations. If the Hawaiian government finds that the federal rule is inappropriate for the unique Hawaiian climate, it may press for local rules.

Efficiency standards embody a different kind of regulation. They apply to the performance of equipment or buildings, usually by limiting the maximum energy needs for a given application or entire system without specifying which components or technologies must be used to fulfill the standards. Hawaii, for example, might enact minimum efficiency standards for ordinary hot water heaters, refrigerators, stoves and air conditioning equipment. The state is somewhat limited, however, in that is represents a small market, and almost all appliances are manufactured elsewhere. Federal appliance and building efficiency standards have been under study (11), but their future is in doubt.

Some states, such as California, have enacted efficiency standards for refrigerators and other devices, including shower heads. The impact of these standards on residential consumption is expected to be considerable in the coming years. A major mail order catalogue, for example, marks certain low-efficiency air conditioners as "Not for sale in California." The implication is that they are bought in other states, though their low efficiency makes them expensive to operate and more costly in the long run than those sold in California. Marketplace irregularities--such as a lack of consumer understanding of the advantages of conservation investments, or the inability of sales people to explain the economic advantages of more efficient appliances--can make the first-cost penalty a barrier to market penetration of more efficient appliances.

Standards covering the thermal performance of commercial buildings are also under congressional consideration and have been studied extensively (12). Like appliance efficiency standards, building energy performance standards are intended to reduce the life-cycle costs of building and operating structures because the present marketplace chain of financer-developer-owner-tenant does not respond very well to energy price signals (9). There are no hard data yet to indicate how building designs have responded to the oil embargo or to the energy price increases since 1978.

Performance standards for buildings and efficiency standards for new appliances and equipment remain an important option for Hawaii, because of the high number of rental units of both housing and offices in the state. Another option that works more directly through the marketplace is the taxation of autos according to weight, both at the time of purchase and as part of a yearly road-use fee. Automobile weight is already taken into account in Hawaii in setting annual registration fees. Such practices have a clear influence on car weight and therefore on fuel economy (13).

Land Use

Land use patterns determine where people live, work, play, visit and shop. They have a critical effect on the number of miles people drive, and on the congestion they face. When most residents could live, work, and spend their free time in or near Honolulu, the car was less important than it is today, when the population is quite dispersed. If, for example, the windward side of Oahu is developed preferentially over the leeward side, there will be many new trans-Pali commuters. If jobs are created on the windward side, commuting may be reduced, but to date, most of the economic activity continues to center around inner Honolulu.

If, on the other hand, residential opportunities were expanded in or near downtown as part of urban renewal, high-density housing near both beach and work might dramatically reduce the distances driven by inhabitants in the new area, and increasing density would favor the greater use of buses. High-density, multiple-family dwellings might be designed to reduce the need for air conditioning and to make maximum use of heat pump or solar hot water devices. The energy and other economic tradeoffs should be examined carefully. Energy alone should not be the criterion for deciding how to expand Honolulu, but direct and indirect energy effects must be considered in any conscious effort to change patterns of land use.

Unfortunately, predicting long range demographic patterns is almost impossible. It is even difficult to create models of possible future development because there are so few specific data on how people actually use energy now in Hawaii. If Hawaii is to design and implement an energy conservation program that will be appropriate for its unique energy use needs and conserve the maximum amount, much data collection on and analysis of present use will have to be done. An effective conservation program could free large amounts of capital that would otherwise go to buy oil or build new generating facilities. It would give Hawaii time to make a transition to the many indigenous, renewable energy resources the state will have at its command by the end of the century.

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Chapter 4: SOCIAL, LEGAL AND INSTITUTIONAL CONSTRAINTS ON ALTERNATE ENERGY RESOURCE DEVELOPMENT

Specific technical and social barriers to each of the alternate energy technologies have been discussed in Chapter 2 of this volume. Only the social, legal and institutional constraints affecting the full range of alternate resources will be discussed here. Some of these constraints are specific to Hawaii, embedded in state law or in Hawaii's unique cultural tradition. Others are more general and almost seem rooted in human nature. The latter include:

* Skepticism about the existence of an energy crisis
* Skepticism about institutional and governmental statements and policies
* Objections to the impact of scaling up from experimental to commercial facilities
* Disinclination to change from known to unknown ways
* The "Great idea, but it doesn't mean me" syndrome

Scientists, engineers, financiers, and developers may overlook social constraints on new technologies, not so much from a lack of sensitivity as from focusing too narrowly on the financial and technical aspects of a particular project. Many developers have already discovered that disregarding the concerns of local residents can be a serious mistake, if only because such disregard can lead to protests or litigation which can add enormously to the already high costs of developing new energy technologies.

WHAT CRISIS? HUMAN NATURE AT WORK

Of the general social barriers to implementing new energy technologies, the refusal to believe an energy crisis really exists is not as prevalent in Hawaii as it may be in some other states. Hawaii's almost total dependence on imported fuel has been well-publicized and emphasized, politically as well as academically. Air and ocean transportation tie-ups have made Hawaii residents uncomfortably aware of how vulnerable they are to interruptions of supplies from the Mainland United States and foreign sources.

While most Hawaii residents believe that the state needs alternate energy sources, they are not at all sure that anyone really knows how to go about developing them. Conflicting statements from both government and business have eroded the credibility of both sectors. Skepticism is found in a wide range of citizen groups -- young and old, rich and poor, professional workers and laborers -- and it is a serious social barrier to implementing a widely accepted development plan for alternate energy sources. (These views are expressed more fully in Volume VI, Perceptions, Barriers and Strategies Pertaining to the Development of Alternate Energy Sources in the State of Hawaii.)

This skepticism is reinforced by the way energy issues have been reported in the news media. It is not uncommon for a story about severe fuel shortages to appear in the same edition of a local paper as a story about lower prices caused by overflowing storage facilities. The stories may concern many different kinds of refinery products, but the perceived contradiction adds to a general climate of cynicism and a general tendency to disbelieve statements about resource need. The confusion is compounded by the quite concrete difficulty in obtaining accurate, detailed and current statistics on supply and demand from either government or business.

Some distrust of statements by government and private industry is warranted. There have been examples of corporations denying charges of pollution up to the moment corroborating photographs of their violations of environmental regulations have appeared in the press. Forced to concede the facts, some companies have fallen back on the claim that the costs of obeying the law would put them out of business, only to be found quite capable of maintaining production, and even profits, when forced to comply. Repeated, well-publicized episodes of this sort have led to a general cynicism about corporate statements.

Government agencies have, in some instances, added materially to one problem. They often ignore in their own actions the regulations and laws they impose on others. The cartoon version of a government official making a speech on the need for energy conservation and then driving off in a limousine which gets 10 miles to the gallon sometimes becomes a reality, inspiring general skepticism about government statements about the energy crisis.

Another problem is that "crash" programs designed to implement desired goals quickly have short-circuited public review and participation processes, leading to policies which cannot be enforced or which, in some cases, are actually counterproductive. This raises the skepticism level about government pronouncements on energy needs or the benefits of commercializing alternate energy resources. In addition, both private developers and federal agencies sometimes seem to operate with complete disregard for local circumstances. Lawyers and investment counselors are often brought in from central offices far removed from the development site. This is particularly a problem in Hawaii where personnel of

Mainland-based companies or agencies may lack even casual knowledge of local social concerns and yet are called upon to make far-reaching decisions.

Even when local conditions are not ignored and public review procedures are used, resentment may arise over the greatly increased impact of a project when it emerges from the laboratory or experimental stage and reaches commercial scale. People may, for example, be willing to accept the visual impact of a single, 125-foot wind turbine on a nearby hilltop but flinch at the thought of 20 such wind turbines covering an entire ridge line. The increased traffic of a few truckloads a day of biomass materials traveling to a nearby experimental boiler might not unduly disturb people living on the access road, but a steady line of such heavy trucks traveling past their front doors all day and all night to supply a very much larger, commercial-sized plant would be a different matter.

Another social barrier to commercialization of new energy resources--or even a change over to an existing but different form of energy supply -- is the very common human disinclination to change from a familiar way of doing business to a new or unknown way. Hawaii at least has the advantage that new ways of life have accompanied each new wave of immigration. This familiarity with different ethnic groups and new cultural patterns has lessened the common resistance to change.

However, a related psychological barrier to change is embedded in the attitude which might be called the "That's a great idea, but it doesn't mean me" syndrome. The individual accepts the theory of change, acknowledges the validity of a need, and has no objection to its implementation -- as long as it is done somewhere else by someone else.

Changes in the life style of a community or area trigger both resistance to change and "It doesn't mean me." The greater the change, the stronger the probability of opposition. For example, the visual intrusion of industrial or unaesthetic facilities in an area treasured by residents for its pristine beauty is likely to generate far more opposition than the same kind of facility in a heavily industrialized area, where the skyline is already studded with steel towers, high-rise buildings, and smokestacks. Similarly, developing a new industrial complex in a predominantly agricultural or retirement community will seriously disrupt the way of life which attracted many of the residents in the first place.

Health and safety concerns, unless they are allayed by valid, carefully thought out, and well-publicized counter-measures, also serve as barriers to commercialization. Active group opposition to nuclear power, for example, has been a real barrier to its expanded commercialization. Plans for major pumped storage facilities which might endanger or force the evacuation of entire communities, obliterate established recreation areas, or endanger certain plant or animal species, are also subject to intense public scrutiny and pressure. Some conservation programs, such as cutting down on street and playground illumination, can cause justified alarm about adverse effects on law enforcement and crime prevention.

CULTURAL BARRIERS

Cultural barriers are also to be considered in the commercialization of alternate energy resources. Although they are often intangible and even more often ignored, these barriers are important and must be considered with respect if the commercialization process is to succeed.

Hawaii has a unique history of pre-Western Polynesian culture. To it have been added the Western religious, social and business patterns of the missionary and annexation eras, and the multi-ethnic cultures of Chinese, Japanese, Portuguese, Puerto Rican, Filipino, and other immigrants who came in great numbers to work in the Hawaiian Islands. Today's society in Hawaii is a blend of these polyethnic and polycultural influences, and this blend is a major feature of Hawaii's charm and gracious life style.

Preserving Hawaiian culture and history and life style is a matter of great concern not only to the people of Hawaiian ancestry, but to the many others who have come to love Hawaii for the very qualities that the Hawaiian heritage has given to the Islands. Careful study and consideration of these specifically Hawaiian cultural constraints can add to an understanding of the way different cultural patterns and traditions throughout the nation could affect alternate energy programs on a much larger scale than in the State of Hawaii.

For Hawaii, these cultural considerations include:

* Sites of religious significance to Hawaii's peoples
* Preservation of archaeological remains
* Preservation of plants, animals and birds of Hawaii
* Life style of Hawaiian families, including land claims
* Life style of "adopted" Hawaiians, those who have lived in the Islands for some time
* Resentment of "takeover" of beaches, etc., by "outsiders"
* Importance of surfing site access and use
* Hawaiian Home Lands
* Importance of "the view" -- preservation of vistas of mountains and ocean

HAWAII'S STATE LAND USE LAW

Another constraint on the commercialization of alternate energy resources in Hawaii is found in the legal restrictions on land use embodied in the State Land Use Law (Chapter 205, Hawaii Revised Statutes).

Hawaii's land area is small. Only Rhode Island, Delaware and Connecticut are smaller. Hawaii's 6450 square miles of land are distributed among the eight major islands and 124 minor islands, atolls and reefs of the Hawaiian Archipelago. Its population, however, exceeds that of 11 states, with densities (including visitors) ranging from 1386 per square mile in heavily urbanized Oahu to 3.2 on the tiny rural island of Niihau.

The major islands are volcanic in origin. Much of the land is mountainous terrain marked by steep cliffs and deep ravines, unsuitable for either agriculture or urban use. In some areas, lava flows have covered large expanses of land.

Property laws and restrictions in Hawaii originated in the early history of the Islands. In ancient Hawaii, land holding was part of a fluid and revocable feudal system under the control of the king. The uses of the land were rigidly controlled by specific restrictions, or "kapus," and penalties for infractions were severe. Permitted uses varied with the characteristics of the land and were based on sound ecological practices.

The Hawaiian Constitution of 1840 declared that the land was not the private property of the king, but belonged to the chiefs and the people in common. In 1843, the precept was reinforced by a decree of King Kamahameha III, which separated and defined the undivided land of the king and the high ranking chiefs and konohikis (lesser chiefs) and led to the end of the feudal system in the Islands. This division, called The Great Mahele, divided the lands into wedge-shaped portions running from the mountain tops to the sea, so that each landowner had a share of the high mountain lands, the middle lands, and the coastal and seashore areas. Property boundaries in Hawaii often have to be traced back through early records, many of which are written in Hawaiian. Since the time of The Great Mahele, annexation of Hawaii to the United States, territorial status, and then statehood have added more layers of law and custom affecting private and public holdings and the interpretation of property rights.

More than 100 years later, in 1961, the Hawaii State Legislature, faced with the limits of usable land and mounting pressure caused by the development boom following statehood, passed its pioneering State Land Use Law. This law gave the state direct regulatory control over the use of most of the land resources in the state. It created a State Land Use Commission which was directed to classify all the lands in the state (public and private) into four land use districts: Urban, Agricultural, Conservation and Rural. Earlier legislation designated certain areas for Hawaiian Home Lands. These lands were to be set aside for the exclusive use of native Hawaiians.

Urban lands are defined in the State Land Use Law as "lands now in urban use and a sufficient reserve for future urban growth." Urban usages include single-family and multi-family residences, hotels and resort areas, and commercial and industrial facilities. Agricultural lands are those lands with "a high capacity for intensive cultivation," crop and grazing lands, and land for sugar mills and other buildings and activities associated with agriculture. Certain lava lands are also classified as agricultural. Conservation lands include all former forest and water reserve zones, and other areas necessary for protecting watersheds and water sources, preserving scenic areas, providing parks, wilderness and beach reserves. Rural areas are primarily small farms mixed with very low-density residential lots of at least one-half acre.

Land uses which require changes in designation, from Agricultural to Urban, for example, have to be approved by the State Land Use Commission. In the case of Conservation Districts, certain usages can be allowed under permits issued by the State Department of Land and Natural Resources.

Requests for changes in Land Use District boundaries, including Conservation District boundaries, must follow a prescribed procedure, which includes a petition for the change, detailed plans for development and use, and hearings. Decisions are rendered by the Land Use Commission, which acts as a quasi-judicial body. The

County Planning Departments and the State Department of Planning and Economic Development must be parties to all proceedings.

Commercial development of an alternate energy resource, except in an Urban Land Use District, requires a petition for a change of district boundaries by the Commission, a Special Use Permit, or a change by the State Legislature in the definition of allowable uses. This latter method was used in 1980 with the passage of a bill which added wind-generated energy production for public, private and commercial use to the list of allowable activities and uses in Agricultural Districts, as long as the facilities are compatible with agricultural uses and cause minimal adverse impact on agricultural land.

Within Urban Land Use Districts, commercial developments for alternate energy are subject to county zoning ordinances, county General Plans and other regulations.

MITIGATING ACTIONS

Many steps can be taken to minimize the adverse effects of social barriers to the development of alternate energy resources in Hawaii. The most basic mitigating action is to recognize the fact that social barriers are real. The barriers may be the product of all human nature or they may be specific to the Hawaiian Islands, but they do exist, and they must be dealt with effectively if commercialization of Hawaii's alternate energy resources is to proceed without frustrating delays.

The common human attribute of resistance to change is susceptible to both education and incentives. The need for commercialization of alternate energy reserves should be explained, verified, and disseminated across a wide range of social groups. It is not enough for scientists or economists or government officials to know the need; users of energy must hear and believe the message too.

Constantly increasing costs of fuel and electricity are already providing incentives to conserve energy and use alternate resources. Tax incentives can be increased to provide enough of an inducement to make installing energy-saving equipment worthwhile for the average household or business owner. Energy-saving devices, such as heat pumps, which are not presently covered by tax definitions, can be added to existing tax legislation.

If public funding were provided for additional equipment and increased maintenance for public transportation systems, adequate levels of service could be achieved to encourage increased use of public transportation instead or private cars.

If skepticism concerning government and industry statements or energy is to be reduced, care must be taken to make these statements creditable. In news releases or public pronouncements, statistical validity is essential, even if the time it takes to make sure figures are correct, up-to-date and in a consistent series results in delaying release or pushing back the deadline for planning programs. Developing an efficient energy data management system would be an important step towards providing accurate figures.

Both private and government interests should have prior knowledge of legal and institutional barriers to the development of energy resources at a specific site. Time scheduled for complying with all regulatory processes should allow for unforeseen but almost inevitable delays. A detailed discussion of the permitting procedures required for and regulations governing alternate energy is given in Volume V of this study, Rules, Regulations, Permits and Policies Affecting the Development of Alternate Energy Resources in Hawaii. Present state and county government efforts to streamline the permitting processes required for alternate energy projects should be continued and encouraged.

Cultural constraints unique to Hawaii are often unknown to Mainland and foreign developers of alternate energy resources. Constraints specific to each of the proposed technologies (and to many of the possible sites) are discussed in detail in Chapter 2. An awareness on the part of developers that these cultural concerns do exist and are important to the Hawaiian people -- both those who are Hawaiian by ancestry and those who are Hawaiian by conviction -- would do much to smooth the path of most projects. Searches for evidence of archaeological remains conducted before, rather than after, bulldozers go through a potential site would be most helpful. It should not be too difficult to shift the site of a facility if necessary to avoid damaging an ancient religious site. This kind of preventive action can do much to avoid ill will from local residents. Assuring continued access to beaches and other important areas which might be cut off by an energy project would do the same. Farsighted handling of these and similar constraints early in a project rather than in its later stages can help mitigate delays or public resentment.

Public opposition to projects can be decreased if the inconveniences development causes and the changes it can bring about in the lives of nearby residents are acknowledged and if the views of those most affected are taken into account. Compensating actions, such as the provision of needed community facilities or aesthetically pleasing landscaping, should be considered. Promises of mitigating actions must be kept faithfully if skepticism about government and industry promises is itself to be mitigated.

Chapter 5: THE FUTURE DEMAND FOR ENERGY

The demand for energy in Hawaii is an essential factor in determining the state's energy future. For example, rapid population growth and an increase in tourism would increase energy demand and make the Hawaiian economy even more dependent on imported oil. On the other hand, higher prices for energy, along with improved efficiency in energy use, could reduce demand to such an extent that much of the state's energy could eventually come from indigenous and renewable energy resources. Developing these alternative resources could open up new employment opportunities. Substituting indigenous sources for imported oil could insulate the Hawaiian economy from disruptions in the world oil supply and might even lead to lower prices for gasoline and electricity.

No one has a crystal ball that can predict with certainty the future demand for fuels and electricity. The best one can do is examine a range of possible energy futures using a range of assumptions about the future price of energy, the growth in population and economic activity, and the extent to which energy conservation will be practiced. Some of these factors can be affected by policy decisions, and to that extent, Hawaii can determine its own energy future.

Contributed by PingSun Leung, DPED, and Henry Ruderman, LBL

THE ASSUMPTIONS BEHIND THE PROJECTIONS

Projecting energy demand into the future requires in part an understanding of how energy demand responded in the past to changes in the state's economy. Historical consumption data for electricity and fuels from 1963 to 1977 were examined to determine how consumption responded to changes in price and income. Price and income were chosen as the explanatory factors because there is a large body of applicable economic theory, and the data are readily available. Once the relationship between consumption and price and income has been established, energy demand can be projected for several different levels of these variables. Furthermore, it is possible to modify the empirical relationships to take into account changes in consumer behavior. For example, improved automobile mileage or widespread use of electric vehicles would change the historical patterns of gasoline usage. Once quantitative estimates of the reduction in gasoline consumption brought about by these changes have been incorporated, it becomes possible to determine more accurately their effects on energy demand.

The demand forecasts in this study cover the period from 1977 to 2005. Separate forecasts were made for seven types of energy sources: electricity, gasoline, diesel fuel, residual fuel, liquid petroleum gas (LPG), aviation fuel, and utility gas. The forecasts for residual and diesel fuels exclude the amounts used to generate electricity. Electricity consumption was further broken down into residential and non-residential sales. These forecasts are presented in the appropriate physical units, such as kilowatt-hours of electricity or gallons of fuel. The total energy consumption, arrived at by summing these seven components, is presented in Btu. Note that the forecasts are for civilian consumption of energy; they do not include military use or petroleum products refined in the state and then exported.

Hawaii's four counties have separate electricity supply systems. Some crude oil is refined into petroleum products on Oahu and shipped to the other islands. Moreover, the counties have different resources for energy production. Geothermal resources, for instance, will be most easily developed on the Big Island, whereas promising wind sites are located on Oahu, Maui and Molokai as well. The counties also differ in their anticipated economic and demographic growth patterns. Therefore, separate demand forecasts for each of the counties were made and then summed to get a state total.

Three scenarios for energy demand in Hawaii were devised. They differ in the future price of energy and in the level of energy conservation assumed, but all three are based on the state's "most likely" projection of population and personal income (1), and they assume that federally-mandated automobile mileage standards will be implemented. The first projection, the Baseline Case, assumes a 3% per year escalation in world oil price above the general inflation rate. In the second, or Savings Case, the Baseline forecast is modified under the assumption that presently mandated or considered improvements in energy efficiency actually take place. In addition to the automobile mileage standards, improved efficiencies in electrical appliances were incorporated into the forecast. The savings realized through these measures, though significant, are a small fraction of those that could actually be achieved if a vigorous program of energy conservation were followed. The third, the High Oil Price Case, examines the effects of much higher energy prices. It is based on a 10% per year increase in oil price, which might come about if there were major disruptions in world oil production.

It should be emphasized that the three demand forecasts presented in this section are all predicated on oil continuing to be the predominant source of energy for the state. The next chapter considers the role of renewables in the state's energy future and how they would decrease its reliance on oil. The forecasts discussed here serve as a starting point for an analysis of how renewables would change the demand for energy.

FORECASTING ENERGY DEMAND

Demand forecasting was done by a computer-based model constructed specifically for this study. The Hawaii Energy Demand Forecasting Model (HEDFM) was designed to forecast energy consumption in each of the four counties through 2005. The HEDFM has two major components: one determines the historical relationships between energy consumption and price and income; the second uses these relationships in conjunction with price and income forecasts to estimate future energy demand. The model provides empirical insight into the structure of energy demand in the state and its relationship to the local and world economy. A detailed description of the structure and operation of the HEDFM is given in Volume III, Projecting Hawaii's Energy Future: Methodology and Results.

The HEDFM employs the concept of constant price and income elasticities of demand. The price elasticity is the percentage by which consumption of a given fuel changes when its price is increased by 1%, holding all other factors constant. If the demand for gasoline, for instance, decreases by 5% when gasoline prices rise by 10%, then the price elasticity is -0.5. Similarly, income elasticity is the percentage change in consumption when consumers' income increases by 1%.

The model also distinguishes between long- and short-term elasticities. A sharp increase in gasoline prices will cause people to drive less, join car pools, and use public transportation. These changes in consumption patterns, which can be immediate, contribute to short-term elasticity. Over a longer period of time, people will buy more fuel-efficient automobiles and improve mass-transit facilities, which contribute to the long term elasticity. Thus, short-term elasticity usually refers to a period of a few months to a year in which there is no significant change in the stock of energy-consuming devices, whereas long-term elasticity refers to the five to ten year period in which most of the devices will be replaced.

A model of the type just described is called an econometric model. Such a model consists of a series of equations that quantify the relationships between consumption of various types of energy and their price and the income of the consumers. Price and income elasticities enter the equations as unknown parameters which must be determined from the historical data on energy consumption.

The HEDFM used consumption data from the period 1963 to 1977. These data as well as the corresponding data on energy prices, population and income were obtained from state agencies. They have been published in Volume III of this report.

Several mathematical forms for the demand equations were investigated. The form eventually used was determined by how well it predicted the historical data and by its suitability for forecasting. The most suitable equations related per capita consumption in one year to the previous year's consumption and to price and per capita income. A model of this form is more sensitive to changes in price and income than to their levels. For residential and non-residential use of electricity, gasoline, and diesel fuel, the best equations had the same elasticities for all the counties. The econometric equations did not appear to be suitable for the other four energy sources. Apparently, this is because the other fuels are used in specialized applications, hence price and personal income are not important considerations. For residual fuel and LPG a simple growth model with income as the determining factor was used; utility gas consumption was assumed to remain constant at current levels. Since these three fuels comprise less than 10% of the total energy use in Hawaii, constructing a more detailed model for them did not seem warranted. Aviation fuel consumption was found to depend linearly on visitor arrivals and passenger load factors.

In using an econometric model for forecasting, it is usually assumed that the demand elasticities remain constant over the forecast period. Such an assumption may not be justified during a period of rapidly increasing prices, rapid technological changes, or threats of supply curtailments. In such cases one can try to modify the model by estimating the changes in elasticity or by modifying the consumption forecasts to take these factors into account. These forecasts take the latter course in incorporating the effects of improved appliance and automotive efficiencies.

The three demand cases use the same set of projected economic and demographic variables adopted from the Hawaii Macroeconometric Model (1). This model of the Hawaiian 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. In Table 1, 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%, taking inflation into account. The largest percentage increase in population and income in the scenario occurs in Maui County.

TABLE 1. -- 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 1.

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 3% 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 (2). These prices were also used in the Savings Case. The 10% per year escalation used in the High Price Case could come about if there were major disruptions in the world's oil supply. How long such a high growth rate could continue is problematical because at some point synthetic fuels would be able to compete economically with petroleum products, thereby placing a ceiling on oil prices. World oil prices assumed are shown in Table 2.

TABLE 2. -- World Oil Price in 1980 Dollars per Barrel

	Forecast	1980	1985	1990	1995	2000	2005
1	Baseline	30	35	40	47	54	63
2	Savings	30	35	40	47	54	63
3	High Price[a]	30	50	80	129	207	334

[a]For computational purposes, values shown differ slightly from 10%/year compounded.

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 are 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.

For the Savings Case, estimates were made of how much the demand for electricity would be reduced by improvements in appliance efficiency. The reduction in gasoline consumption was derived from projections of the national average fleet fuel efficiencies which are based on the federally-mandated automobile mileage standards of 27.5 miles per gallon in 1985. To determine the reduction in electricity sales, the baseline forecasts of residential and non-residential consumption were broken down by end-use. Major end-use categories were water heating, cooking, lighting, refrigeration and clothes drying. For each of the categories, the effects of gradually replacing currently installed appliances by more efficient ones were estimated. Measures considered included installing solar panels or heat pumps for water heating, installing more efficient refrigerators and clothes dryers, and improving the efficiency of electric lamps and motors. The resulting consumption figures were summed to give the residential and non-residential totals.

PROJECTIONS OF FUTURE DEMAND

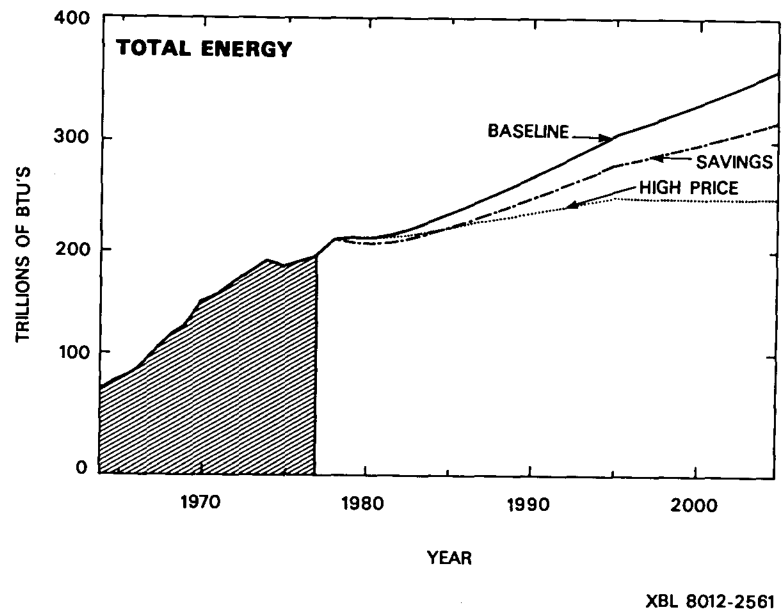
This summary discusses the demand forecasts for the entire state, emphasizing total energy consumption and its major components: electricity, gasoline and aviation fuel. A more detailed description and analysis of the statewide and individual county forecasts may be found in Volume III. These are not final forecasts; they show what the future might be if oil remains the primary source of energy for Hawaii. The final forecasts, incorporating the impacts of renewables, are presented in the next chapter of this volume.

Total Energy Consumption

Energy consumption in Hawaii during 1977 amounted to 200 trillion Btu. Of this total, approximately one-third was electricity, one-third aviation fuel, and the remainder primarily gasoline and other fuels used for transportation. More than 80% of the energy and nearly all of the aviation fuel is consumed on Oahu. Except for a small amount of bagasse and hydropower used to generate electricity, the energy comes from imported petroleum. During 1977, petroleum imports amounted to about 40 million barrels.

According to the Baseline Case, energy consumption is expected to increase to 354 trillion Btu in 2005. Reductions in consumption shown in the High Price Case would bring this total down to 244 trillion Btu, whereas the improved efficiencies assumed in the Savings Case would reduce demand to 311 trillion Btu. These results are plotted in Figure 1. The average growth rate in the Baseline Case is about 2.1% per year. The largest growth would occur during the period from 1985 to 1995. The Savings Case shows a similar behavior. The High Price Case, on the other hand, shows a growth in energy consumption of about 1% per year until 1995 and then no growth thereafter.

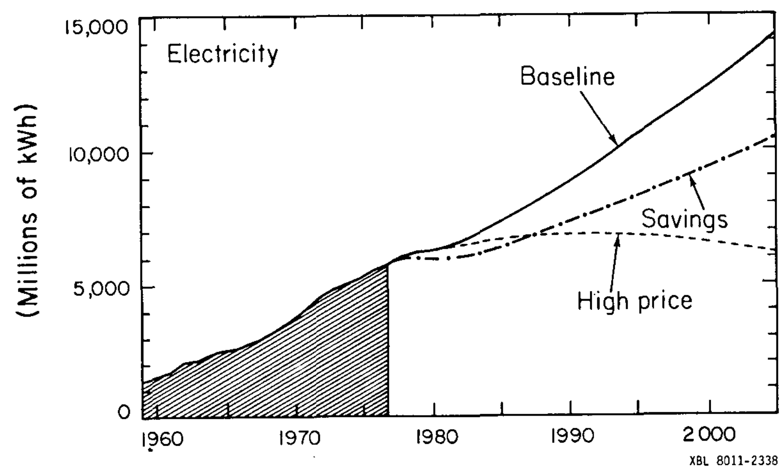
FIGURE 1. -- HEDFM Model: Total Energy Demand, 1963 to 2005



The model also forecasts a change in Hawaii's fuel mix. Diesel fuel and gasoline use are expected to decline relative to aviation fuel as more automobiles and other vehicles are affected by fuel efficiency standards. Increasing use of renewable resources for electricity generation would lower the amount of residual and diesel fuel burned. However, there seems little chance that aviation fuel use would decline. The resultant mix of petroleum products would change the state's fuel importing, refining, storage and distribution system.

For all three cases, the largest growth rates in energy consumption are expected in Maui County. Maui's energy consumption is expected to surpass that of the Big Island in the 1980s, making it the second largest county in terms of energy use. Honolulu County would continue to dominate the state's energy consumption, still accounting for about 80% of the total in 2005 in all three cases. Honolulu is also expected to have the highest per capita energy consumption because of its large aviation fuel requirements. Supplying fuel and electricity to Honolulu will be the major obstacle in the state's path to self-sufficiency.

FIGURE 2. -- HEDFM Model: Electricity Demand, 1963 to 2005



Electricity

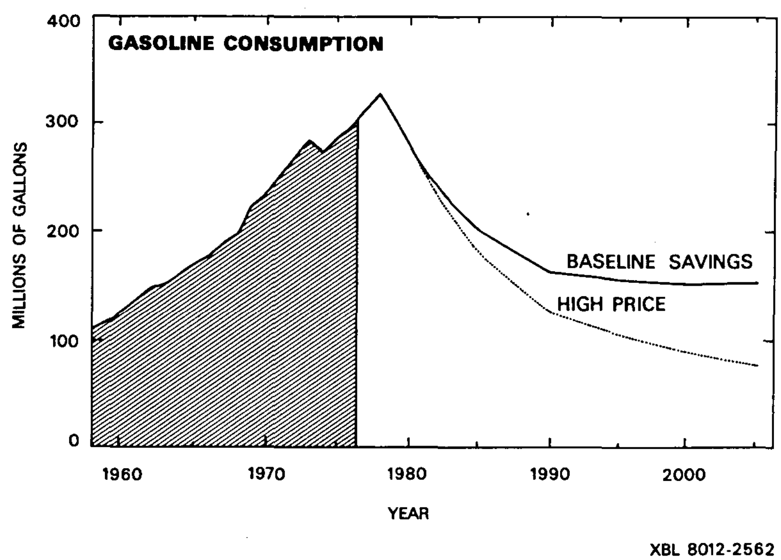
The forecasts for total electricity sales in the state are shown in Figure 2. The Baseline Case shows an increase from 5.8 billion KWh in 1977 to 14.3 billion KWh in 2005. Most of this growth would occur in non-residential sales. Residential sales would increase only by one-third because the large long-term price elasticity coupled with the forecast price increases would dampen demand growth. Savings from improved appliance efficiencies could amount to 3.8 billion KWh in 2005. This represents a potential reduction of oil imports of about seven million barrels per year.

The High Price Case shows a leveling off and eventual decline in electricity consumption. By 2005, statewide consumption would be about 40% of the Baseline. Achieving this decrease, however, would require a 10% per year increase in oil prices. An escalation rate this large would probably not continue over the forecast period without some non-petroleum-based technology providing electricity more cheaply. In either case, high world-oil prices are expected to reduce significantly the amount of petroleum used for electricity generation relative to the other cases.

The results indicate that price has a more important influence on electricity consumption in the residential than in the non-residential sector. This is probably because much of the non-residential use occurs in hotels and restaurants that cater to visitors, who are less influenced by price than residents are. It implies that mechanisms other than price increases will have to be used to decrease non-residential consumption. Non-price mechanisms include energy-saving building and lighting standards, improved appliance efficiencies, and possibly, informational programs to encourage visitors and workers in the service sectors to conserve energy. The Savings Case shows that improving efficiencies can lead to reductions in electricity consumption of 25% or more. The largest percentage decrease occurs in the residential sector, but the largest absolute decrease is in the non-residential.

These three cases have different implications for the future mix of generating capacity in the state. In the Baseline and Savings Cases, renewable indigenous resources may be able to supply the needed capacity increment. If the indigenous supplies are less expensive, they also could displace some petroleum for generation. The High Price Case requires little new generating capacity, but plants using alternative resources might be built if they can supply electricity at lower prices than can petroleum.

FIGURE 3. -- HEDFM Model: Gasoline Demand, 1963 to 2005[a]



[a]Except for a dip after the 1973 Arab oil embargo, gasoline has shown a steady increase. The HEDFM projects that, because of increased gasoline prices and more fuel-efficient automobiles, consumption will decline sharply after 1979.

Gasoline

The demand model projections indicate a decline in gasoline sales over the next 25 years. As shown in Figure 3, in the Baseline and Savings cases, gasoline sales would drop from 315 to 155 million gallons per year. The model results indicate that the currently mandated mileage standards can reduce projected gasoline consumption by 60%. The model shows that gasoline sales are quite sensitive to price; a 10% increase in price would result in a 4% decrease in per capita sales. In the High Price Case, statewide gasoline sales in 2005 decrease to 79 million gallons, about 75 million gallons below the baseline forecast or one-fourth the 1977 sales. The combination of high gasoline prices and increased fuel efficiency would be likely to cause Hawaii's future gasoline use to sink far below current levels.

Gasoline demand could also be reduced if some of the state's biomass resources were used to make alcohol or synthetic gasoline as transportation fuels. The widespread introduction of electric vehicles would further reduce the demand for gasoline. This would not necessarily reduce the demand for imported petroleum unless the electricity were produced from indigenous resources. These changes in energy use patterns were not considered in the demand forecasts.

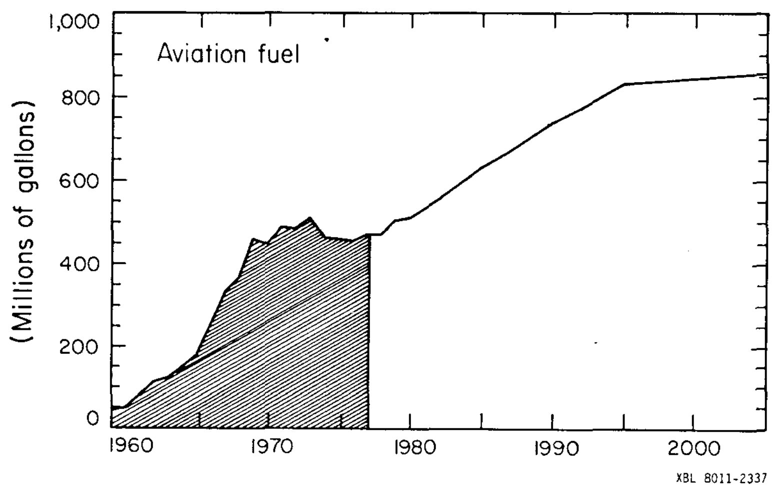
The decline in gasoline sales from current levels would go far toward making the state energy self-sufficient. At these reduced consumption levels, it may be possible to satisfy the entire automotive fuel demand with biomass-derived fuels and/or electricity produced from indigenous resources.

Aviation Fuel

Aviation fuel consumption was forecast differently from other fuels in the HEDFM. Price and income variables were not used; instead, consumption was taken as a linear function of visitor arrivals and passenger-load factor (the average fraction of the seats that are occupied). Only one forecast for aviation fuel was made. It was assumed that visitor arrivals would increase from 3.4 million in 1977 to 8.2

million in 2005 while load factors would increase gradually. As shown in Figure 4, consumption would nearly double over the period, reaching 860 million gallons by 2005. The change in growth rate after 1994 was a result of the projected slowing down of visitor arrivals after that year.

FIGURE 4. -- HEDFM Model: Aviation Fuel Demand, 1963 to 2005

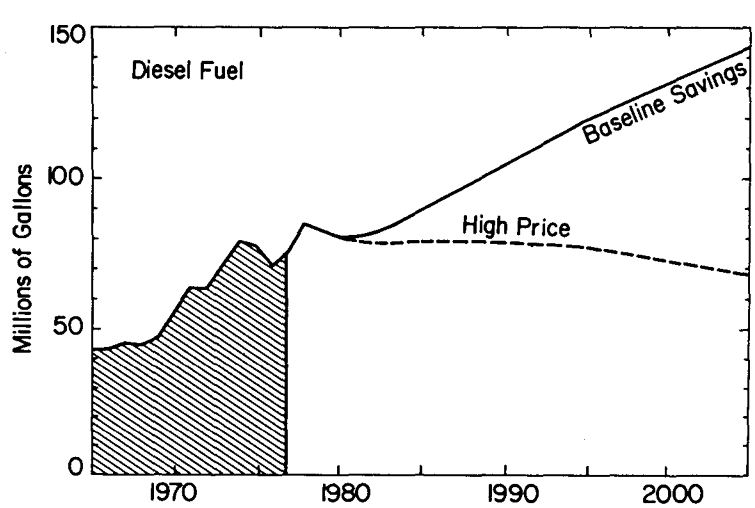


Hawaii is unlikely to become completely self-sufficient in liquid fuels in the near future. New and more efficient aircraft that will be introduced during the 1980s do not have the range to reach Hawaii from the Mainland. Hydrogen-powered aircraft are not expected to be in commercial operation before the year 2000. A continuing increase in aviation fuel consumption is expected as long as tourism and economic growth are encouraged. Because gasoline and diesel fuel use is expected to decline, this would change the mix of petroleum products refined in or imported into the state and would also affect the liquid fuel storage and distribution system.

Other Fuels

The transportation sector consumes a large portion of the diesel and residual fuel used in Hawaii. The forecasts indicate that diesel use would continue to increase unless there were very large price increases. The results are shown in Figure 5. The model does not take into account anticipated improvements in diesel engine efficiency or the substitution of synthetic fuels made from indigenous biomass for diesel fuel. Many of the structural modifications that enhance automotive efficiency are also applicable to diesel-powered vehicles.

FIGURE 5. -- HEDFM Model: Diesel Fuel Demand, 1963 to 2005



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The combination of improved efficiency and high price would be likely to lead to a decline in diesel fuel sales parallel to, but not as great as, the decline in gasoline sales.

Residual fuel is used for a few specialized purposes other than electricity generation. The most important of these is as bunker fuel for waterborne transportation upon which the state's economy is very dependent. However, no quantitative data are available to measure the impacts of conservation efforts and improvements in end-use efficiency.

Utility gas and LPG comprise the smallest component of energy use in Hawaii. The amount of utility gas supplied by pipeline is expected to stabilize or even decline slightly. For forecasting purposes, utility gas consumption is assumed to stay at the current level even though improved efficiencies in electrical appliances may also apply to gas appliances. LPG use is expected to increase steadily at the same rate as the growth in per capita income. Highway use of LPG would probably be affected by vehicle efficiency improvements, although they may not be as great as those achieved by gasoline and diesel-powered vehicles.

IMPLICATIONS FOR HAWAII'S ENERGY FUTURE

The three forecasts show a range of possibilities for future energy demand. The highest and lowest forecasts differ by nearly 50% in total energy consumption by 2005. Nobody can guarantee that energy demand will lie within this range, but currently mandated policies to reduce consumption, as well as those being considered, make it unlikely that it would exceed our highest forecast. On the other hand, the two lower forecasts indicate that higher prices and vigorous conservation efforts could substantially reduce demand, thereby raising the possibility of no growth or even a reduction in total energy consumption.

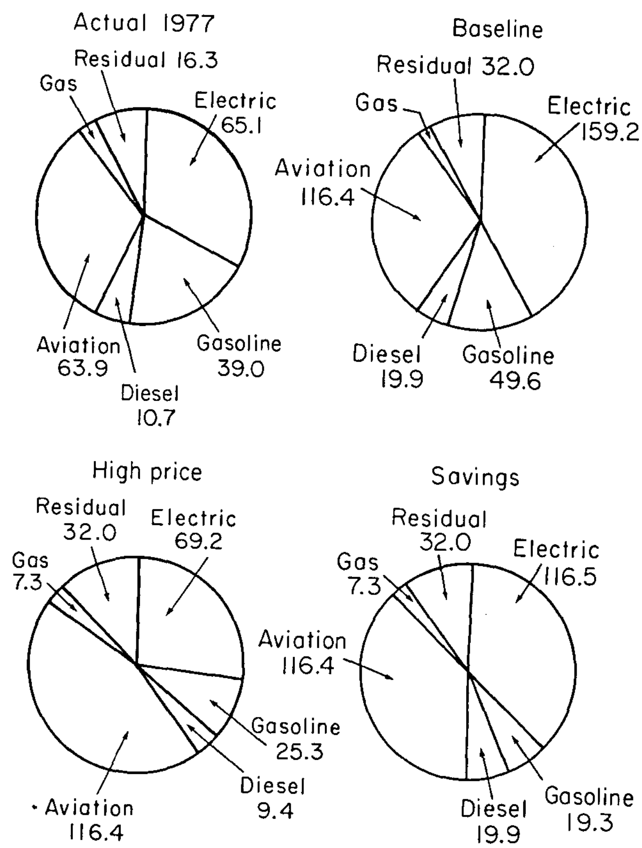
The forecasts also indicate a change in the fuel mix during the next 25 years (see Figure 6). In the Baseline Case, electricity sales would increase relative to liquid fuels, whereas in the High Oil Price Case, aviation fuel then would become dominant. The Savings Case lies between the two, with both aviation fuel and electricity growing in importance. The results indicate that the use of petroleum for ground transportation, and probably for electricity generation, would decline relative to aviation fuel. This could lead to changes in refinery operations and the mix of imports.

Higher prices and improvements in appliance efficiency would substantially reduce the residential demand for electricity. Reducing non-residential demand will be a tougher problem. Improved appliance efficiencies would help, as would new building and lighting standards, but the major emphasis should be on changing consumer behavior. Visitors should be made to feel that they are part of a statewide effort to make the islands energy self-sufficient. They can be encouraged to turn off lights and air conditioners when leaving their hotel rooms. They should also be encouraged to turn off air conditioners and leave windows open whenever there is a breeze. Hotels can instruct staff members to turn off all lights and air conditioners after the rooms have been cleaned and vacated.

Hawaii is unlikely to become completely energy self-sufficient within the next 25 years. The main obstacle will be aviation fuel consumption. Improved appliance efficiencies, better vehicle mileage, and other conservation measures in combination with higher energy prices may reduce the projected demands for electricity and ground transportation fuels to such a point that they can be satisfied by indigenous resources. Since there is no substitute for aviation fuel, and since no major improvements in aircraft efficiency are anticipated, aviation fuel consumption is expected to continue increasing. The individual islands of Hawaii could possibly become self-sufficient in the energy needed locally by 2005, but the statewide demand for aviation fuel will still be impossible to fulfill domestically.

It should be noted that the three demand forecasts described above do not take into account the impact of the development of alternative energy technologies. They were considered to be the business-as-usual cases for which the continuation of the current dependence on imported petroleum is assumed. Different energy supply scenarios will have different impacts on the economy in general which, in turn, will generate different energy demand patterns because of changes in the economic and demographic characteristics of the state.

FIGURE 6. -- Changes in Mix of Fuel Consumption, 1977 to 2005



The next chapter of this report examines several energy supply scenarios that could satisfy the three demand forecasts. In these scenarios renewable resources were used as the source of most of the electricity, and electricity prices were therefore significantly lower than those used in the HEDFM. The forecasts were then revised using these lower electricity prices. This procedure was repeated until supply and demand were balanced, and a consistent set of prices were obtained. This final set of forecasts, which are higher than those shown here, were used in the economic impact assessment. They are discussed in the following chapter.

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1. Hawaii Department of Planning and Economic Development, Long-Range Population and Economic Simulations and Projections for the State of Hawaii, 1977.

2. U.S. Energy Information Administration, Annual Report to Congress, 1979, DOE/EIA-0173(79)/3, vol. 3, 1980.

Chapter 6: ENERGY FUTURES FOR HAWAII

Earlier sections of this report have given us reason to believe that Hawaii's indigenous energy resources are sufficiently abundant to supplement and, to some degree, substitute for conventional energy sources, and that they can be exploited in a relatively benign fashion. The next question to address is: to what extent can or should these resources be used during the next 25 years? An attempt to answer this question must compare the renewable energy technologies with one another in light of the existing energy supply system. The answer will depend primarily on the future demand for energy and on the economics of the technologies that are developed to use the indigenous resources. Other important factors to consider include environmental and social impacts and the potential for reducing demand through conservation.

Energy demand is intimately related to the levels and types of economic activity energy consumers pursue 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 from an increase in manufacturing. However, the strongest influence on future economic activity, and hence on 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, and the end to these increases is nowhere in sight. It is therefore prudent to examine the consequences of a range of world oil prices for future energy demand and for alternative energy supply options.

Contributed by Jayant Sathaye and Henry Ruderman, LBL

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

TABLE 1. -- Hawaii Energy Futures: Projections for 2005

Future	De Facto Population (Thousands)	Per Capita Personal Income (1967 $)	Visitor Arrivals (Thousands)	World Oil Price Growth	Conservation
1	1475	7716	8219	3% per year	mandated automobile mileage standards
2	1475	7716	8219	3% per year	Improved appliance efficiencies & mandated automobile mileage standards
3	1475	7716	8219	10% per year	Mandated automobile mileage standards

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 for or at least supplemented by a single source, biomass-derived alcohol or gasoline. Electricity, on the other hand, can be provided by several indigenous energy resources: wind, OTEC, geothermal, solar radiation and biomass. This analysis considers only energy consumed by civilians in Hawaii; energy for the military and petroleum products refined in the state and then exported were not included.

The maximum extent to which each resource 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, in general, 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.

Generating electricity and supplying it to consumers is a complex activity. Capital costs, reliability of operations, generation and fuel costs, matching load requirements, and environmental constraints must be considered within an interdependent system of generation technologies, each with its unique characteristics, designed to meet a fluctuating electricity demand. The indigenous energy technologies will have to mature in this complex environment.

The complexity of the energy futures increases with each new supply or demand option. The possible use of interisland submarine transmission cables, for example, is being seriously examined by the utilities as well as by private firms in Hawaii. The choice of electricity generating technologies will be strongly influenced by the technical feasibility, costs and timing of interisland cables. A computer model was developed to evaluate these possibilities for the three energy futures. The model identified the electricity supply system that would meet the projected demand for each future at the lowest cost. The capital costs and labor requirements, both direct and indirect, were computed for the optimum mix of supply technologies.

The following sections first present the analytical methodology and the basic assumptions in the analyses. Each future is described separately, and its energy demand and supply options and their economic impacts are discussed. The three futures are then compared to illustrate their major differences. Two other options were also considered: the widespread use of biomass as a feedstock for producing liquid fuels and as a boiler fuel in power plants, and the use of coal for baseload power generation.

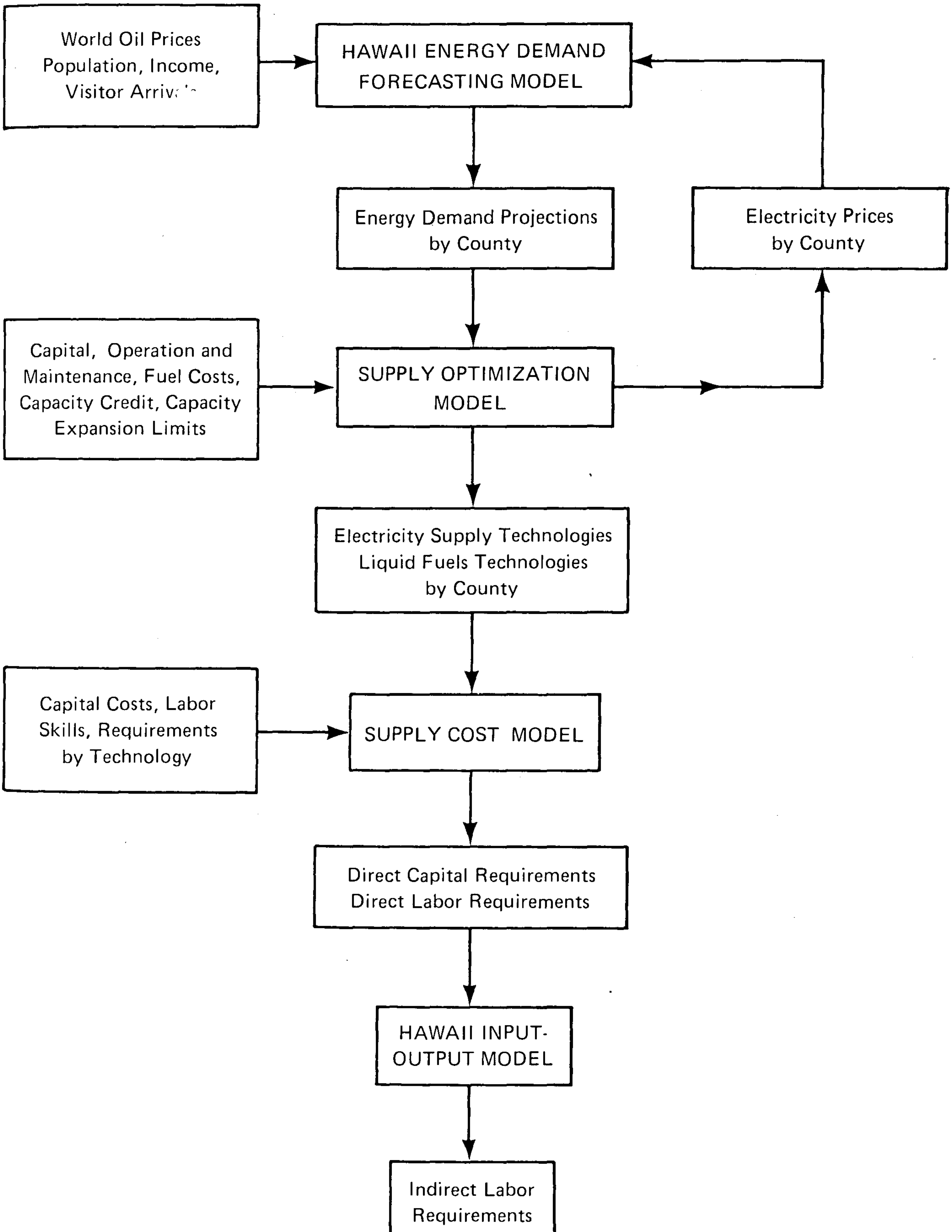
METHODOLOGY

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, described in the previous chapter, provided energy demand projections for each of the counties by year up to 2005. Three forecasts which differed in their assumptions about energy prices and the level of energy conservation were made. 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 demand and generating capacity demand at the lowest cost. 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 the Demand Forecasting Model projected. The new prices were fed back into the Demand Forecasting Model, 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 Chapter 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. -- Integration Assessment Methodology



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Demand Forecasts

The three energy futures were based on different demand forecasts: the Baseline, Baseline with Savings, and High World Oil Price cases described in the previous chapter. All three used the same economic and demographic projections characterized by medium growth in population, income and visitor arrivals (1). They differed in energy prices and the level of conservation. The federally-mandated automobile gasoline mileage standards of 27.5 mpg in 1985 were assumed in each future. In addition, the second future incorporated estimates of electricity savings resulting from the implementation of proposed appliance efficiency standards. Initially, the energy prices used in forecasting demand were based on projections of world oil prices. The final prices were determined by balancing supply and demand.

The Baseline demand forecast was used for the first energy future. This case assumed a 3% per year escalation in world oil price. This would lead to a growth in energy consumption of about 2% per year if no additional renewables were used. Electricity sales in the state would increase during the next 25 years, while gasoline sales would decline by a factor of two. The use of other fuels would increase more slowly than electricity.

The second 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 by improved appliance efficiencies. The demand results of this forecast fell between the Baseline and High Price cases. It showed the same liquid fuel consumption as the first future, and electricity sales were greater than in the third.

The third energy future assumed that oil prices would increase in real terms by 10% per year. Such large price increases could occur as a result of major disruptions in the world oil market. This scenario exhibited the lowest growth in overall demand. Both diesel fuel and gasoline sales decreased, while electricity sales remained nearly constant, and aviation fuel consumption increased.

Aviation fuel demand, the largest component of the demand for petroleum products, was assumed to be the same in all three futures. The demand was primarily a function of the number of visitor arrivals, which were taken from a State of Hawaii projection. In the high price case, however, it is likely that the number of visitor arrivals would be lower than in the other two cases. Thus, the projections of aviation fuel consumption in the third future may be an overestimate.

A summary of the demand forecasting methodology may be found in Chapter 5. A complete description of the Demand Forecasting Model and the forecasts for each energy type and county are contained in Volume III, Projecting Hawaii's Energy Future: Methodology and Results.

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 generation electricity. For each future we have projected the expected demand for fuels and electricity to the year 2005.

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. Alcohol supplies were assumed to be 10% of projected gasoline consumption, limited only by the forecast production of alcohol.

Electricity may be generated by several types of power plants. Steam, hydroelectric, gas turbines and internal combustion engines are currently used to generate electricity. Steam generators burn oil or an oil-bagasse mixture. On Oahu there are plans to supplement these by municipal solid waste (MSW) incineration within 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 energy, ocean thermal (OTEC), solar thermal (STEC), and photovoltaics (PV) can all be used to generate electricity. Hydroelectric and pumped storage also have some limited potential in Hawaii.

Due to the nature of their resources, geothermal and ocean thermal energy are available continuously and hence with high reliability. 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 the base or intermediate loads. No storage was assumed for the photovoltaic system; it 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, this resource can be used best if the generated electricity can be stored or if backup capacity is available. In Hawaii, oil- and biomass-fired generating capacity can be used as a backup for 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. Cost and reliability of the energy supply system are usually major considerations. Other criteria include economic, 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.

The objective was to minimize the sum of levelized cost and the operation, maintenance and fuel costs. 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.

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. The constraints ensured that sufficient capacity would 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 the ratio of peak power to electricity sales. A reserve margin of at least 20% was required.

The total capacity of each type of generating unit is limited by constraints other 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 limit to which each technology may be developed in each time period. Limits were placed 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.

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. The OTEC plant will be a 40 MW plant, and the MSW plant is assumed to be rated at 45 MW. Because wind is an intermittent source of energy, it is necessary to ensure that system reliability is not affected when wind generation is introduced into the system. Studies have shown that reliability decreases rapidly when wind generation exceeds 20% of the installed capacity (2). A constraint to limit wind generation to this level was incorporated in the model. Furthermore, wind generation was not included when calculating the capacity available to meet the power demands.

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 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 demand model 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.

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 be directed 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.

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. These costs were broken down into manpower, materials, land, equipment and other components.

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. Costs may also increase as a result of unforeseen circumstances, stricter health and safety requirements or environmental regulations, and more expensive on-site resources: 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 (3) and the Technology Assessment of Solar Energy Study (4) 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 secondary employment and income generated in the state by the construction of new energy facilities was also examined. Some of the capital expenditures on materials, equipment and manpower go to purchase goods and services produced in Hawaii. For example, the concrete used in constructing a power plant will be supplied by local industry, whereas engines and turbines will be imported. Similarly, the wages and salaries paid to the construction workers will, in part, be used to purchase food and clothing produced locally. The industries that produce these commodities purchase goods and services from other local industries which, in turn, require additional local purchases. Thus, the impacts of new construction will spread throughout the state's economy

These secondary or indirect expenditures could be a major stimulus to the Hawaiian economy. If the economy is sluggish, more jobs and income would be generated; if it is strong, inflation would be exacerbated. New construction might result in new industries being established, which would attract additional workers and their families, thereby adding to population pressures and social and institutional problems.

Indirect impacts were estimated using an input-output (I-O) 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. An input-output, or interindustry transactions, table shows the flow of goods and services throughout the entire economy during one year. Thus, an I-O table embodies in mathematical form the interrelationships between different sectors of the economy. It can be transformed into a set of equations by which economic impacts can be calculated within a consistent industrial framework. An I-O model is especially suited for estimating the impacts of new investment programs on employment, income and patterns of industrial activity.

HDPED developed input-output tables for each of the four counties by updating earlier tables (5). 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. Details of the construction of the I-O tables are given in Volume III.

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.

This assumption of behavioral constancy means that conservation programs, mandated efficiency standards, and emerging energy use technologies were not explicitly accounted for in the model. To remedy this deficiency, each future incorporated the assumption that the currently mandated gasoline mileage standards will be implemented. In addition, electricity forecasts in the second energy future were decreased by the estimates of the amount of energy saved through improved appliance efficiencies.

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. Since some 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.

Electric utility systems are designed to operate with a safety margin to ensure reliability of operation. A flat 20% reserve margin beyond the estimated peak demand for electricity was assumed. Usually, system reliability is estimated on the basis of a combination of unit reliabilities. Renewable or unconventional technologies need a careful evaluation before their reliability can be ascertained. It was assumed that the 20% reserve margin adequately ensured that reliability, quick load pick-up capability and other operating criteria, does not constrain generation. A more careful analysis of these factors would be warranted in some future study.

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.

THE THREE ENERGY FUTURES

The models examined three energy futures. Oil price increased at a rate of 3% per year in Future 1 and Future 2, the base and savings cases, and at a rate of 10% 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.

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 2, 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 5% and 10% 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 2. Capital costs of conventional technologies were assumed to remain constant over the next 25 years, while those of unconventional technologies were assumed to decline for reasons mentioned earlier.

TABLE 2. -- 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

Costs shown for 1980 reflect the cost of power plants already depreciated or they reflect the capital cost after depreciation of existing plants. A cost of $65/KW was used for old oil plants based on data in HECO's annual report (6). An analysis of utility finances would be necessary for a better estimate of average plant costs for 1980. The costs of geothermal plants were assumed to include cable costs between Hawaii and Oahu and Maui. Geothermal plant costs on the Big Island were therefore lower by $800/KW.

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.

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. Fuel costs for diesel were assumed to be 15% higher than for residual oil. Coal costs were assumed to be 38% of oil costs, based on a comparison of estimated delivered fuel cost to Hawaii (7).

This analysis assumes that the cost of generating electricity from indigenous resources includes only the capital and operating and maintenance costs. Once the technology has been proven, this may be the case; but in the early stages of development, the cost borne by a utility may be considerably higher.

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 assumed.

The 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 (8) 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 (9).

Wind generation was limited to 20% of total installed capacity or to the resource limit of 432 MW on Oahu, whichever is smaller. The 20% figure was based on studies which limit the maximum generation because of load matching considerations (2). The 432 MW limit was based on choice sites in Oahu (10).

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.

Future 1

This future presents the energy demand and supply forecasts for each county and the state as a whole based on a 3% per year growth in world oil price. This future may be 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 3.

Energy Demand

In Future 1, the demand for electricity in the state and in Honolulu County would almost triple during the next 25 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 heavily 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% 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 25 years, the use of indigenous resources would save the state $8.5 billion that would otherwise be spent on imported petroleum.

The demand for liquid fuels was discussed in the previous chapter. Only gasoline consumption declines due to the combined effects of higher prices and mileage standards. Aviation fuel becomes increasingly dominant, its use rising by 68% over the next 25 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 7% to 9% of renewables, while for Honolulu County, oil use would drop to 37% 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, the largest fraction of their electricity would come from renewables.

(Figures 2 and 3 show the Statewide Future 1 forecast of generating capacity and the amount of electricity generated by each type of power plant for the next 25 years. Tables 4 through 7 show the forecasts for each county. The peak loads and reserve margins are indicated on the bars in the figures that show generating capacity).

Supply Mix

The capacity demand includes a 20% reserve margin. It was assumed that all the oil generating capacity available in 1980 would remain online 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 2. -- Hawaii Generating Capacity, 1980-2005: Future 1

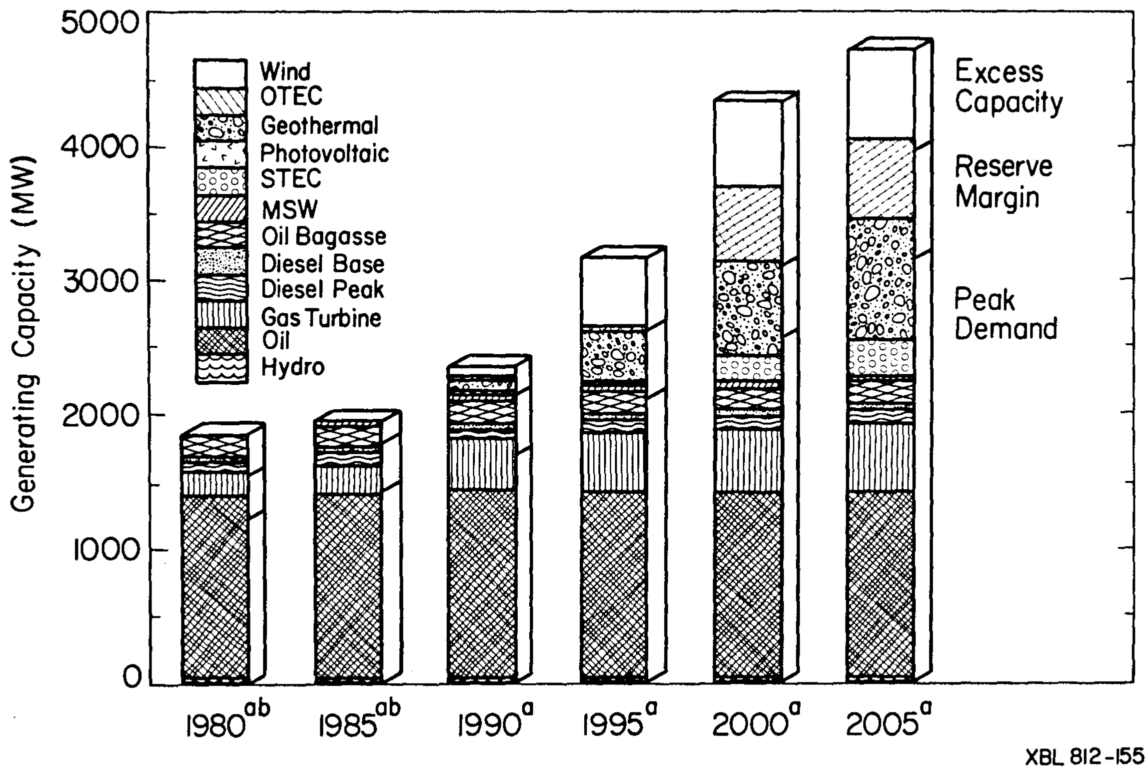

FIGURE 3. -- Hawaii Electricity Generation, 1980-2005: Future 1

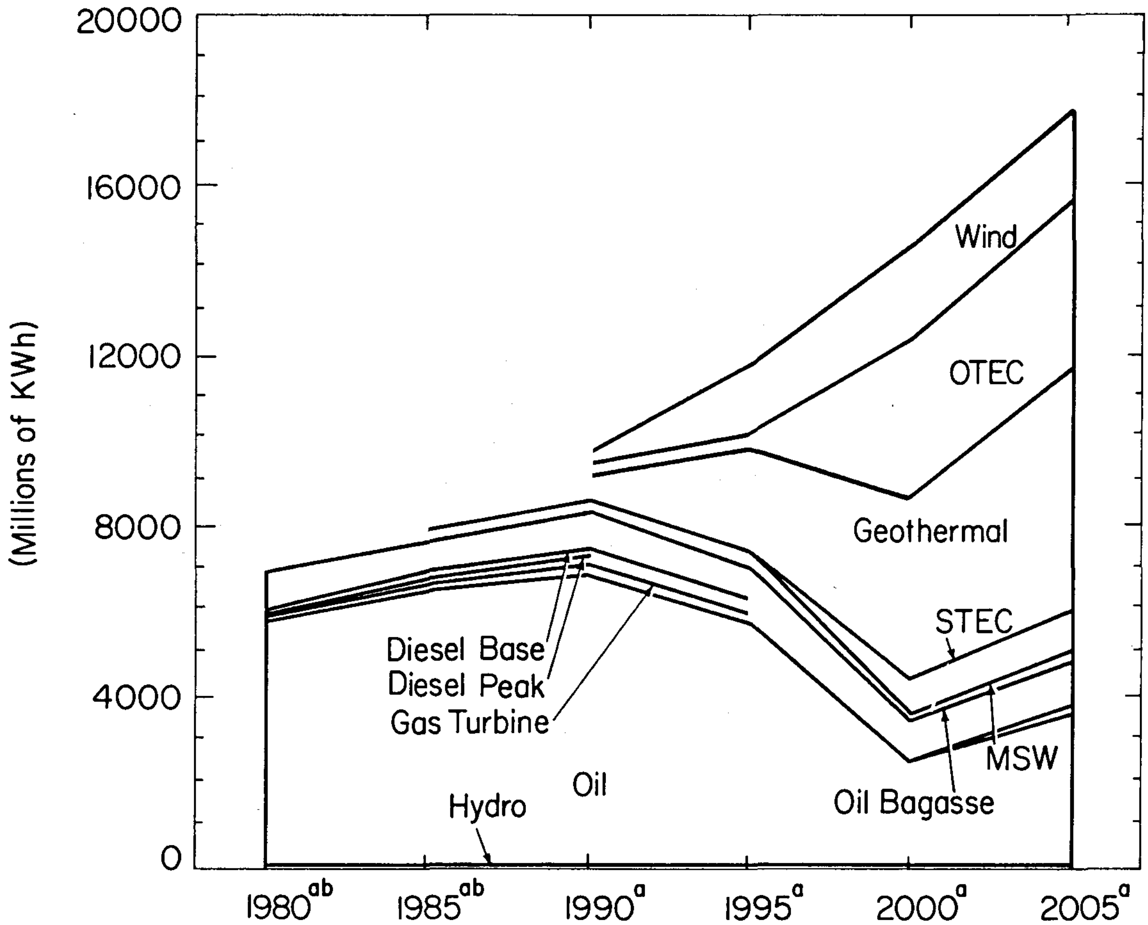

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TABLE 3. -- Statewide Energy Demand Projections, Future 1
Baseline Case with Interisland Cable
(Trillions of Btus)

	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 10% of gasoline consumption beyond 1990.

Oahu (see Table 4) 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 (see Table 5) 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 5% of the total electricity supply. OTEC and geothermal would supply about 60%, while wind and solar thermal would supply about 25%. Hydro-power and bagasse would continue at their current levels.

Hawaii County (see Table 6) 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 (see Table 7) 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 hydro-electric 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.

TABLE 4. -- Future 1, Honolulu County

	1980	1985	1990	1995	2000	2005
			Generating Capacity (MW)			
Oil	1,245	1,245	1,245	1,245	1,245	1,245
Gas Turbine	105	107	244	244	244	244
Oil-bagasse	27	27	27	27	27	27
MSW	0	45	45	45	45	45
STEC	0	0	0	0	130	180
Photovoltaic	<1	<1	<1	<1	<1	<1
Geothermal	0	0	17	250	488	642
OTEC	0	0	40	40	440	440
Wind	<1	<1	39	370	432	432
Total	1,377	1,424	1,656	2,222	3,052	3,256
Peak demand plus reserve margin	1,155	1,307	1,521	1,852	2,259	2,811
			Electricity Generation (Millions of KWh)			
Oil	5,102	5,446	5,842	4,884	2,062	3,371
Gas Turbine	0	70	161	26	0	34
Oil-bagasse	142	142	142	142	142	142
MSW	0	276	276	276	276	276
STEC	0	0	0	0	569	788
Photovoltaic	<1	<1	<1	<1	<1	<1
Geothermal	0	0	102	1,535	2,994	3,939
OTEC	0	0	245	245	2,698	2,698
Wind	<1	<1	135	1,298	1,514	1,514
Total	5,245	5,935	6,903	8,406	10,256	12,762

Note: Figures are independently rounded, may not add to indicated totals.

TABLE 5. -- Future 1, Maui County

	1980	1985	1990	1995	2000	2005
			Generatng Capacity (MW)			
Hydro	5	5	5	5	5	5
Oil	40	71	91	91	91	91
Gas Turbine	0	45	78	125	125	125
Diesel Peak	46	46	46	46	46	46
Diesel Base	40	40	40	40	40	40
Oil-bagasse	48	48	48	48	48	48
STEC	0	0	6	6	44	58
Geothermal	0	0	3	51	100	132
OTEC	0	0	0	0	101	118
Wind	0	0	35	82	101	123
Total	179	255	353	495	700	785
Peak demand plus reserve margin	164	237	318	412	505	613
			Electricity Generation (Millions of KWh)			
Hydro	32	32	32	32	32	32
Oil	231	435	559	559	60	60
Gas Turbine	0	30	51	82	36	57
Diesel Peak	30	81	81	0	0	0
Diesel Base	158	182	210	203	0	0
Oil-bagasse	250	250	250	250	250	250
STEC	0	0	28	28	191	254
Geothermal	0	0	19	314	613	807
OTEC	0	0	0	0	617	724
Wind	0	0	124	289	354	429
Total	701	1,009	1,354	1,757	2,153	2,612

Note: Figures are independently rounded, may not add to indicated totals.

TABLE 6. -- Future 1, Hawaii County

	1980	1985	1990	1995	2000	2005
			Generating Capacity (MW)			
Hydro	4	4	4	4	4	4
Oil	61	61	61	61	61	61
Gas Turbine	12	19	19	29	57	92
Diesel Peak	28	28	28	28	28	28
Oil-bagasse	55	55	55	55	55	55
STEC	0	0	0	0	9	17
Geothermal	0	0	62	90	119	153
Wind	0	0	0	51	64	78
Total	160	167	229	318	397	488
Peak demand plus reserve margin	129	155	198	257	318	390
			Electricity Generation (millions of KWh)			
Hydro	25	25	16	16	16	16
Oil	223	315	136	46	40	33
Gas Turbine	8	12	12	10	21	41
Diesel Peak	4	18	8	0	0	0
Oil-bagasse	289	289	289	289	289	289
STEC	0	0	0	0	37	70
Geothermal	0	0	383	553	732	939
Wind	0	0	0	180	233	273
Total	549	659	845	1,095	1,358	1,662

Note: Figures are independently rounded, may not add to indicated totals.

TABLE 7. -- Future 1, Kauai County

	1980	1985	1990	1995	2000	2005
			Generating Capacity (MW)			
Hydro	8	8	8	8	8	8
Oil	10	10	10	10	10	10
Gas Turbine	40	40	40	45	45	45
Diesel Peak	13	13	13	13	13	13
Oil-bagasse	34	34	34	34	34	34
STEC	0	0	0	0	0	2
OTEC	0	0	0	0	31	38
Wind	<1	<1	<1	22	25	28
Total	105	105	105	132	166	178
Peak demand plus reserve margin	67	79	94	110	125	140
			Electricity Generation (Millions of KWh)			
Hydro	49	49	49	49	49	49
Oil	43	61	61	61	7	7
Gas Turbine	13	48	105	104	17	20
Diesel Peak	0	0	6	0	0	0
Oil-bagasse	179	179	179	179	179	179
STEC	0	0	0	0	0	7
OTEC	0	0	0	0	192	236
Wind	1	1	<1	77	87	98
Total	284	338	401	470	531	595

Note: Figures are independently rounded, may not add to indicated totals.

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 go from 86 to 109 mills/KWh, a 27% increase. During the following 15 years, prices would increase by only 5%. 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% more for electricity than Hawaii.

Future 2

Demand and supply forecasts in the second future, like the first, were based on a 3% per year growth in world oil price. In addition, Future 2 incorporates the effects of increased efforts toward energy conservation and improvements in end-use efficiency. In making the demand forecast, additional measures based on proposed appliance efficiency standards were considered. These included more efficient refrigerators and clothes dryers, the use of solar panels or heat pumps for water heating, and improved electric motors and lamps. The percentage of electricity savings that would result if these measures were implemented in each of the counties was estimated. These demand reduction factors were applied to the baseline forecasts to calculate the new demand levels. The demand for electricity and fuels for this future are presented in Table 8. Figures 4 and 5 show the statewide Future 2 forecast of generating capacity and the amount of electricity generated.

Tables 9 through 12 forecasts generating capacity and electricity generation by county.

Energy Demand

The electricity demand levels found by using the supply-demand integration procedure for Future 2 were lower than those in the first future. Statewide sales in 2005 went from 17,100 million KWh to less than 12,700 million KWh, a decrease of 25%. The percentage change was lower for intermediate years. The largest percentage change occured for Hawaii County, where inexpensive geothermal and wind power would supply nearly all the electricity. The demand for gasoline and other fuels was the same as in the first future. Over the next 25 years, renewables would replace 155 million barrels of oil. This would reduce the state's expenditures for imported petroleum by about $7 billion.

Since the demand for electricity would be lower in this future, a smaller amount of renewable resources would be required for generation. By 2005, the need for oil-fired generation would decline to less than one-third of that needed in Future 1. Electricity prices would again increase rapidly during the 1980s and then would remain the same thereafter. Since the demand for electricity is influenced by both prices and conservation measures, it would not increase as rapidly as in the first future after prices stabilize.

Supply Mix

In Future 2, oil would be the primary source of electricity for Oahu through the 1980s and well into the 1990s (see Table 9). OTEC, geothermal and wind generation would become important after 1990, and by 2005 they would supply about 80% of the county's electricity.

FIGURE 4. -- Hawaii Generating Capacity, 1980-2005: Future 2

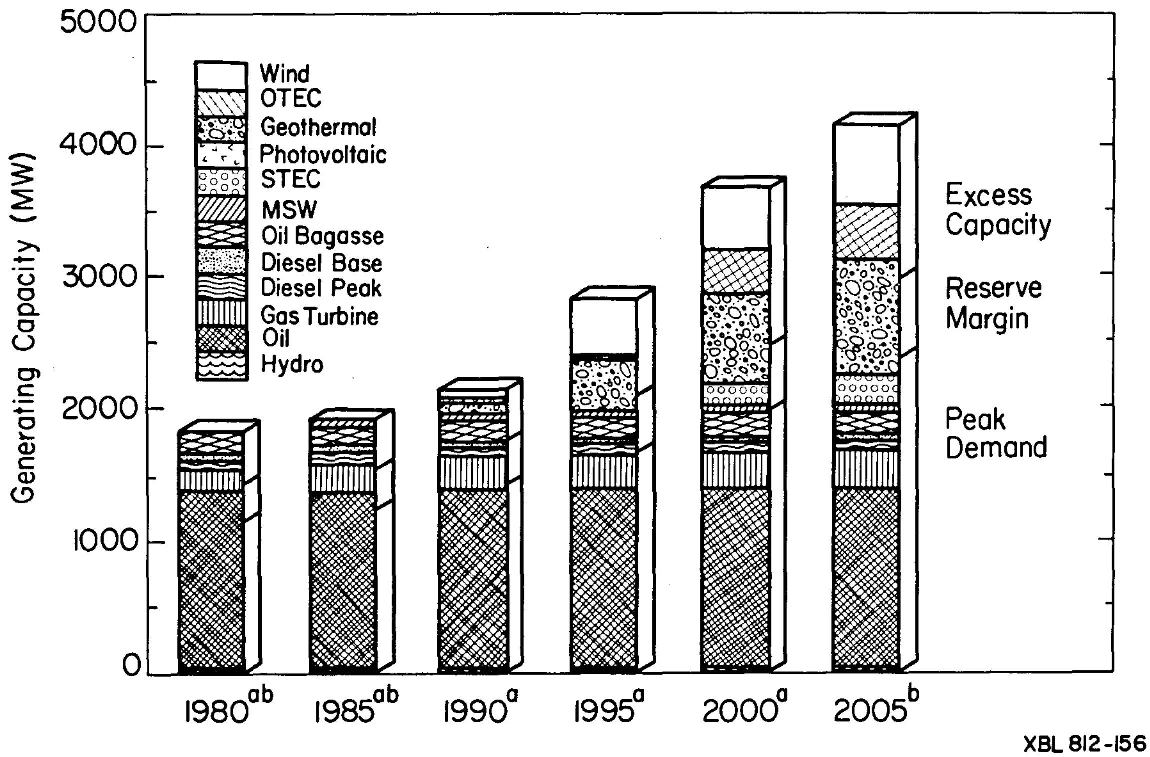


FIGURE 5. -- Hawaii Electricity Generation, 1980-2005: Future 2

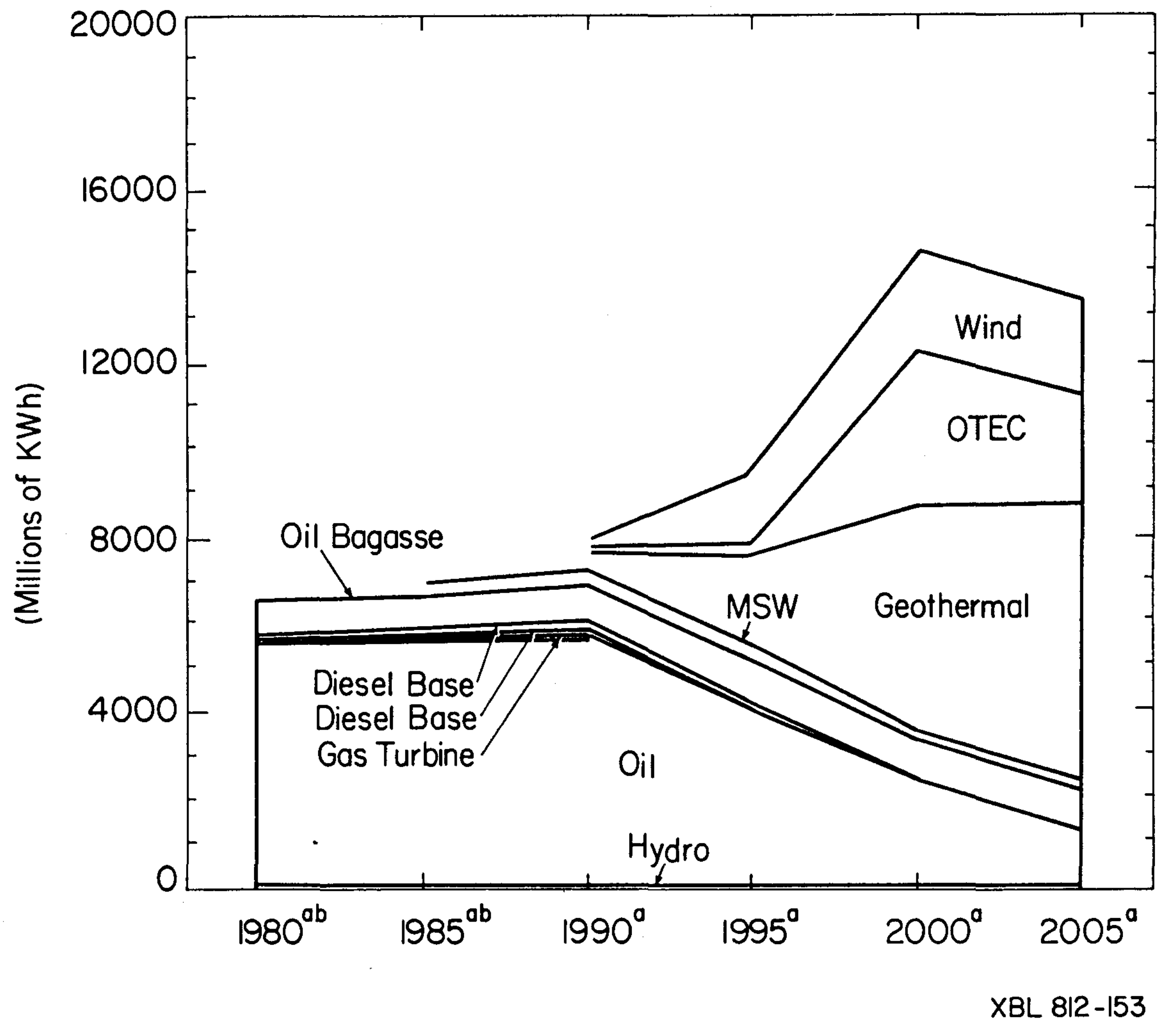


TABLE 8. -- Statewide Energy Demand Projections, Future 2
Savings Case with Interisland Cable
(Trillions of Btus]

	1980[a]	1985	1990	1995	2000	2005
Electricity						
Residual	61.0	61.0	61.5	43.6	11.0	11.4
Diesel	1.9	3.8	4.5	6.8	0.5	0.5
Oil total	62.9	64.8	66.0	50.4	11.5	12.0
Renewables at oil equivalent	9.1	12.2	22.5	56.8	111.1	135.1
Generation (Millions of KWh)	6,463	6,908	7,933	9,276	10,993	13,200
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	6.7	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	201.8	213.7	229.6	231.3	198.6	206.8
Oil demand without renewables	201.8	215.7	241.6	269.5	286.7	306.9
World oil price (1980 dollars/barrel)	30	35	40	47	54	63

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

[b]Alcohol could substitute for at least 10% of gasoline consumption beyond 1990.

OTEC and geothermal would supply baseload power, while wind would be used whenever possible. By 2000, oil generation would provide less than 10% of the total. The existing oil-fired units would remain on line, serving mainly as a backup for wind. Solar thermal would not be a significant source of electricity until the year 2000, when it would furnish about 10%.

Because of the rapid growth in electricity demand on Maui, (see Table 10) new oil-fired generating units would be brought on line during the 1980s. Wind generation would begin in the late 1980s, reaching 40 MW by 1990. Geothermal would begin to play a large role by 1990, and OTEC by 2000. By then oil would supply less than 10% of the electricity sold. Bagasse would continue to be used at current levels. Some gas turbines would be built to supply peak power. As on Oahu, solar thermal would begin to contribute about the year 2000.

The use of oil for electricity generation would nearly disappear on the Big Island (see Table 11) when the first geothermal power plants come on line in the 1990s. Oil-fired generators would remain on line to serve as a backup for wind generation. These changes would be accelerated by the increased use of wind after 1995. Some diesel and gas turbine peaking units would still be required. Solar thermal would not be significant on Hawaii.

Kauai (see Table 12) would not receive geothermal power; instead, it would rely on OTEC and bagasse to supply two-thirds of its electricity in 2005. The remainder would come primarily from wind and hydro-electric. Solar thermal is not expected to be developed on Kauai, although a photovoltaic demonstration project is planned for a medical facility on the island. Gas turbines and diesel engines would continue to supply peaking power.

TABLE 9. -- Future 2, Honolulu County

	1980	1985	1990	1995	2000	2005
Generating Capacity (MW)						
Oil	1245	1245	1245	1245	1245	1245
Gas Turbine	105	105	105	105	105	105
Oil-bagasse	27	27	27	27	27	27
MSW	0	45	45	45	45	45
STEC	0	0	0	0	130	180
Photovoltaic	<1	<1	<1	<1	<1	<1
Geothermal	0	0	21	251	486	643
OTEC	0	0	40	40	303	332
Wind	<1	<1	<1	287	344	421
Total	1377	1422	1483	2000	2685	2999
Peak demand plus reserve margin	1100	1119	1251	1436	1721	2107
Electricity Generation (Millions of KWh)						
Oil	4852	4662	4887	3312	785	896
Oil-bagasse	142	142	142	142	142	142
MSW	0	276	276	276	276	276
STEC	0	0	0	0	569	788
Photovoltaic	<1	<1	<1	<1	<1	<1
Geothermal	0	0	129	1537	2978	3944
OTEC	0	0	245	245	1859	2039
Wind	<1	<1	<1	1006	1206	1476
Total	4995	5081	5681	6519	7815	9562

Note: Figures are independently rounded, may not add to indicated totals.

TABLE 10. -- Future 2, Maui County

	1980	1985	1990	1995	2000	2005
			Generating Capacity (MW)			
Hydro	5	5	5	5	5	5
Oil	40	55	66	66	66	66
Gas Turbine	0	38	68	88	88	88
Diesel Peak	46	46	46	46	46	46
Diesel Base	40	40	40	40	40	40
Oil-bagasse	48	48	48	48	48	48
STEC	0	0	0	0	29	37
Geothermal	0	0	4	51	99	123
OTEC	0	0	0	0	53	57
Wind	0	0	39	69	80	92
Total	179	232	315	412	553	600
Peak demand plus reserve margin	157	215	277	344	398	458
			Electricity Generation (Millions of KWh)			
Hydro	32	32	32	32	32	32
Oil	232	336	402	403	43	43
Gas Turbine	0	25	45	58	33	44
Diesel Peak	30	81	81	3	0	0
Diesel Base	125	194	210	164	0	0
Oil-bagasse	250	250	250	250	250	250
STEC	0	0	0	0	128	163
Geothermal	0	0	23	315	610	751
OTEC	0	0	0	0	323	348
Wind	0	0	136	241	279	321
Total	669	918	1179	1465	1697	1953

Note: Figures are independently rounded, may not add to indicated totals.

TABLE 11. -- Future 2, Hawaii County

	1980	1985	1990	1995	2000	2005
			Generating Capacity (MW)			
Hydro	4	4	4	4	4	4
Oil	61	61	61	61	61	61
Gas Turbine	12	12	12	12	22	42
Diesel Peak	28	28	28	28	28	28
Oil-bagasse	55	55	55	55	55	55
STEC	0	0	0	0	<1	5
Geothermal	0	0	48	64	86	105
Wind	0	0	0	42	49	58
Total	160	160	208	266	306	358
Peak demand plus reserve margin	123	140	169	210	247	288
			Electricity Generation (Millions of KWh)			
Hydro	25	25	17	24	16	16
Oil	202	264	109	40	40	40
Gas Turbine	8	8	8	0	7	15
Diesel Peak	1	13	1	0	0	0
Oil-bagasse	289	289	289	289	289	289
STEC	0	0	0	0	3	22
Geothermal	0	0	295	394	525	644
Wind	0	0	0	147	173	202
Total	524	598	720	894	1053	1228

Note: Figures are independently rounded, may not add to indicated totals.

TABLE 12. -- Future 2, Kauai County

	1980	1985	1990	1995	2000	2005
Generating Capacity (MW)						
Hydro	8	8	8	8	8	8
Oil	10	10	10	10	10	10
Gas Turbine	40	40	40	40	40	40
Diesel Peak	13	13	13	13	13	13
Oil-bagasse	34	34	34	34	34	34
OTEC	0	0	0	0	18	22
Wind	<1	<1	<1	19	20	21
Total	105	105	105	124	143	148
Peak demand plus reserve margin	64	73	83	93	100	107
Electricity Generation (Million of KWh)						
Hydro	49	49	49	49	49	49
Oil	35	55	61	61	7	7
Gas Turbine	11	27	63	43	12	13
Oil-bagasse	179	179	179	179	179	179
OTEC	0	0	0	0	111	134
Wind	1	1	1	65	70	75
Total	275	311	353	398	428	457

Note: Figures are independently rounded, may not add to indicated totals.

Electricity Prices

Instead of increasing at about 2.5% per year as in the initial demand forecast, electricity rates in Future 2 would level off after 1990. On the Big Island, with its abundant geothermal and renewable resources, prices would be below current levels. On the other islands, they would be about 20% higher. Historically, Oahu has had the lowest electricity rates because the large oil-fired steam generators were the most efficient in the state. In the future, Oahu would have more difficulty replacing these plants with renewables, so that electricity rates would eventually be the highest there.

Future 3

The energy demand and supply forecast for Future 3 was based on a 10% per year increase in world oil price. The price of oil was assumed to be $30 per barrel in 1980. By 2005, the price in constant dollars would escalate to $334 per barrel. This is the highest price of oil assumed in this analysis. Although it is generally believed that the high oil prices contemplated in this future would severely depress the Hawaiian economy, it was a requirement to use the state's forecast of the demographic and economic variables that drive the Demand Forecasting Model. Therefore, the same values for these quantities were used as in the first two forecasts. As in the first future, it was assumed that the federally-mandated automobile gasoline standards would be implemented.

Energy Demand

Statewide, and for Honolulu and Kauai Counties, the demand for electricity would double during the next 25 years (see Table 13). Electricity demand on Maui would increase four-fold, while on Hawaii it would increase three-fold during the same period. Electricity prices, and consequently demand, would follow the same pattern as in the first future. Prices would increase rapidly from 1980 to 1985 while oil is still the major source of electricity; then they would decline as renewables begin to take over. Consequently, demand would increase slowly until 1995 and more rapidly thereafter.

Electricity demand in general would be lower than in Future 1 because the prices would be higher. The difference in demand would be 3200 million KWh in 2005. The total amount of electricity generated by renewables in 2005 would be only slightly lower.

The demand for petroleum products would reach its peak in 1990, rather than in 1995 as it does in the first future, because higher oil prices would make generation from renewables more competitive. The non-electric demand for petroleum would continue to increase through 2005, although at a slower rate. By using renewable resources rather than imported petroleum, the state would save itself $21 billion in fuel costs. Approximately 110 million fewer barrels of oil would be burned.

As discussed in the previous chapter, the demand for gasoline would decrease by nearly a factor of four during the next 25 years. Diesel fuel use would be lower than in the other two futures. Since the same visitor arrival projections were used in all three futures, the aviation fuel projection is the same. This is probably an overestimate of the amount of aviation fuel that might be consumed because the high oil prices in this future would be likely to raise airline ticket prices and depress the number of tourists flying to Hawaii.

Supply Mix

The statewide Future 3 forecasts of generating capacity and the amount of electricity generated are shown in Figures 6 and 7. County forecasts are given in Tables 14 through 17. Oil would remain in the primary source of electricity for Oahu (see Table 14) through the 1980s, then would decline sharply after 1990. By 2005, all the renewable resources would play a role in electricity generation.

FIGURE 6. -- Hawaii Generating Capacity, 1980-2005: Future 3

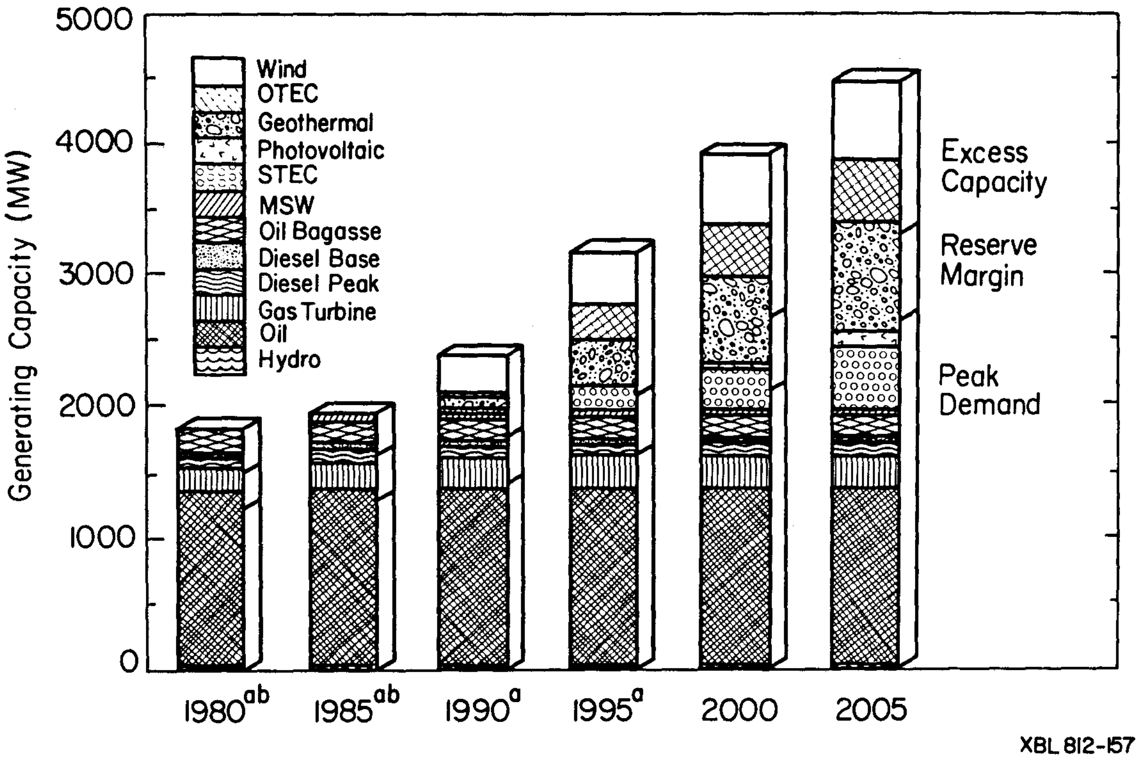


FIGURE 7. -- Hawaii Electricity Generation, 1980-2005: Future 3

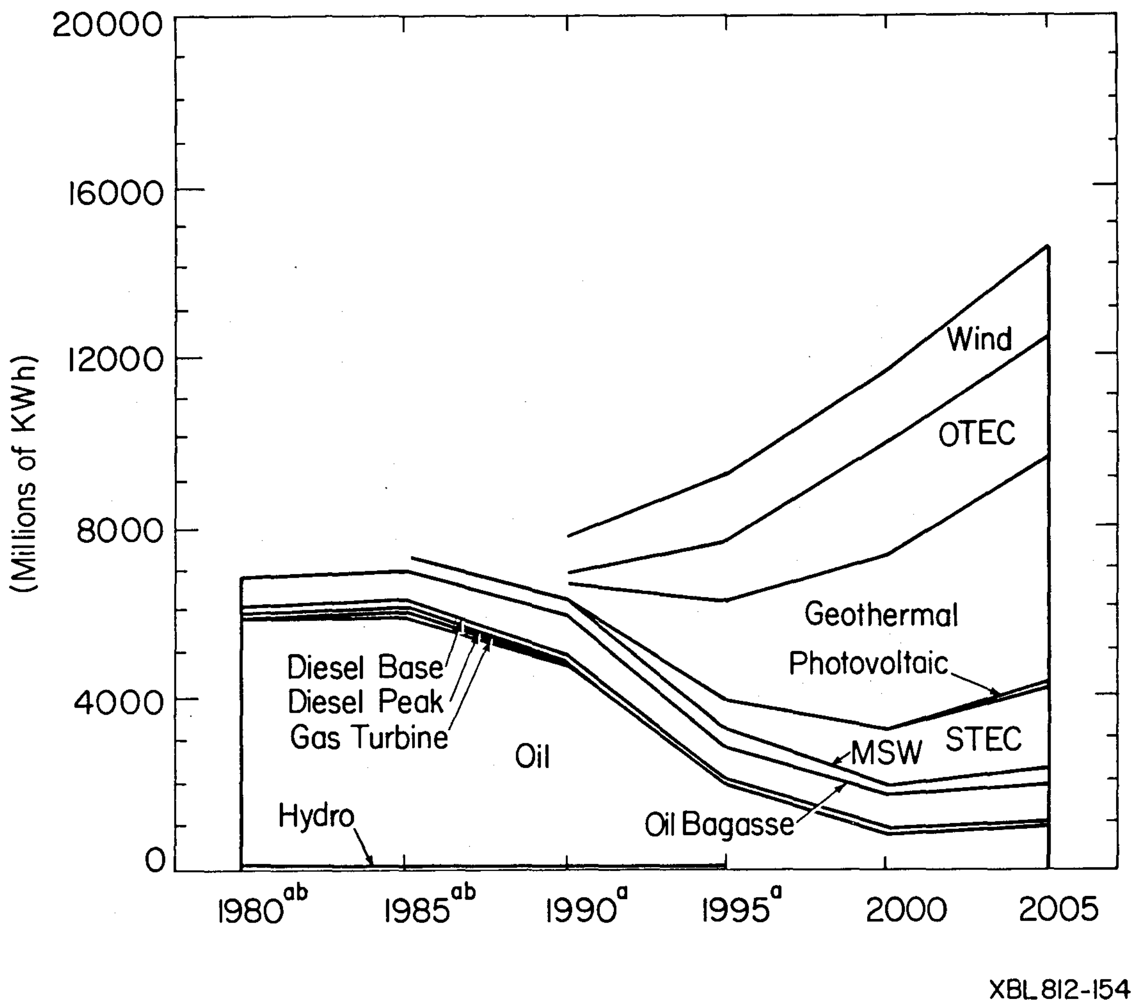


TABLE 13. -- Statewide Energy Demand Projections, Future 3
High Price Case with Interisland Cable
(Trillions of Btus)

	1980[a]	1985	1990	1995	2000	2005
Electricity						
Residual	64.1	64.5	51.4	23.9	6.4	10.0
Diesel	2.4	3.9	3.0	0.2	0.0	0.0
Oil total	66.5	68.4	54.4	24.1	6.4	10.0
Renewables at oil equivalent	9.1	12.2	32.5	77.4	123.4	150.1
Generation (Millions of KWh)	6,780	7,236	7,790	9,096	11,638	14,363
Liquid fuels						
Gasoline[b]	35.5	22.8	16.0	13.4	11.3	9.9
Residual and Diesel	28.4	30.9	33.4	36.2	38.6	41.5
LPG and Utility Gas	5.8	6.1	6.4	6.7	6.9	7.2
Subtotal	69.7	59.8	55.8	56.3	56.8	58.6
Aviation fuel	69.2	85.2	99.8	112.5	114.3	116.4
Total	138.9	145.0	155.6	168.8	171.1	175.0
Total oil demand	205.4	213.4	210.0	192.9	177.5	185.0
Oil demand without Renewables	205.4	215.8	228.2	240.5	238.2	237.5
World oil price (1980 dollars/barrel)	30	50	80	129	207	334

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

[b]Alcohol could substitute for at least 10% of gasoline consumption beyond 1990.

OTEC, geothermal, solar thermal, and wind would reach the limits assumed for their generating capacity limits. Photovoltaics, which in the other two futures did not compete economically with oil and the other renewables, would reach a capacity limit of about 115 MW by 2005 in this future. In 2000, oil accounts for only 5% of the total generation. Although the existing oil-fired units would stay on line, they would be used only a fraction of the time as backup for the renewables.

On Maui, (see Table 15) all the new technologies except for photovoltaics would be used by 2005. Solar and geothermal would account for 24% and 18% of the total installed capacity, while wind and OTEC would account for 17% and 7%. These four technologies would supply over 97% of the electricity in 2005. This percentage is much higher than for Oahu because the demand for renewables would be higher, and they do not reach their capacity limits.

On the Big Island (see Table 16) geothermal, since it is cheaper than OTEC, would supply all the baseload power, with solar and wind providing the bulk of the intermediate load. Oil, bagasse and hydroelectric would be used primarily for peak loads. These would amount to about 5% of the demand.

Kauai (see Table 17) would rely on OTEC, solar thermal, wind and hydroelectric for most of its power. It is the only island where demand would be low enough that no oil would be required for electricity generation after 2000. Bagasse would be used to the same extent, but gas turbines and diesel peaking units would be phased out by 1995.

TABLE 14. -- Future 3, Honolulu County

	1980	1985	1990	1995	2000	2005
			Generating Capacity (MW)			
Oil	1245	1245	1245	1245	1245	1245
Gas Turbine	105	105	105	105	105	105
Oil-bagasse	27	27	27	27	27	27
MSW	0	45	45	45	45	45
STEC	0	0	10	80	130	180
Photovoltaic	<1	<1	<1	<1	16	116
Geothermal	0	0	11	237	465	602
OTEC	0	0	40	240	422	440
Wind	<1	<1	180	276	358	432
Total	1377	1422	1663	2256	2813	3193
Peak demand plus reserve margin	1156	1182	1215	1382	1791	2274
			Electricity Generation (Millions of KWh)			
Oil	5102	4945	4108	1614	552	807
Oil-bagasse	142	142	142	142	142	142
MSW	0	276	276	276	185	264
STEC	0	0	44	350	534	788
Photovoltaic	<1	<1	<1	<1	29	204
Geothermal	0	0	69	1453	2848	3694
OTEC	0	0	245	1472	2587	2698
Wind	1	1	631	969	1255	1514
Total	5245	5364	5515	6276	8132	10,112

Note: Figures independently rounded, may not add to indicated totals.

TABLE 15. -- Future 3, Maui County

	1980	1985	1990	1995	2000	2005
	Generating Capacity (MW)					
	5	5	5	5	5	5
Oil	40	59	59	59	59	59
Gas Turbine	0	40	59	59	59	59
Diesel Peak	46	46	46	46	46	46
Diesel Base	40	40	40	40	40	40
Oil-bagasse	48	48	48	48	48	48
STEC	0	0	10	80	130	174
Geothermal	0	0	2	49	95	132
OTEC	0	0	0	8	8	8
Wind	0	0	54	68	87	108
Total	179	238	322	461	577	679
Peak demand plus reserve margin	164	221	269	339	434	538
	Electricity Generation (Millions of KWh)					
Hydro	32	32	32	32	32	3
Oil	231	360	360	196	39	39
Gas Turbine	0	26	39	33	24	30
Diesel Peak	30	81	10	0	0	0
Diesel Base	158	191	210	0	0	0
Oil-bagasse	250	250	250	250	250	250
STEC	0	0	44	350	569	764
Geothermal	0	0	12	297	583	810
OTEC	0	0	0	49	49	49
Wind	0	0	188	238	304	349
Total	701	940	1,145	1,445	1,850	2,294

Note: Figures independently rounded, may not add to indicated totals.

TABLE 16. -- Future 3, Hawaii County

	1980	1985	1990	1995	2000	2005
	Generating Capacity (MW)					
Hydro	4	4	4	4	4	4
Oil	61	61	61	61	61	61
Gas Turbine	12	12	12	14	19	19
Diesel Peak	28	28	28	28	28	28
Oil-bagasse	55	55	55	55	55	55
STEC	0	0	0	0	27	60
Geothermal	0	0	55	78	104	130
Wind	0	0	28	46	57	68
Total	160	160	243	286	355	426
Peak demand plus reserve margin	129	144	182	232	286	341
	Electricity Generation (Millions of KWh)					
Hydro	25	25	16	16	3	16
Oil	223	276	36	40	40	33
Gas Turbine	8	8	0	4	0	0
Diesel Peak	4	15	0	0	0	0
Oil-bagasse	289	289	289	289	289	289
STEC	0	0	0	0	110	247
Geothermal	0	0	336	478	637	797
Wind	0	0	99	163	139	71
Total	549	613	776	990	1,218	1,454

Note: Figures are independently rounded, may not add to indicated totals.

TABLE 17. -- Future 3, Kauai County

	1980	1985	1990	1995	2000	2005
	Generating Capacity (MW)					
Hydro	8	8	8	8	8	8
Oil	10	10	10	10	10	10
Gas Turbine	40	40	40	40	40	40
Diesel Peak	13	13	13	13	13	13
Oil-bagasse	34	34	34	34	34	34
STEC	0	0	10	19	29	38
OTEC	0	0	0	0	0	2
Wind	<1	<1	17	18	21	24
Total	105	105	132	142	154	168
Peak demand plus reserve margin	67	75	83	90	103	118
	Electricity Generation (Millions of KWh)					
Hydro	49	49	49	49	49	49
Oil	43	57	17	7	7	7
Gas Turbine	13	33	7	6	6	8
Oil-bagasse	179	179	179	179	179	179
STEC	0	0	44	82	125	167
OTEC	0	0	0	0	0	11
Wind	1	1	58	63	72	83
Total	285	319	354	385	438	503

Note: Figures independently rounded, may not add to indicated totals.

BIOMASS FUELS

Transportation

In all three futures, gasoline consumption would be lower than the estimated 1980 level of 35.5 trillion Btu, or 284 million gallons. By 2005, gasoline consumption would be 155 million gallons in Futures 1 and 2, and 80 million gallons in Future 3. All three futures assumed the same automobile mileage standards. They differed in that Future 3 assumed that world oil price (and therefore gasoline price) would increase by 10% per year rather than 3% per year.

In the HIEA report on biomass (See Volume II) it was estimated that 30 million gallons of ethanol could be produced annually by 2005. The ethanol could come from molasses and, to a lesser extent, from pineapple trash. Most present automobiles can operate on a 10% mixture of ethanol and gasoline (gasohol). With minor modifications today's engines could burn a 20% ethanol mixture. By 2005, ethanol production could certainly meet the projected demand for use in automobiles at the 10% level and could come close to meeting the demand in Futures 1 and 2 at the 20% level.

Molasses was considered the best source of ethanol because it is available in significant quantities. It is however, quite valuable in other markets. In the future, the use of other feedstocks such as cellulosic materials may become feasible, but the technology has not been developed sufficiently to be included in the analysis. This is also true for the conversion of wood products to methanol, and eventually to synthetic gasoline. With present technology cellulosic materials could supply more energy if they were burned directly in boilers rather than converted to alcohol. As boiler fuel in power plants they could replace a significant fraction of the imported petroleum that is currently used for generating electricity.

Electricity

In addition to MSW and bagasse, wood, hay, cane trash, pineapple waste, and macadamia shells are potential replacements for oil in power plants. MSW and bagasse have already been included in the analysis. Cane trash could supplement the use of bagasse supplies for generating electricity on sugar plantations, providing 110 MW by 2005.

Wood could provide up to 300 MW on the Island of Hawaii, assuming that 200,000 acres of eucalyptus and other wood crops (giant Koa-haole) would be available for burning. Each acre could yield 10 bone dry tons per year with a heating value of 8500 Btu/lb at a cost of $41/ton. At this price, wood could easily compete with oil. Macadamia shells could provide an additional 10 MW.

If an interisland transmission cable were built, the electricity generated from wood on the Big Island could be used on Oahu and Maui. In the futures, base and intermediate loads would be supplied by renewables after 1995. Thus, to have an impact on oil use, power plants burning wood or other biomass would have to operate as peaking units.

THE COAL OPTION

In addition to the renewables, coal is a possible alternative to oil which needs to be examined carefully. The analysis shows that renewables could make a substantial contribution to electricity generation in Hawaii, and to some extent, to replacing liquid fuels. It was assumed for the purposes of analysis that renewable technologies would be available at various times in the future. However, almost all of the generating technologies which use renewable resources face uncertainties about reliability, cost and technology development. Hence a comparison is being made here between a known technology and an emerging technology.

The analysis views coal as an alternative on Oahu to geothermal energy from the Big Island. The ultimate availability of geothermal energy depends both on the resource limit and on the feasibility and costs of the cable connecting the two islands. If either the resource or the cable are not proven or long delayed, coal could be a major alternative to geothermal energy. To investigate the extent that coal could be used on Oahu to generate electricity, Futures 1 and 3 were modified to include coal rather than geothermal for baseload power. A comparison of the results for the two futures are shown in Tables 18 and 19. The high conservation future was not considered because it was believed that coal would play a relatively minor role in it.

Coal is available in abundance from the Mainland US, and from Alaska, Australia, and China. The technology of electricity generation from coal has been well known for decades, but the feasibility of small-scale power plants appropriate for Hawaii is not entirely clear. Coal prices in the analysis were assumed, for lack of a window on the future, to be 38% of oil prices on a per Btu basis. This amounts to $55 per ton of delivered coal in 1980. Coal is already being used in cement plants on Oahu, and its use could be expanded further. Coal is available from domestic sources and should not be vulnerable to political disruption. However, its use would continue Hawaii's dependence on external sources of energy.

Future 1

Either geothermal energy from the Big Island or coal could penetrate Oahu's electricity market in substantial amounts only after 1990. Coal would be more expensive than geothermal energy, even with the cost of the cable, so that electricity prices would be higher. As a result, the demand for electricity would be smaller with coal-fired plants as part of the generation mix. In 2005, electricity prices would be 13% higher, and the demand would be 6% lower than they would be with geothermal energy.

The amount of oil used for electricity generation would not change substantially between the two cases. The limits on renewable resources, OTEC, wind, and STEC, would be reached in both cases.

Coal capacity in Future 1 would be 255 MW in 1995 and would increase to 485 MW by 2005. The competing renewable technology, OTEC, reaches its resource limit of 440 MW in 2000. If OTEC limits were removed, the coal use would actually decline in 2005.

TABLE 18. -- Electricity Demand Projections for Oahu
Comparison of Coal vs. Geothermal
Future 1: Baseline Forecast

	1980	1985	1990	1995	2000	2005
Electricity demand (Millions of KWh)						
With geothermal	5,136	5,833	6,773	8,286	10,159	12,580
With coal	5,136	5,833	6,799	8,112	9,715	11,791
Oil use (Trillions of Btu)						
With geothermal	57.1	61.7	67.1	54.9	23.2	38.2
With coal	57.1	61.7	65.8	52.8	34.2	39.2
Oil displaced by (Trillions of Btu)	0.0	0.0	1.2	17.1	33.4	43.9
Geothermal use						
Coal use	0.0	0.0	0.0	17.5	17.5	33.3
Electricity prices (Mills/KWh)						
With geothermal	86	90	109	107	112	114
With coal	86	90	107	115	122	129

TABLE 19. -- Electricity Demand Projections for Oahu
Comparison of Coal vs. Geothermal
Future 2: High Price Forecast

	1980	1985	1990	1995	2000	2005
Electricity demand (Millions of Kwh)						
With geothermal	5,136	5,255	5,405	6,170	8,025	10,000
With coal	5,136	5,255	5,409	6,048	7,243	8,479
Oil Use (Trillions of Btu)						
With geothermal	57.1	55.3	46.0	22.1	5.6	9.2
With coal	57.1	55.3	39.6	7.8	2.0	3.0
Oil displaced by (Trillions of Btu)	0.0	0.0	0.8	16.2	31.8	41.2
Geothermal use						
Coal use	0.0	0.0	7.5	36.5	27.7	33.6
Electricity Prices (Mills/KWh)						
With geothermal	86	123	174	181	145	168
With coal	86	123	174	192	191	230

Future 3

The demand for electricity in Future 3 would be smaller by 15% when coal is used instead of geothermal. This difference in demand was much more than in the first future. The lower demand, again, was due to higher electricity prices (230 mills/KWh compared to 129 mills/KWh in the first future).

The use of coal and geothermal energy was virtually identical in both cases. Oil use, however, would decline rapidly in the high world oil price case. With coal as part of the generating mix, oil use would drop to 2 trillion Btu by 2000. Oil would be used entirely for peaking, and its use would increase slightly in 2005 as the overall demand increases.

Coal-fired power plants become economical by 1990 as a result of higher oil prices. Coal capacity in 1990 would be 110 MW. It increases to 535 MW in 1995 and remains constant thereafter. The generation from coal-fired plants would decline between 1995 and 2000, then would increase again in 2005 as the renewable resources reach their generation limits. As in the first future, the renewable resources could contribute more if more resources were available for their development.

Depending on the amount of renewable resources that would be available, coal could provide a viable short-term alternative to oil. In both futures, coal power plants could provide a substantial amount of electricity through the 1990s followed by a gradual reduction in generation after 2000 as renewables take over. The sludge disposal problem associated with coal plants has been cited as a major concern because there is a shortage of land for disposal sites on Oahu. A ten year interim use of coal as an alternative to oil followed by rapid increases in renewables and a decline in coal use would create less of a disposal problem than operating coal plants for 30 years or more.

ECONOMIC COMPARISON OF ALTERNATE ENERGY FUTURES

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

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 (6). 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% of its assets. The results show that the utilities would need to raise 22% of their non-depreciated assets and probably 35% 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 New York appellate court recently allowed such an expection for the Long Island Lighting Company. 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.

Future 1

Capital requirements start declining beyond 2000 in the first future 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 (11), 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 3 to 5% 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.

Future 2

Capital and labor requirements in Future 2 would follow the same trend as in the first future. Their magnitudes would be considerably smaller because of the lower demand for electricity and hence for new capital investment. An investment of $400 million per year would also be required in this future during the 1994 to 1998 period. By 1994, utilities on Oahu, Hawaii and Maui would have to invest about $1600 million to meet the construction schedule for renewable and other technologies. The capital be required in 1994 would again be about 25% of the utilities' undepreciated assets. The discussion about the difficulties in raising such capital in Future 1 also applies in this case. The total capital requirements over the 25-year period amount to $4.7 billion, of which $1.1 billion would be required during the next ten years. These requirements were the lowest of the three futures.

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 (6). 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% of its assets. The results show that the utilities would need to raise 22% of their non-depreciated assets and probably 35% 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 New York appellate court recently allowed such an expection for the Long Island Lighting Company. 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.

Future 1

Capital requirements start declining beyond 2000 in the first future 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 (11), 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 3 to 5% 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.

Future 2

Capital and labor requirements in Future 2 would follow the same trend as in the first future. Their magnitudes would be considerably smaller because of the lower demand for electricity and hence for new capital investment. An investment of $400 million per year would also be required in this future during the 1994 to 1998 period. By 1994, utilities on Oahu, Hawaii and Maui would have to invest about $1600 million to meet the construction schedule for renewable and other technologies. The capital be required in 1994 would again be about 25% of the utilities' undepreciated assets. The discussion about the difficulties in raising such capital in Future 1 also applies in this case. The total capital requirements over the 25-year period amount to $4.7 billion, of which $1.1 billion would be required during the next ten years. These requirements were the lowest of the three futures.

Future 3

Capital requirements for renewable technologies in the third future would increase rapidly as they become competitive with oil. Investment would reach $450 million per year in 1990. This amount represents 20% to 25% of the undepreciated utility assets which,again, raises questions about their ability to finance the new capacity. Over the 25-year period, capital requirements total $5.9 billion, of which $1.5 billion would be expended during the first decade. These expenditures were not significantly different from those required in the first future because in both cases the renewables would reach their capacity limits. In the third future, the large capital and manpower requirements would be spread out over more years than in the first and therefore might be somewhat easier to finance.

Statewide, construction labor requirements would be slightly smaller with the peak occuring during the 1994 to 1998 period. They would reach 900 man-years in 1995. During the 1980s, the annual labor requirements would be about 200 to 300 man-years, while after 1998, they would amount to about 400 man-years.

Indirect Impacts

The indirect employment associated with the three energy futures are plotted in Figure 8. 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 25 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 Future 2 have the same temporal and sectoral distribution as in the first. However, since energy conservation reduces the need for new capacity, their level would be lower. During the period 1981 to 2005, secondary employment and income would total

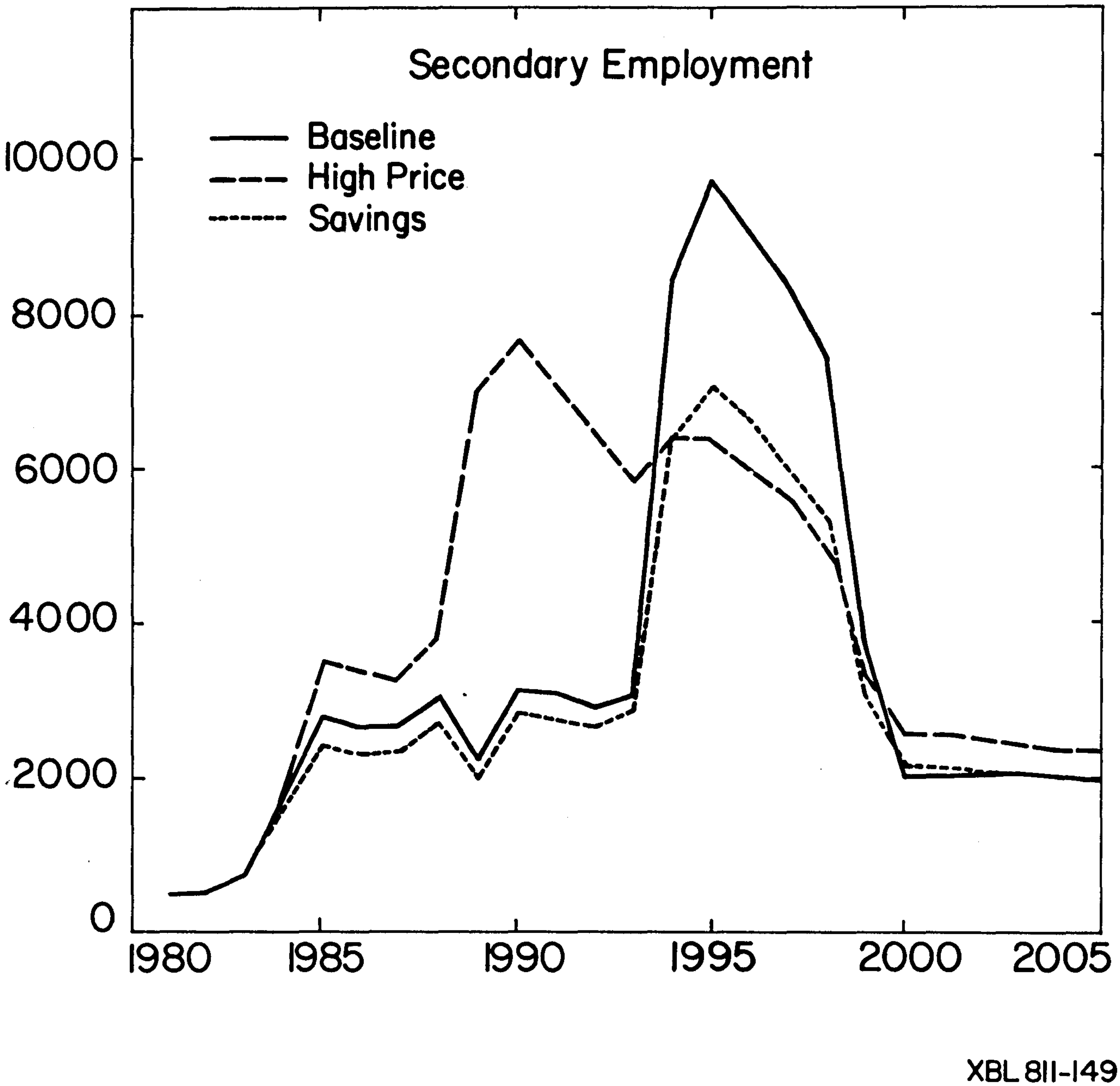
74,000 man-years and $1.7 billion, respectively.

The secondary impacts of the third future would be more spread out over time because the alternative technologies become competitive about five years earlier. At the peak in 1990, secondary employment would be 7700 workers, and income would be $185 million. The total indirect impacts during the next 25 years would be larger, amounting to 99,700 man-years of employment and $2.3 billion of income.

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 (12). Total personal income during 1979 was about $8.3 billion. According to the state's "most likely" projections (1), 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 8. -- Hawaii Secondary Employment, 1980-2005: Futures 1, 2, and 3



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