Hawaii County Baseline Energy Analysis

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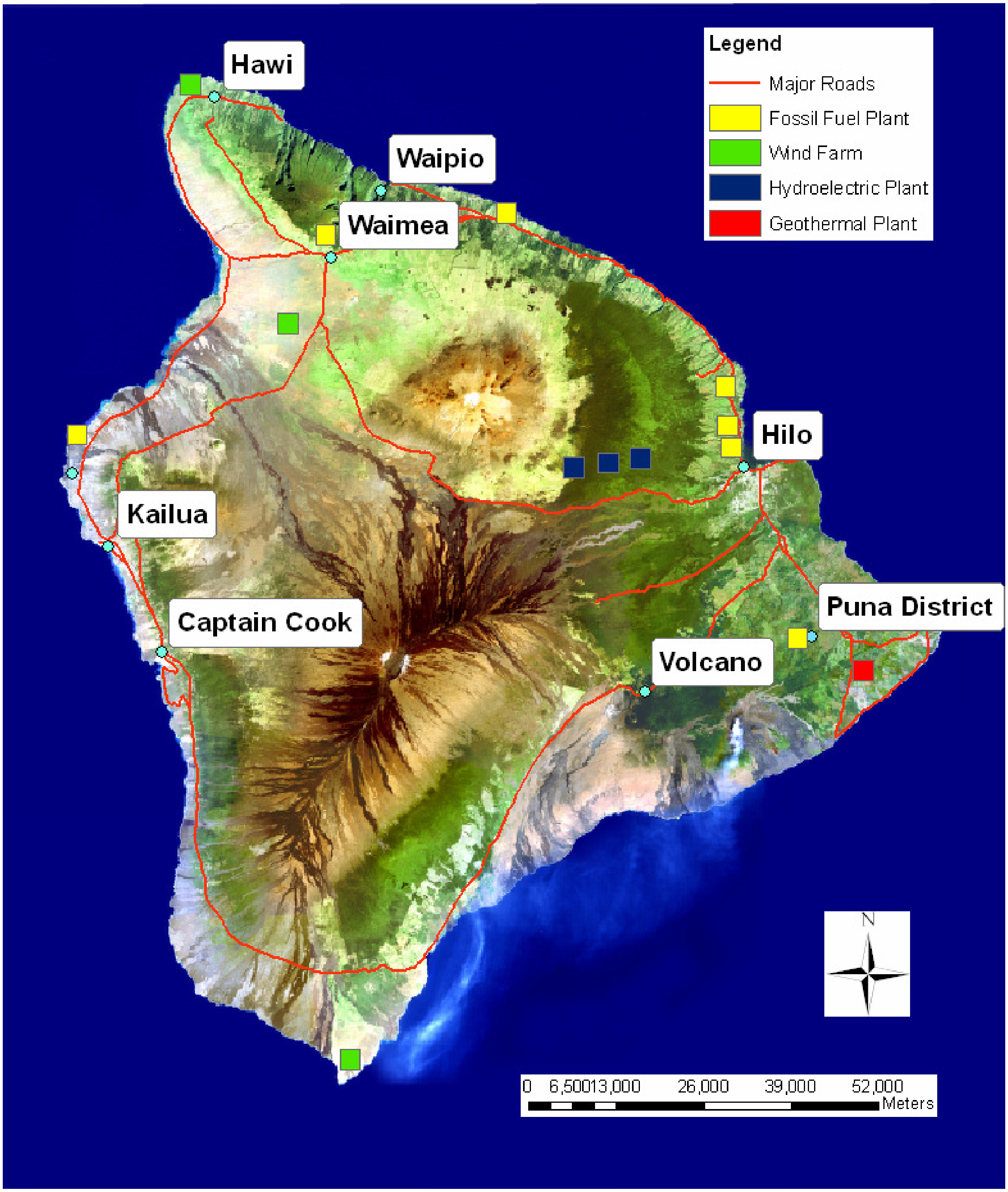
Glossary of Acronyms

BAU	Business as Usual
CAES	Compressed Air Energy Storage
CAGR	Compound Annual Growth Rate
DBEDT	Department of Business, Economic Development and Tourism
DG	Distributed Generation
EIA	Energy Information Administration
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information System
HECO	Hawaii Electric Company
HELCO	Hawaii Electric Light Company
HNEI	Hawaii Natural Energy Institute
INL	Idaho National Laboratory
IPP	Independent Power Producer
IRP	Integrated Resource Plan
KERZ	Kilauea East Rift Zone
KSRZ	Kilauea Southwest Rift Zone
LPG	Liquefied Petroleum Gas
MSW	Municipal Solid Waste
NELHA	Natural Energy Laboratory of Hawaii Authority
OTEC	Ocean Thermal Energy Conversion
PGV	Puna Geothermal Venture
PSH	Pumped Storage Hydro
PTC	Production Tax Credit
PURPA	Public Utility Regulatory Policies Act
PUC	Public Utilities Commission
PV	Photovoltaic
QF	Qualifying Facility
RFP	Request for Proposal
RPS	Renewable Portfolio Standard
SWH	Solar Water Heating



Study Area and Location of Major Roads and Power Plants.
Source: Hawaii Statewide GIS Program

Executive Summary

This paper presents a baseline analysis of the energy system of the Big Island of Hawaii. It is the first step in a multi-year study exploring the feasibility of a sustainable energy transition for the island. This phase of the project details the current energy system of the island and its evolution over time, the current and potential use of various renewable energy technologies, and the political and social factors that influence and constrain different energy options. Future research will build on this baseline analysis, adding greater detail and developing a plan for the Big Island's ongoing transition from fossil fuel reliance to a system dominated by the abundant renewable energy options.

The data for this report were gathered through an initial review of the available literature, on-site stakeholder interviews conducted in March 2006, and additional follow-up research and interviews completed in May. It was completed as an independent study project through the School of Forestry and Environmental Studies at Yale University, in collaboration with the Kohala Center of Waimea, Hawaii.

<u>Determinants of Demand</u>

Thanks to its mild climate, low population density, and small industrial base, the Big Island's demand for energy is relatively low: final energy demand was 18,470 billion BTU in 2005. Transportation fuels dominate this figure, accounting for more than three-quarters of final demand. The imports and primary energy entering the system amounted to 25,930 billion BTU. Final electricity demand was 1,120 million kWh in 2005, or 3,810 billion BTU. Electricity from petroleum-based generation is approximately 31% efficient on a system-wide basis.

Because of the relatively low levels of manufacturing and commercial activity, Hawaii County's electricity demand is driven primarily by tourism and residences. Since the down year resulting from the September 11, 2001 terrorist attacks, the tourist presence has increased steadily: 1.5 million tourists spent an average of 7 days on the Big Island in 2005, a 14.4% increase in visitor days compared to 2004. For the entire state, tourist spending grew by 9%, to a 2005 total of almost $12 billion statewide. In the residential sector, new houses were built at an annual growth rate of 2.4%. Electricity demand has kept pace with the growth in tourism and housing, growing by 3.2% between 2004 and 2005. Demand growth has occurred in spite of Hawaii's 28 cents per kWh residential electricity rates, the highest in the nation. However, there is evidence that this electricity demand growth has begun to stabilize somewhat, as recent growth rates have been smaller than the historical growth rate of 4.7% per year over the past 35 years.

In 2005, 123 million gallons of transportation fuel were sold on the island, for a total energy use of more than 14,300 billion BTU. While most of this fuel went to ground transportation, aviation fuel accounts for a surprising 23% – only Alaska uses more aviation fuel than Hawaii on a per capita basis. Gasoline use rose steadily from 1980 to 2003 at a compound annual growth rate of 3.3%, but declined in 2004 and 2005 as a result of rising prices. Public transit use is relatively small, averaging about two trips per person per year. Aviation fuel use has grown even more rapidly than gasoline, at a compound rate of 3.9% between 1980 and 2005.

The peak demand for electricity, reached in early December, 2005, was 196 MW. Not surprisingly, this date coincides with the peak of the tourist season. Seasonal differences are modest, with only a 23 MW difference in peak demand between the lowest and highest days of the year. The daily peak consistently occurs shortly after sunset, when most people arrive home

from work. Per capita demand is lower than the U.S. average across all sectors – commercial, industrial and residential.

Energy planners at Hawaii Electric Light Company (HELCO) believe the greatest single residential end-use application of electricity to be water heating on the eastern side of the island and air conditioning on the western side. The existence of air conditioning as a driver of residential demand is a new phenomenon, and anecdotal evidence suggests that new, inefficiently designed homes are largely responsible for the increase in the air conditioning load. Most residential buildings in Hawaii County are exempt from energy efficiency requirements in the local building codes.

Historical data were used to create four scenarios of future demand for energy on the Big Island: business as usual (BAU), two times BAU, no growth, and negative growth. The growth rates for both of the BAU projections were derived from historical data, resulting in a projected 5% annual growth in electricity demand and 2.5% growth in liquid fuels demand. Under these assumptions, total demand would rise to more than 2 billion kWh electricity and 20 billion BTU liquid fuels by 2020.

<u>Energy Supply and Generating Capacity</u>

Hawaii is heavily dependent on oil to meet its energy needs, with petroleum products accounting for 78% of electricity generation and more than 95% of primary energy. The proportion of electricity generated by renewable energy sources has varied significantly over the past thirty years, due mainly to geothermal production and changes in biomass-based generation tied to the now-defunct sugar plantations.

The island currently has approximately 300 MW of electricity generation capacity. Petroleum based generators account for roughly 80% of this capacity, roughly one third of which is combined-cycle. The remainder of the island's existing capacity comes mostly from a single geothermal power plant, Puna Geothermal Venture, with smaller contributions from wind, hydropower, and distributed solar.

More than a quarter of the Island's generation capacity comes from oil-fired plants built over 30 years ago. After 1975, there was a lag in construction, with virtually no new power plants built between 1976 and 1986. Since 1986, 200 MW of mostly petroleum-based capacity has come online. Over the ten years prior to 2006, when the 10.5 MW Upolu Point wind farm began operation, no new renewable capacity was added. According to HELCO, no existing capacity is slated for retirement within the next 20 years.

The electricity transmission system has not been fully modernized to accommodate increased levels of supply. The majority of the system consists of 69 kV lines, and the long, cross-island distances between generators and customers result in system line losses of about 8%. There is a spatial mismatch which exacerbates this problem: recent population growth, and thus electricity demand, has occurred on the west side of the island, whereas the bulk of electrical generating capacity is in the east. Since there is no inter-island transmission, the Big Island's grid must be completely self-sufficient.

Hawaii County's liquid fuels, whether for electricity generation or for transportation use, all come from two refineries on Oahu, the only such facilities in the state. The Kapolei plant, owned by Tesoro, produces gasoline, diesel, and aviation fuel. The second plant, owned by Chevron, supplies most of the state's gasoline. Both refineries were built in the 1960s.

The local environmental impacts of the island's energy system are fairly modest and well within regulatory guidelines. Public pressure for increased use of renewable energy therefore seems to be motivated more by price and supply security concerns, as well as concern about more large-scale problems such as climate change. Estimated emissions in 2005 were 8,000 tons of NO_x, 6,000 tons of SO_2, and 2,075,000 tons of CO_2. Natural SO_2 emissions from volcanic sources far exceed anthropogenic emissions.

There are a number of supply scenarios describing possible developments in the county's energy system over the next few decades. HELCO's Integrated Resource Plan (IRP), used to plan for capacity additions, is perhaps the most influential of these. It describes five possible pathways: Least-cost, Maximize Renewables, Optimize Distributed Generation, Renewable Resource Flexibility, and Alternate Timing Pumped-Storage Hydro and Wind. All plans call for roughly 30 to 60 MW of additional capacity in the next 20 years. The diversity of sources used in the different scenarios illustrates the flexibility the island is afforded by its relative abundance of wind, solar, and geothermal resources.

However, if observed trends in energy demand continue for the near future, the proposed capacity additions will be insufficient to meet peak demand. None of the five plans can keep pace with the current 3.2% peak demand growth rate throughout the entire 20-year planning period. Incorporating projected savings from demand-side management and combined heat and power could close the gap between supply and demand, but would not make up for the entire shortfall. This shortfall can likely be explained by the inability of the IRP process to include independent power producers in its future expected generation.

Other scenarios present very different pictures of Hawaii's possible energy choices. An older version of HELCO's IRP describes a system that maintains its current heavy reliance on oil, while a study of feasible renewable energy projects completed for the Hawaii Energy Policy Forum estimated the potential for 160 MW of added renewable capacity in the near future.

Renewable Energy Technologies: Current Production and Potentials

Installed capacity of all renewable electricity sources is approximately 60 MW, half of which is considered firm capacity from geothermal. In terms of production, renewable sources accounted for 285 million kWh of energy in 2005, or about 23% of the Big Island's electricity needs.[1] Geothermal dominates the production of energy from renewable sources, but there are sizeable inputs from solar thermal and run-of-the-river hydropower as well. There is more than enough resource potential for the island to meet all of its electricity needs through renewable sources, but it will be more difficult to displace significant quantities of transportation fuels.

Wind is only a small part of the energy system, providing less than 1% of the island's electricity in 2005. This production came mostly from two major wind farms. A newly completed wind project at Upolo Point and proposed expansions of the existing projects should increase this proportion substantially in the near future, but there is room for greater contribution. Indeed, there is sufficient potential to allow production of all of the Big Island's electricity from wind. This assumes, however, the resolution of wind intermittency issues, which is most likely to occur through storage schemes such as pumped storage hydro (PSH).

[1] This total includes the contribution of solar water heaters, which do not generate electricity but do displace electricity demand.

Biomass could provide energy through a variety of forms, three of which are discussed in detail: the use of dedicated energy crops, such as sugar cane for ethanol; the use of waste oil to produce biodiesel; and the combustion of wastes, either agricultural residues or municipal solid wastes. None of these options are currently in practice on the island, but dedicated energy crops and biomass combustion hold significant potential. The demand for ethanol will rise as a result of the recent directive mandating a 10% ethanol blend in most gasoline statewide. A planned 10-million gallon ethanol plant in Hilo should be sufficient to meet the county's need. Big Island-produced ethanol, in total, has the technical potential to displace a maximum of 27% of the island's current gasoline usage. Waste oil and waste-to-energy only have the potential for smaller contributions, but still warrant discussion. Waste-to-energy, in particular, is hindered by the island's low population density and dispersed population centers, but landfill constraints may make this an attractive option in the coming years. In addition to these biological-based energy sources, there is also considerable research and planning being conducted on biodiesel from dedicated energy crops and algae, lignocellulosic biomass utilization, and biomass gasification.

Geothermal currently contributes the vast majority of Hawaii County's renewable energy production, accounting for over two-thirds of renewable energy used in 2005. There is one existing geothermal plant, Puna Geothermal Venture, which plans to ramp up its capacity incrementally as demand grows in the coming years. There is sufficient economic potential to satisfy the entirety of the island's energy needs.

Solar energy is harnessed both directly, for thermal applications, and through photovoltaics (PV) for electricity generation. A popular incentive program has led to widespread use of solar water heaters, which are in place in about 10% of the island's residences and displace the equivalent of 1.5% of electricity demand. PV use is considerably smaller, with distributed sources existing at hotels, other businesses, and individual residences. PV is not currently in use for large-scale grid distribution. Both forms of energy production have huge potential for growth, although PV systems are quite expensive and therefore not as competitive as other renewables under current prices.

There are three main run-of-the-river hydropower plants on the Big Island, as well as a number of smaller ones. A recent assessment has identified several more sites where hydropower could be developed, but even if all of these possibilities were to be realized, run-of-the-river hydro would remain a relatively minor part of the overall energy mix.

The intermittency issues surrounding certain renewable resources can be addressed through energy storage, preventing the loss of excess generation and creating greater grid stability. There are a number of different storage options. PSH seems to be the most likely bet for the near future, and HELCO already has plans to pursue PSH in conjunction with wind generation. Other possibilities include hydrogen and various forms of batteries. Technological advances will be necessary before hydrogen is economically viable, but it remains a very promising option for the future.

<u>Review of Stakeholder Interests and Institutional/Political Boundary Conditions</u>

A number of federal and state level policies have played a role in shaping the Big Island's energy system. The federal Public Utility Regulatory Policies Act is perhaps foremost among these, requiring utilities to purchase power from qualifying facilities at a rate equal to the avoided cost of generation. Since Hawaii County's avoided cost is tied firmly to oil prices, this law has generated high profits for independent power producers, even while consumer rates remain high. In addition, HELCO has no direct incentive to expand the use of renewable energy from such independent power producers. A competitive bidding process would eliminate this disincentive by allowing HELCO to negotiate lower prices for wholesale electricity and pass savings on to customers.

Important state-level energy laws include net metering, the Hawaii Renewable Portfolio Standard (RPS), and the aforementioned 10% ethanol standard for gasoline. Net metering allows grid-connected customers who own distributed generation units to sell surplus generation back to the utility. The Hawaii RPS sets a nonbinding statewide goal of procuring 20% of electricity from renewable sources by 2020.

In addition to the regulatory context, cultural and social forces also determine the viability of proposed energy projects. The contentious history of geothermal development on the island is particularly illustrative of these issues. Volcanoes are extremely important to native Hawaiian culture, and spiritual leaders argue that the harnessing of geothermal energy violates their religious beliefs. Community-based opposition to geothermal power is strong as well, with residents citing competing land use issues and health concerns surrounding releases of hydrogen sulfide. Thus, while there are persuasive arguments supporting geothermal production on the Big Island, opinions are strong and polarized. Any future plans must honestly consider the concerns and incorporate the diverse needs of the numerous stakeholders involved.

Social, cultural, and political factors place significant constraints on Hawaii County's other energy options as well. There is significant pressure from environmental groups and the general public to reduce the proportion of electricity coming from imported fossil fuels. HELCO's recent public commitment to refrain from building any new fossil fuel plants indicates that this pressure is having a very real effect.

HELCO has resisted the increased use of wind power, citing concerns about the effects of intermittent resources on grid stability and predictability. A more fundamental problem, however, is that under the current regulatory framework they have no financial incentive to actively promote increased use of wind power. There are no obvious constraints to reintroducing biomass power, but it seems likely that it would be administratively (and perhaps politically) difficult to expand production beyond former sugar plantation land into previously undeveloped acreage. Finally, the major potential constraint on expanding solar power is not so much opposition but its dependence on subsidies that require continuous political support. Land availability and a prohibition against third-party electricity transactions (i.e., bypassing the utility) may also act to inhibit the growth of solar power.

The Total Systems Approach to Industry, Materials, and Energy

Industrial activity and the use of physical materials are inextricably tied to energy consumption. While we conducted our baseline energy analysis of the Big Island, another group of Yale students conducted a parallel project focusing on industry and materials usage. Using the tools of industrial symbiosis, overlapping opportunities were identified where waste heat and byproducts from energy generation could spur industrial development and local materials could be utilized for energy generation. By taking a holistic approach to the study of both energy and material flows, it is possible to identify opportunities to reuse resources, minimize waste, and limit environmental degradation. For additional information, please refer to the complementary paper, entitled "Material Flows on the Big Island of Hawaii."

Conclusions and Recommendations for Future Research

This report lays the foundation for more detailed studies and analyses of the energy system in Hawaii County. The following are several opportunities for future study:

- Perform detailed analyses of economic trends and projections
- Determine trends in fuel economy of vehicle fleet and utilization of public transportation
- Assess the potential impact of inter-island boat transportation on fuel use
- Describe long-term trend in annual growth of peak electricity demand
- Create annual cumulative load curve of electricity demand
- Provide greater detail on end use applications of energy
- Examine in detail transmission line losses
- Perform an economic analysis of ethanol production potential as a function of gasoline prices
- Improve estimates of renewable energy resource potentials
- Develop supply scenarios incorporating greater economic analysis, renewable resource potentials, and power plant retirements

1. Determinants of Energy Demand

We begin our study of the Big Island's energy system with a discussion of its energy demand. We first provide some context by presenting an overview of the economic and population trends on the island. While there is little industrial base and low population density on the island, strong economic and population growth in recent years have fueled a steady increase in the demand for energy. Following that introduction, we analyze the Island's total final energy demand, looking not just at an aggregate value but also exploring different categories of demand (business vs. residential, electricity vs. transportation, etc.). We will also review a number of the factors that influence the options for demand-side management. We conclude by developing a simple scenario for future energy use, based on an extrapolation of current trends.

1.1. County of Hawaii – Demographics and Economics

The Big Island of Hawaii, also known as Hawaii County, is the state's largest island. It spans 4,028 square miles – almost two thirds of the state's entire land area. The island is less densely populated than the rest of the state: its 167,000 residents account for only 13% of the state's population. This percentage is increasing, though, as the island's population has grown at an annual rate of 2.4% since 2000, making it the most rapidly growing county in Hawaii.[1] Still, with only 42 people per square mile, the high ratio of landscape to people remains a defining characteristic of the island, especially as energy planners discuss the island's future needs.

The Big Island's climate is relatively mild. The need for artificial heat is minimal except in the high elevations, and buildings that are built to maximize airflow should not require much if any air conditioning. However, the proliferation of mainland-influenced construction and the growth of the resort population, on top of the inelastic demand for electricity, have increased the demand for air conditioning. Consequently, electricity demand has continued to grow substantially from year to year.

As with the rest of the state, Hawaii County's economy is heavily dependent on tourism. In 2005, 1.5 million people visited the Big Island by air, a 16% increase over 2004. The average visit was about 7 days, with visitors spending $175 per day.[2] According to the Hawaii Department of Business, Economic Development & Tourism (DBEDT), total visitor spending in the state was up to $11.2 billion, accounting for more than 20% of the gross state product.[3]

As a result, the economy has been booming in recent years. Job growth and inflation-adjusted personal income growth both increased by 2-3% on the Big Island in 2005.[4] The unemployment rate in February 2006 dropped to 2.6%, a dip fueled mostly by increased activity in the construction and the service industries. The statewide unemployment rate of 2.3% – the lowest in the nation – is the state's lowest since 1990.

As a consequence of this unbridled growth, inflation rates and electricity use have risen steadily. In 2005, the Honolulu Consumer Price Index rose by 3.8%, compared to 3.4% for the mainland. This increase stems primarily from inflated housing prices, which rose 5.6% in 2005, and transportation cost increases, which rose 5% due to increased fuel prices.[5]

While high fuel costs may have contributed to decreasing gasoline demand since 2003, they have not had a dampening effect on electricity use. Electricity use on the Big Island continues to keep pace with the economy. Hawaii Electric Light Company (HELCO) projects sales growth of about 3% per year in 2005 and 2006. While these numbers are down from the 4-5% increases seen in 2003 and 2004,[6] they still speak to Hawaii County's growing need to address its dependence on oil for electricity generation.

1.2. Total Final Energy Demand

Table 1.1 depicts final energy use on the Big Island of Hawaii. These numbers do not include primary or secondary fuel use, such as fuel used in electricity generation. The table shows only final energy, as delivered to the customer. Note that transportation – gasoline (45%), aviation fuel (17%) and diesel oil (14%) – account for more than three quarters of all final energy use, with electricity use (22%) accounting for the bulk of the remainder. The high proportion of energy used for transportation stems primarily from long average commutes, inefficient vehicles, extremely low public transportation use, and a lower per capita electricity use.

Table 1.1: Hawaii County Final Energy Demand, 2005

Source: Liquid Fuels - Hawaii Department of Taxation

Source	Quantity	Final Energy (Billion BTU)	% of Total
Gasoline (gallons)	74,148,000	8,527	46%
Diesel Oil (gallons) 1/	20,810,000	2,672	14%
Electricity (kWh)	1,117,000,000	3,811	21%
Aviation Fuel (gallons)	27,610,000	3,175	17%
Synthetic Natural Gas (therms)	2,275,000	228	1%
Liquid Petroleum Gas (gallons)	17,200	2	0%
Solar Water Heaters (kWh)	16,670,000	57	0%
Final Energy Total		**18,473**	**100%**

1/ Excluding diesel for electricity generation.
Lower heating values: gasoline 115,000 BTU/gal; diesel 128,400 BTU/gal; aviation fuel 115,000 BTU/gal; LPG 100,000 BTU/gal

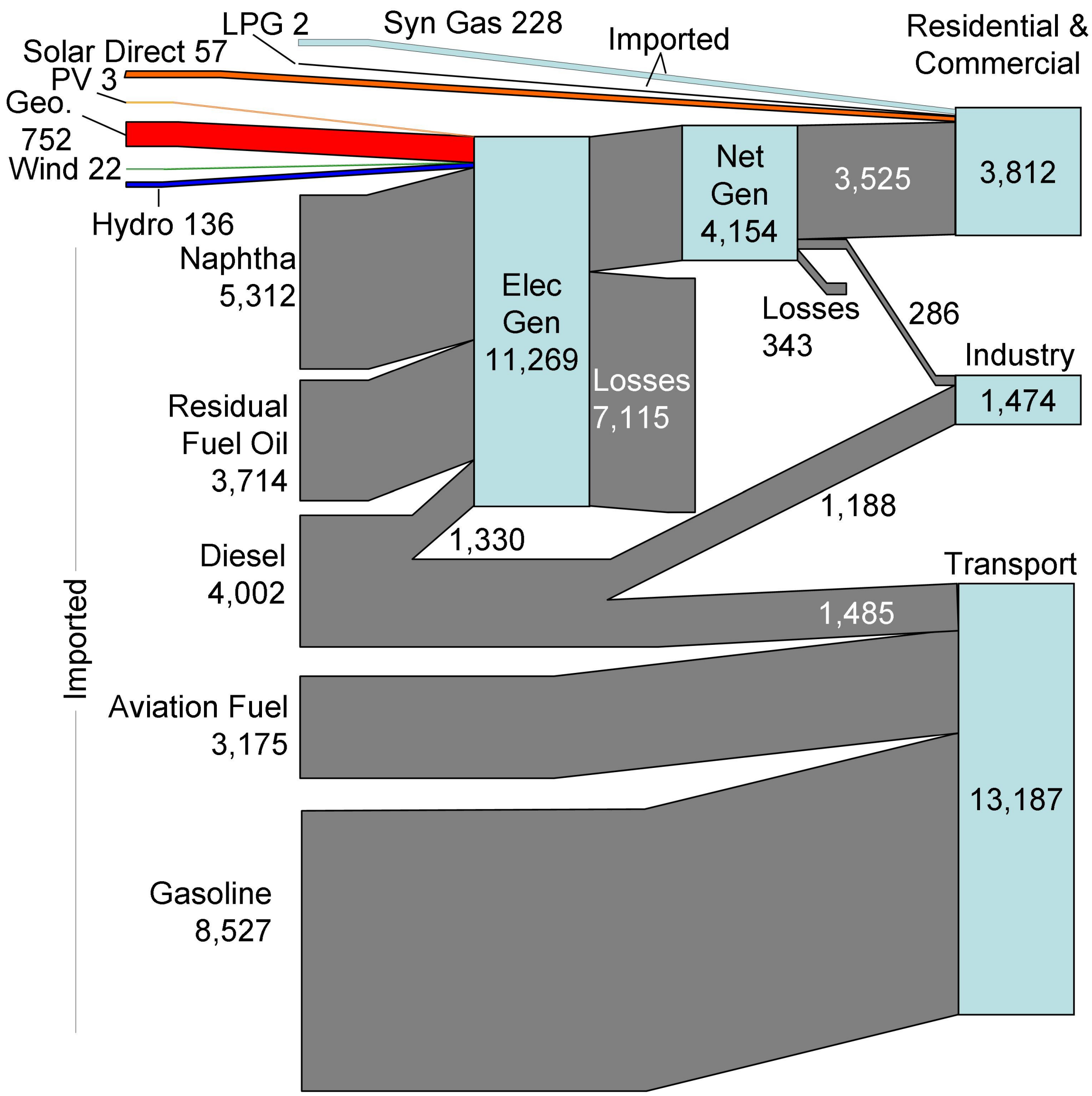


Figure 1.1: Energy Use on the Big Island, 2005
(Values in billion BTU)

Figure 1.1 shows a summary of the energy use on the Big Island, from primary energy through final energy. The only forms of primary energy generated on the island are the renewable energy sources: direct and photovoltaic (PV) solar, geothermal, wind, and hydropower. All of the liquid fuels are imported onto the island. In constructing this figure, the renewable contribution is equal to the energy in the electricity produced (i.e., a direct equivalence method was used which assumes 100% conversion efficiency between primary and final energy). In doing so, the amount of renewable electricity generation appears small, but if one looks at the amount of fossil fuel that it replaces, it is quite substantial. For example, assuming that the 970 billion BTU of renewable energy replaced a naphtha plant running at 30% efficiency, the renewable generators actually prevented over 3,200 billion BTU of naphtha from being burned.

The amount of naphtha, residual fuel oil, and diesel entering power plants was obtained from the Energy Information Administration (EIA)-906/920 and 860 databases.[2] HELCO data were used to calculate the net generation, resulting in efficiencies of 30%, 28%, and 49%, respectively. Line losses of 343 billion BTUs were calculated based on the difference between net generation and sales and amount to 8% of net generation. All electricity was assumed to be residential and commercial, except manufacturing, food processing, farming, and "other pumping," which were all linked to industrial use. The liquid fuels data were obtained from the tax office. Diesel, which the data show was used considerably more in previous years, is broken into highway and non-highway uses. It is assumed that non-highway uses are industrial, such as farming and construction.

Primary energy used for electricity generation is nearly as much as for transportation energy, although electricity is a much smaller fraction of final energy demand. When discussing energy systems, it is essential that you consider both of these.

[2] Lower Heating Values assumed: diesel = 128,400 BTU/gal, aviation fuel = 115,000 BTU/gal, gasoline = 115,000 BTU/gal

Table 1.2: Energy Balance Sheet in Billion BTU's

Supply and Consumption	Gasoline	Diesel	Naphtha	Aviation Fuel	Residual Fuel Oil	LPG	Natural Gas	Hydro 1/	Geo. 1/	Solar (Direct)	Solar (PV) 1/	Wind 1/	Electricity
Production	0	0	0	0	0	0	0	136	752	57	3	22	0
Imports	8527	4002	5312	3175	3714	2	228	0	0	0	0	0	0
Exports	0	0	0	0	0	0	0	0	0	0	0	0	0
TPES	**8527**	**4002**	**5312**	**3175**	**3714**	**2**	**228**	**136**	**752**	**57**	**3**	**22**	**0**
Electricity Plants	0	-1330	-5312	0	-3714	0	0	-136	-752	0	-3	-22	4154
Distribution Losses	0	0	0	0	0	0	0	0	0	0	0	0	-343
TFC	**8527**	**2672**	**0**	**3175**	**0**	**2**	**228**	**0**	**0**	**57**	**0**	**0**	**3811**
Industry	0	-1188	0	0	0	0	0	0	0	0	0	0	-286
Transportation	-8527	-1485	0	-3175	0	0	0	0	0	0	0	0	0
Residential	0	0	0	0	0	-2	-228	0	0	-57	0	0	-3525
Net Electricity Generation (1000 kWh)	***0***	***192,483***	***431,413***	***0***	***326,616***	***0***	***0***	***39,804***	***220,639***	***0***	***930***	***6,700***	***0***

1/ Assumes a direct conversion (efficiency of 100%) for renewable source

1.3. Energy Demand by Source

Electricity

Figure 1.2 displays year-over-year electricity sales growth for Hawaii County.

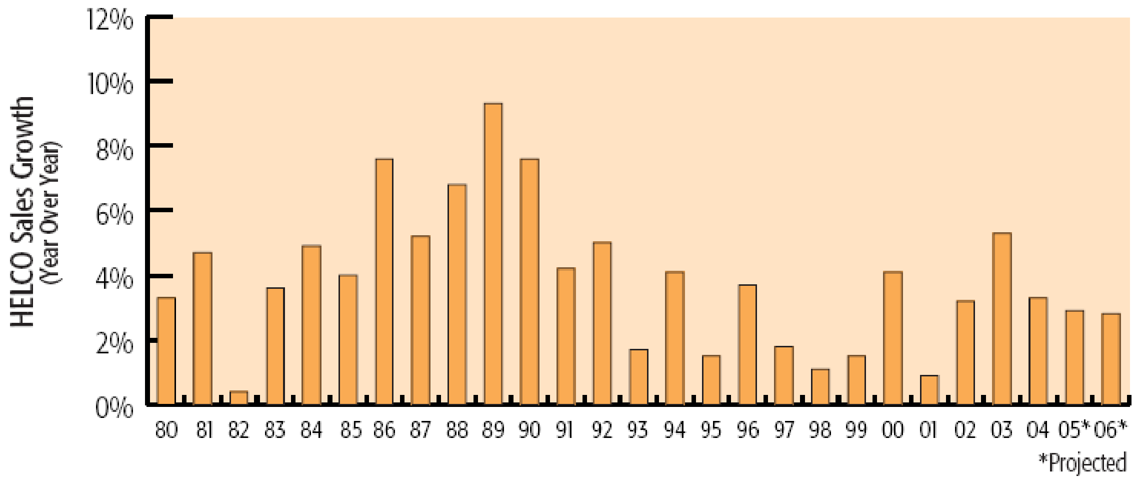


Figure 1.2: Electricity Use Tracking the Economy
Source: Economic Forecast: Big Island Edition 2005-2006, First Hawaiian Bank website, http://www.fhb.com/pdf/EconForecastBigIsle05.pdf

In most cases, the wild fluctuations closely mirror the state of the local economy: the booming late 1980's, a slowdown concurrent with the collapse of the sugar industry, the tourism slump following September 11th, and the economic rebound since. While this statement holds true in many economies, it is particularly apropos in Hawaii, where tourism plays such a big role in energy use. On top of the 167,000 Big Island residents, the island holds an average of 13,000 visitors at any given time.[7]

The local economy is booming. Visitor numbers were up 16% in 2005. There is construction everywhere, from new resorts to new homes. Between 2000 and 2004, the number of housing units on the Big Island increased by 2.3% per year. In spite of the growth in hotel supply, occupancy rates still rose from 70% to 72.2% in 2005.[8] Supporting all of this growth takes massive amounts of electricity.

Electricity demand grew by 3.2% in 2005, with much of this growth derived from the ongoing growth in new housing. For a breakdown of Hawaii County's electricity sales by sector, refer to Figure 1.3. For electricity sales by district, refer to Figure 1.4.

Total: 1,117,000,000 kWh

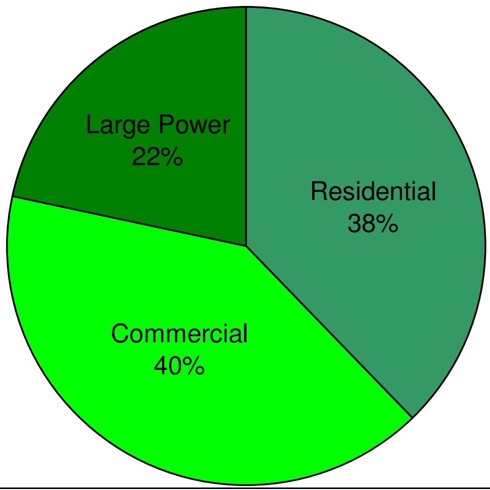


Figure 1.3 2005 Electricity Sales By Sector
Source: HELCO

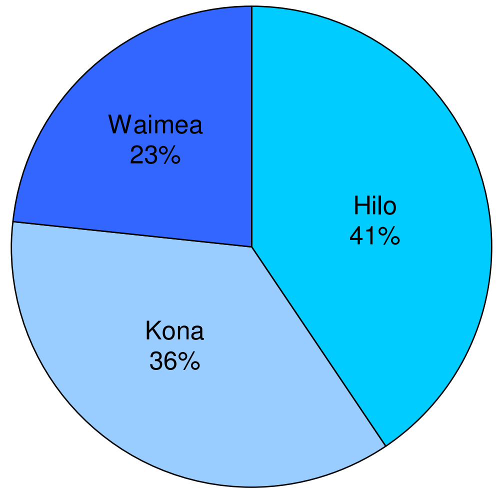


Figure 1.4 2005 Electricity Sales By District
Source: HELCO

Figure 1.5 provides a detailed breakdown of HELCO's 2005 electricity sales by demand category. In examining the sales broken down by category, one can see the major role played by housing and hotels on the island.

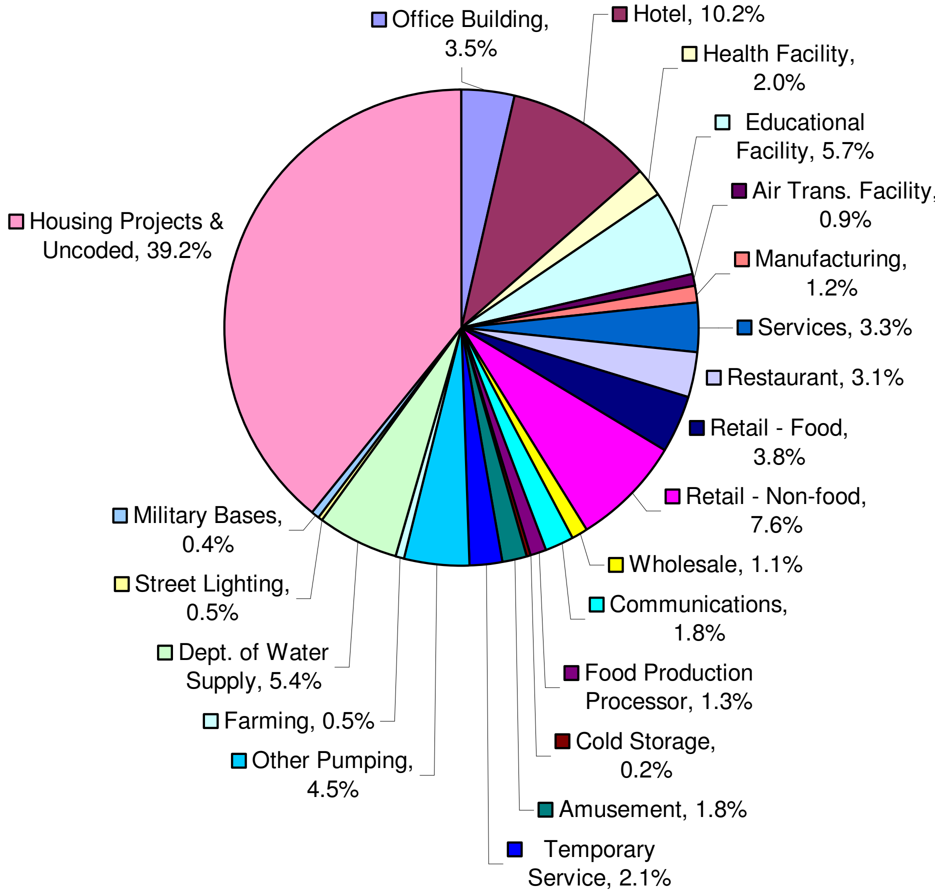


Figure 1.5: Big Island Sales by Category, 2005
Total: 1,117,000,000 kWh
Source: HELCO

Liquid Fuels - Transportation

Note that liquid fuel numbers in this section include only that used for transportation – fuels used in electricity generation are discussed in the supply section (Section 2). Table 1.3 depicts Hawaii's liquid fuel use, broken down by fuel type and category. Under the diesel and liquefied petroleum gas (LPG) categories, the "highway" numbers refer to normal automobile use while the "off highway" numbers refer to non-highway vehicles such as heavy trucks, farming and construction vehicles, etc.

Table 1.3: Hawaii County Transportation Fuel Use, 2005
Source: Hawaii Department of Taxation

Fuel Type	Use (gallons)	% of Total Use
Gasoline	74,148,000	60%
Diesel Oil	20,810,000	17%
Off Highway	9,249,000	
Highway	11,535,000	
Small Boats (diesel oil)	28,000	
Liquid Petroleum Gas	17,200	0%
Off Highway	6,350	
Highway	10,850	
Aviation fuel	27,610,000	23%
Totals	**122,587,000**	**100%**

The principle liquid fuels used for transportation on the Big Island are gasoline, diesel oil, and aviation fuel. Figure 1.6 shows the annual consumption of each on the Big Island between 1980 and 2005.

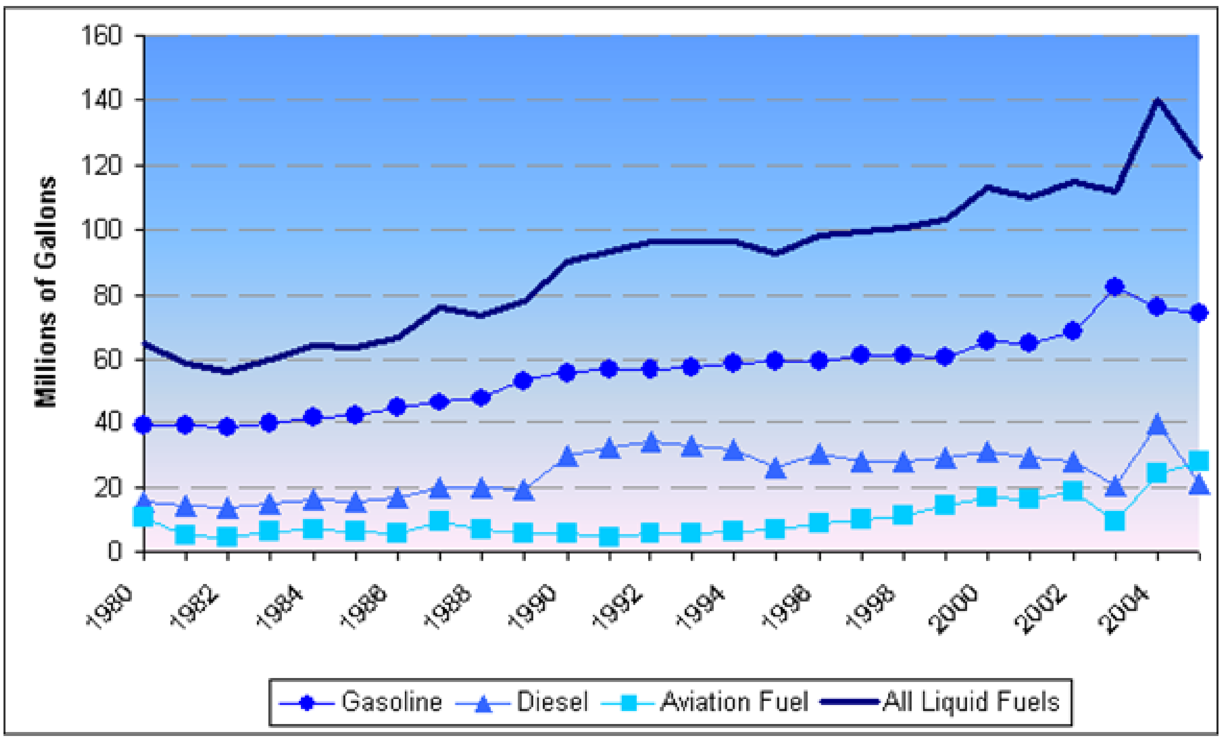


Figure 1.6: Liquid Fuel Use, 1980-2005
Source: Hawaii Dept of Taxation

Gasoline use rose steadily from 1980 to 2003 at a compound annual growth rate (CAGR) of 3.3%, but declined by 7.4% in 2004 and by 2.7% in 2005 as a result of rising prices. The spike in 2003 was likely a product of increased tourism and economic growth after a period of relative stagnancy brought on by the September 11, 2001 terrorist attacks. Aviation fuel use has grown even more rapidly, at a CAGR of 3.9% between 1980 and 2005, with a decline of almost 50% in 2003 as tourism slumped early in the year.

Diesel oil shows the most intriguing rates of change. Demand grew at a CAGR of 2.7% from 1980 to 2002, in spite of the post-sugar cane years of 1996-2002, where usage rates remained steady at 30 million barrels. Since 2002, usage rates have been very volatile, dropping by 27% in 2003, then increasing by nearly 100% in 2004, before dropping by almost 50% in 2005. Highway use, which refers to diesel cars and pickups, maintained steady growth in this period. Most of the variation, particularly in the last 3 years, can be explained by off highway numbers, which indicates changing usage rates of construction equipment, heavy trucks, etc. In addition, we posit that the nearly 50% decline in 2005 may have something to do with the recently enacted wholesale price caps (discussed in section 4.1.2) which caps gasoline prices but does not regulate diesel prices.[9] It is unclear at this point, if these dramatic fluctuations are representative of demand changes or tax accounting changes.

Aviation

The aviation fuel use of 28 million gallons, which accounted for about 23% of total liquid fuel use in 2005, covers only fuel purchased at Hawaii County airports. It is worth noting that much of the fuel consumed in flights to and from the island is purchased off-island.

Air transportation is of critical importance to Hawaii. Overseas air transportation brings millions of tourists to the state each year. Similarly, air transportation is the only passenger connection between the islands, with residents and tourists alike relying on the air system much as mainlanders use highways. Unfortunately, short inter-island flights are inherently less efficient than longer ones, since they must make the same high fuel expenditures for acceleration and takeoff without the balancing effect of longer cruising times. Obviously, this results in lower fuel efficiency rates; on a per capita basis, only Alaska uses more jet fuel than Hawaii.[10]

Thus, in the effort to reduce Hawaii's petroleum dependence, airline efficiency gains may be just as important as those in ground transportation. Still, the ENERGY 2020 model, used in the Hawaii Energy Strategy 2000, predicts aircraft efficiency improvements to be offset by increased passenger traffic, resulting in more or less steady demand from now until 2020. Specifically, aviation fuel demand in 2020 is predicted to be 1% below 1990 levels.[11]

Ground

Of the transportation fuel purchased on the Big Island, 77% by volume is consumed for ground transportation. The total size of the island's registered motor vehicle fleet, excluding trailers and semi-trailers, grew from 111,532 in 1994 to 159,627 in 2004, a CAGR of 3.65%. Table 1.4 details the state and county breakdown of registered vehicles.

Table 1.4: Registered Vehicles in Hawaii County, by Type of Vehicle, 2004
Source: Hawaii State Dept of Transportation, Motor Vehicle Safety Office

Type of vehicle	Hawaii County	% of Total
Motor vehicles	159,627	95%
Passenger vehicles 1/	124,632	78%
Ambulances	9	0%
Buses	281	0%
Trucks 1/	31,079	19%
Truck tractors	142	0%
Truck cranes	58	0%
Motorcycles, motorscooters 2/	3,426	2%
Trailers and semi-trailers	8,602	5%
Total 3/	**168,229**	**100%**

1/ Vans, pickups, and other trucks under 6,500 lb. in personal use legally classified as passenger vehicles, are included in the totals for trucks.
2/ Excluding mopeds (1.5 HP or less), which are legally classified as bicycles.
3/ Taxable and exempt vehicles includes vehicles registered but subsequently scrapped or shipped out of State

Public Transportation

Due to the island's relatively small population and large land area there is a restricted capacity for public transportation. As of 2003, the mass transit system consisted of a limited bus line, run by the county government, known as the Hele-On bus, as well as a shared-ride taxi service. There are a total of 39 buses and vans in the county fleet.[12] Transportation between the major population centers is extremely limited, with very few buses traveling between Hilo and Kona each day.

Due to a change in county data reporting requirements, there are no readily available public statistics regarding public transit usage since 2002. Data from 1996-2002 show a trend towards increasing ridership, as displayed in Table 1.5. However, growth was considerably slower during 2000-2002 than in earlier years, and the total of 320,309 trips means less than 2 trips per year per resident. The recent increase in hotel employee transport may explain this slowing growth, as hotels on the western side of the island transport their employees from the eastern population center around Hilo. The county buses recently stopped charging for service, but it is not clear whether or not this shift has had a noticeable effect on ridership.

Table 1.5: Hawaii County Public Transportation Use, Fiscal Year 1996 – 2002
Source: Hawaii County Reports

	1996	1997	1998	1999	2000	2001	2002
Total passenger trips	239,377	266,055	277,002	301,759	310,812	318,542	320,309
% annual growth	*10%*	*11%*	*4%*	*9%*	*3%*	*2%*	*1%*

Boat Use

Outside of shipping, for which fuel use is not well-documented, boat use accounts for an insignificant percentage of Hawaii County's fuel consumption. Currently, there is no commercial inter-island water transportation in Hawaii. All tourists and business travelers must travel by plane, resulting in the high levels of jet fuel consumption described earlier.

Starting in 2009, Hawaii Superferry plans to operate a daily trip from Honolulu to Kawaihae on the Big Island. The 353-foot catamarans each have a planned capacity of up to 866 people and 282 cars,[13] but it is as yet unclear how the ferries' commencement will influence the aggregate fuel used in inter-island transport. According to Hawaii Superferry CEO John Garibaldi, "Our ferries, because of the short inter-island distances, use just 1/10th of the fuel per passenger or pound compared to flying."[14]

1.4. Key Determinants of Energy Demand Management Options

Load Curves

The highest recorded load in 2005 on the Big Island electricity grid was 196 MW, a peak that occurred at 6:45pm on December 19th (see Figure 1.7). Throughout the year, the daily load consistently peaks 45 minutes after sunset.[15] This coincides with when the majority of island residents are home from work using their appliances and lights. Therefore, the load curve of the island is driven by residential demand. It is interesting to note that a high correlation exists between televised National Football League games and peak electricity demand.[16]

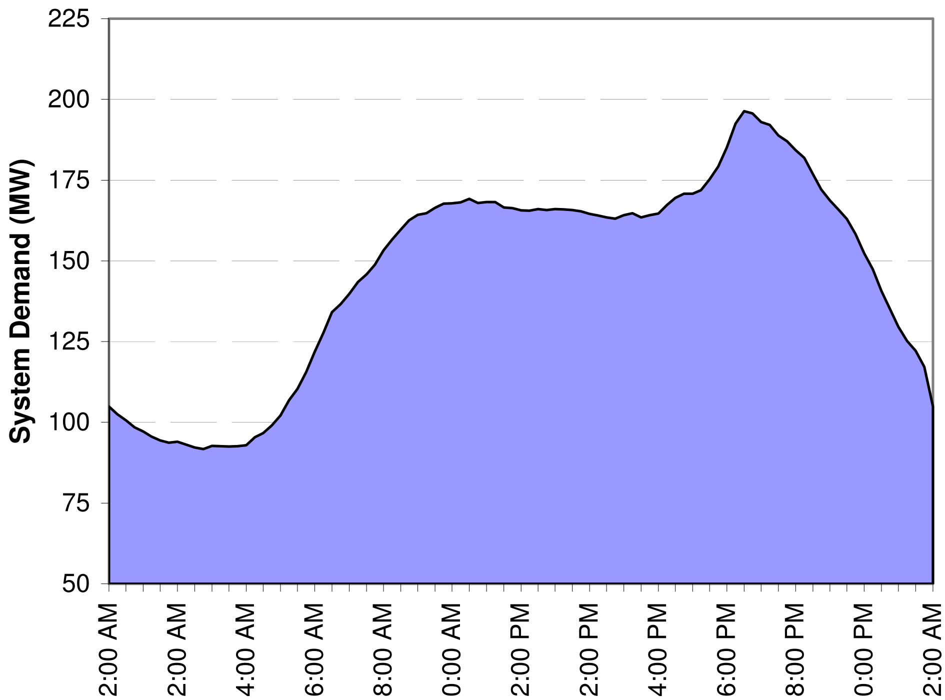


Figure 1.7: Daily Load Curve for Hawaii County
December 19, 2005 – Highest Daily Peak
Source: HELCO

In 2005, the lowest daily peak load was 174 MW, occurring on June 13th at 7:30pm (see Figure 1.8). The difference between the highest and lowest daily peaks in 2005 was only 23 MW. The relatively consistent demand for electricity over the year is largely a factor of the constant climate and number of daylight hours Hawaii enjoys due to its geographic location. Figure 1.9 tracks the daily peaks over the year and illustrates that while there is seasonal variation, it is not as pronounced as it would be in more variable climates.

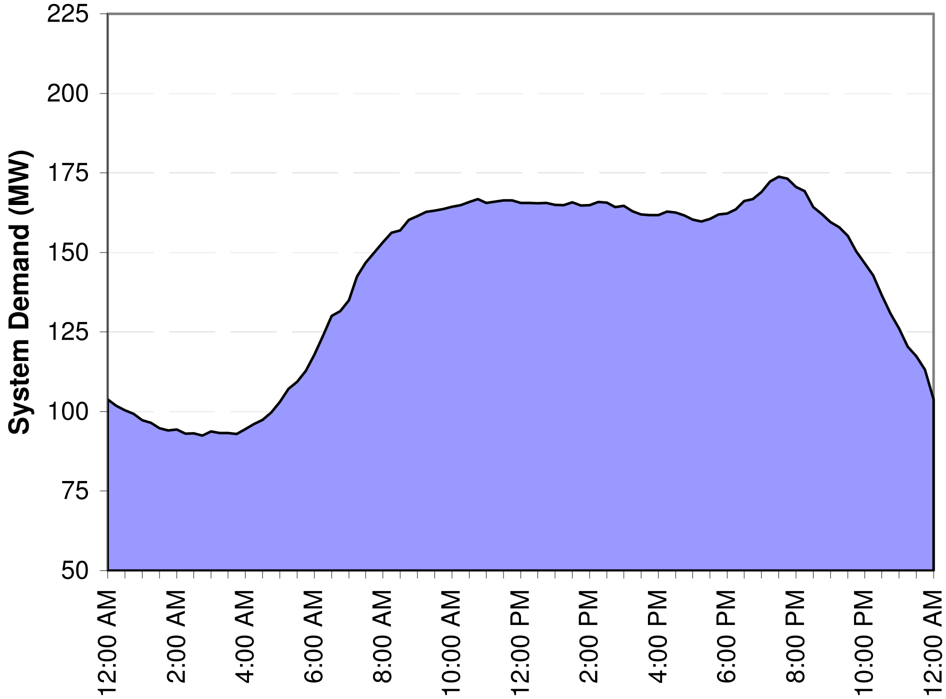


Figure 1.8: Daily Load Curve for Hawaii County
June 13 2005 – Lowest Daily Peak
Source: HELCO

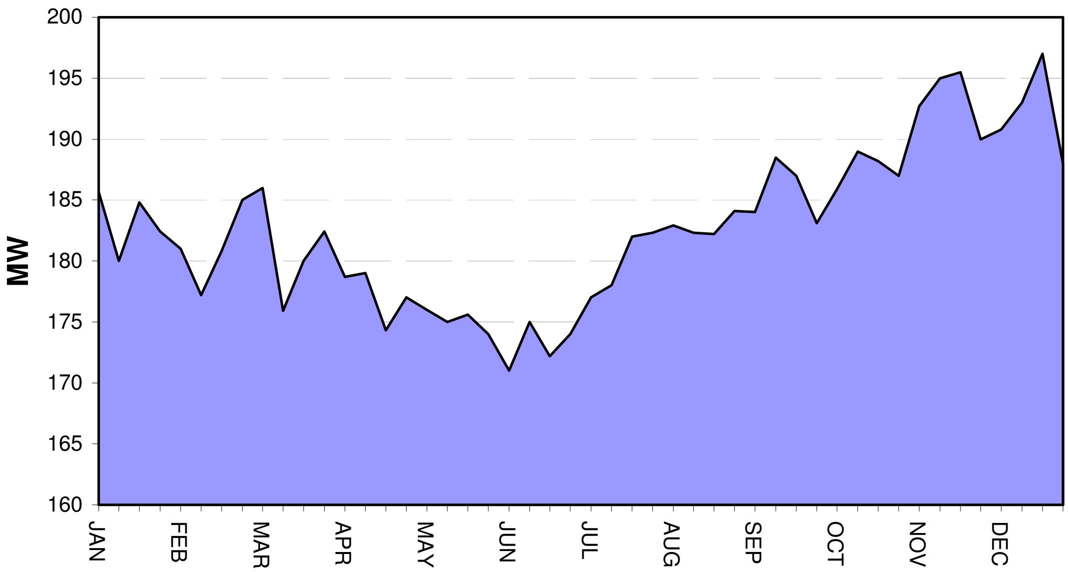


Figure 1.9: Daily Peak Electricity Demand Over 2005
Source: HELCO

Utility operators use annual load duration curves to understand and manage the variability in their system load. The data required to construct a complete 8,760-hour load duration curve for the HELCO grid is confidential. Figure 1.10 illustrates a 48-hour duration curve compiled from the two publicly available load curves shown in Figure 1.7 and Figure 1.8. Considering the low variation in the daily load and the fact that the source data captures the highest and lowest daily peak, the shape portrayed in this "snapshot" is representative of what an annual duration curve might look like.

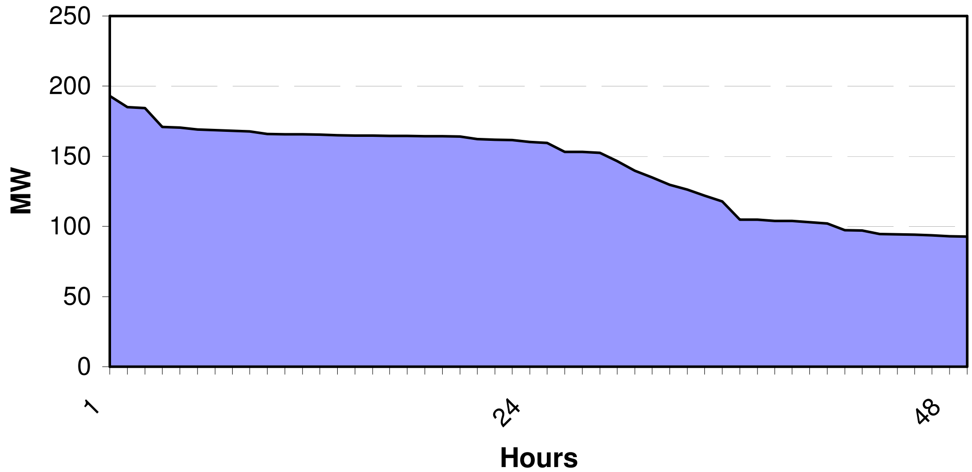


Figure 1.10: 48-Hour Load Duration Curve Compiled from Data on December 19th and June 16th, 2005

Source: HELCO

Electricity Rates

The State of Hawaii has the highest electricity rates in the nation.[17] On average, residential customers pay 23 cents per kWh.[18] This is 130% higher than the national residential average of 10 cents per kWh.[19] The average rate for electricity on the Big Island, 28 cents per kWh, is even higher.[20]

Per capita residential consumption of electricity on The Big Island, 2,500 kWh/yr, is significantly less than the national average, 4,300 kWh/yr.[21] In fact on the Big Island, total per capita electricity consumption across all sectors is almost half of the total per capita consumption in the nation as a whole (Figure 1.11).

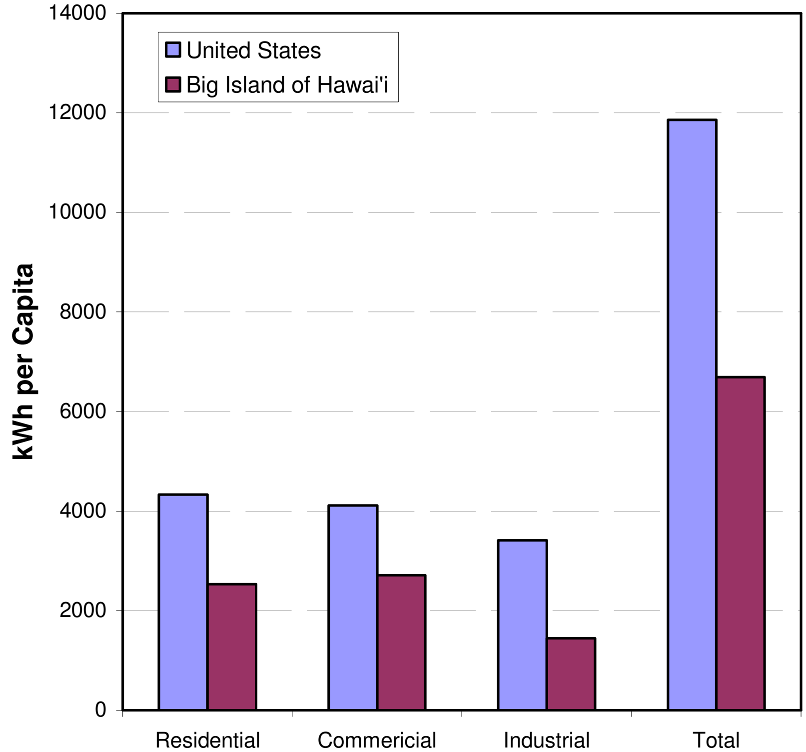


Figure 1.11: Per Capita Electricity Sales by Sector:
Hawaii County vs. the USA Average
Source: EIA and HELCO

It is difficult to say whether the high retail price of electricity contributes to the relatively low per capita consumption given that there are many other competing factors such as climate, daylight hours, income, etc. We do know that in the short run the residential demand for electricity is relatively inelastic in the State of Hawaii (see Figure 1.12). However, this is typical of most of the United States.

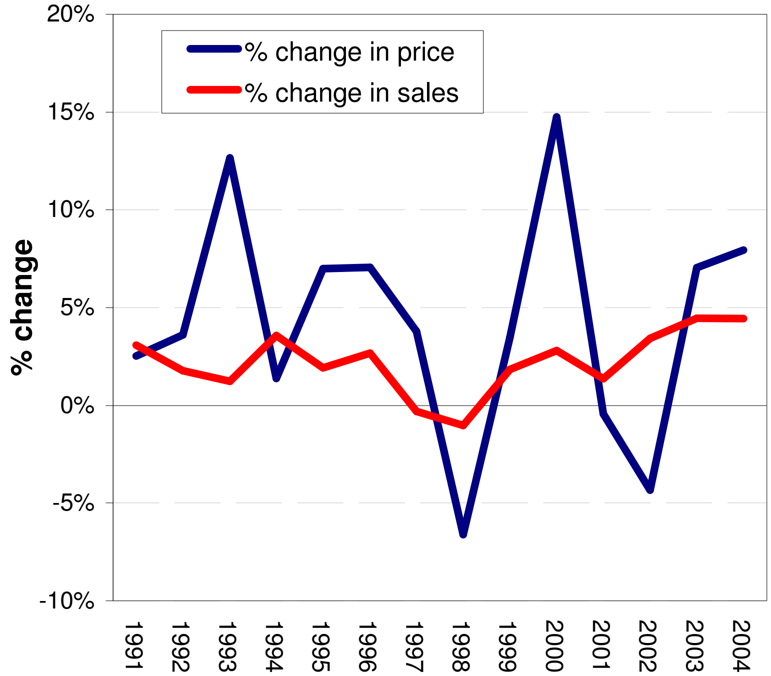


Figure 1.12: Inelastic Demand for Electricity in Hawaii Since 1990
Source: EIA database 861

The demand for electricity in the industrial and commercial sectors displays a flatter load curve than that of the residential load. Figure 1.13 illustrates a daily load curve for an aggregate of five commercial/industrial (i.e., rate P accounts) load curves on December 17th, 2001. Notice that this load curve is significantly flatter than the total system peak load curves shown earlier. Commercial and industrial accounts present an opportunity for HELCO to flatten the entire Island's load curve by implementing time-of-use planning which shifts their peak demand for electricity to times when the island-wide load is at its lowest, typically in the middle of the night. To date, HELCO has successfully brokered a deal with the Department of Water Supply to adjust their pumping schedule to help flatten the island-wide load curve. This has had a measurable effect, as the Department of Water Supply accounted for 5% of HELCO's sales in 2005.[22]

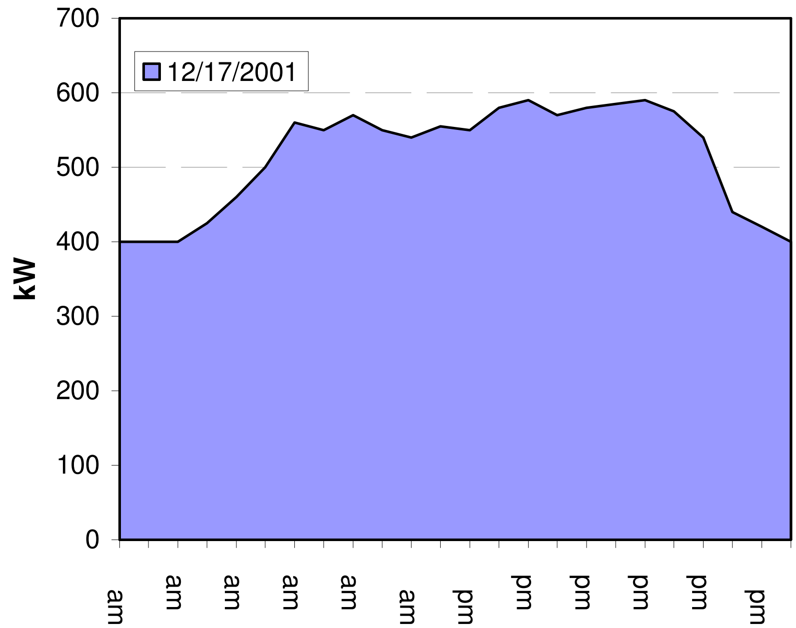


Figure 1.13: Aggregate Demand for Five HELCO Rate P Accounts

Source: HELCO

Housing Stock and Air Conditioning

On the east side of the island, the highest residential demand for energy is water heating and on the west side, it is air conditioning.[23] The presence of air conditioning as a driver of residential demand is a new phenomenon – not long ago water heating was the largest energy demand on the west side.[24] Anecdotal evidence suggests that new buildings are largely responsible for the increase in the air conditioning load. The common perception is that wealthy newcomers to the island build large homes that require significant air conditioning. Much of the housing boom has occurred in lava fields on the west side of the island where it is very hot. The vernacular architecture of Hawaii takes advantage of passive cooling by orientating the house in line with the trade winds and having semi-open facades. New home construction typically disregards this traditional style and opts for standard designs found on the mainland. Residential buildings in Hawaii County are exempt from energy efficiency requirements in the local building codes.[25]

Future research should focus on quantifying the use of air conditioning, the growth in this end-use demand, and opportunities to offset the demand with alternative air conditioning systems such as direct solar air conditioning and ocean water cooling. In addition, a detailed analysis of the thermal characteristics of the current housing stock must be conducted to identify opportunities for demand side management options at the residential level.

1.5. Development of Demand "Trend Scenario"

Historical data were used to create four scenarios of future demand for energy on the Big Island out to the year 2020. The scenarios are business as usual (BAU), two times BAU, no growth, and negative growth (same magnitude but opposite sign as BAU). For the purpose of these trend extrapolations final energy demand is divided into electricity and liquid fuels, which encompass the large majority of final energy. While demand for these two forms of energy is not completely de-coupled, the creation of separate scenarios portrays a more refined projection of the future. The growth rate for both of the BAU projections was calculated using a CAGR derived from the available historical data. Figure 1.14 displays the results of the trend extrapolations and scenario projections for electricity sales. Historic electricity sales are estimated from data on historic electricity generation by taking out an 8.3% line loss factor, which is the documented difference in generation and sales for HELCO in 2005.[26] It is likely that generation losses were greater in the past, assuming there have been improvements in transmission technology in the last 35 years. If the exact sales numbers were available, future scenario projections would be slightly higher due to the steeper slope of demand over time. In the case of liquid fuels, the growth rate used for the BAU projection is half as great, 2.5%, as that of electricity end-use, 5% (Figure 1.15).

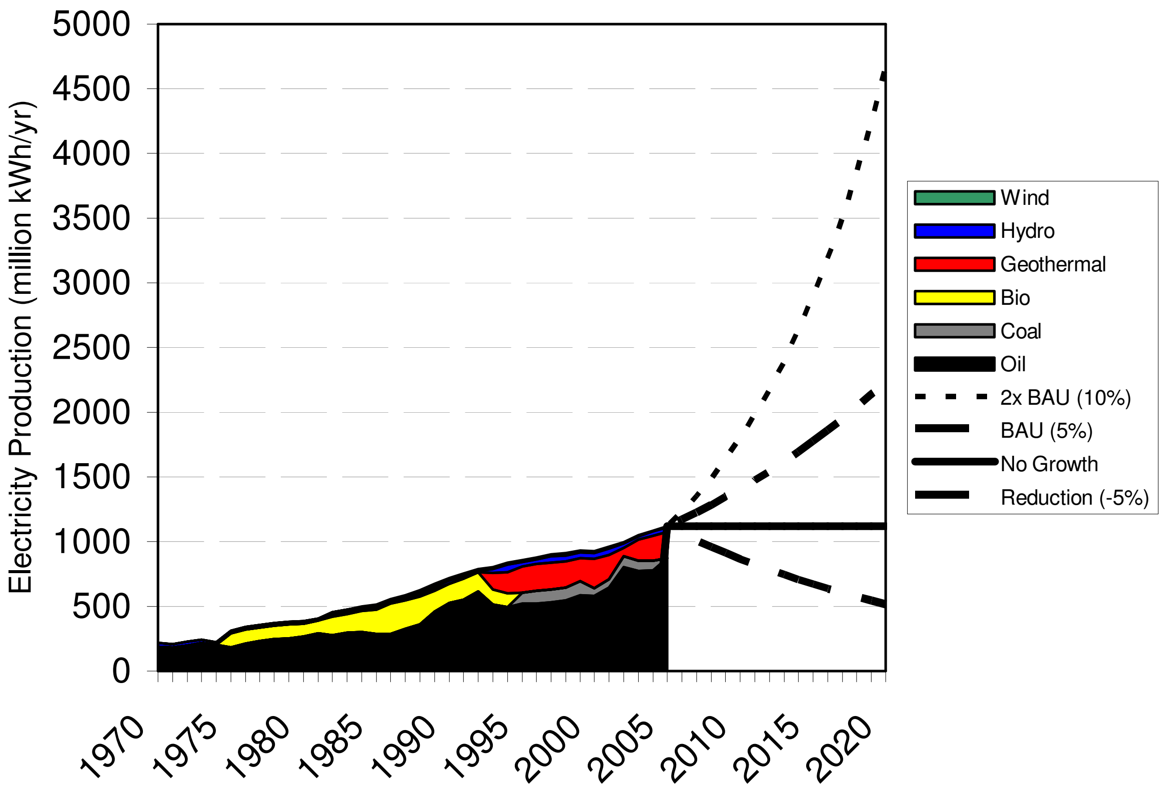


Figure 1.14: Electricity Demand Trend Scenarios to the Year 2020
Source: HELCO, EIA, PGV

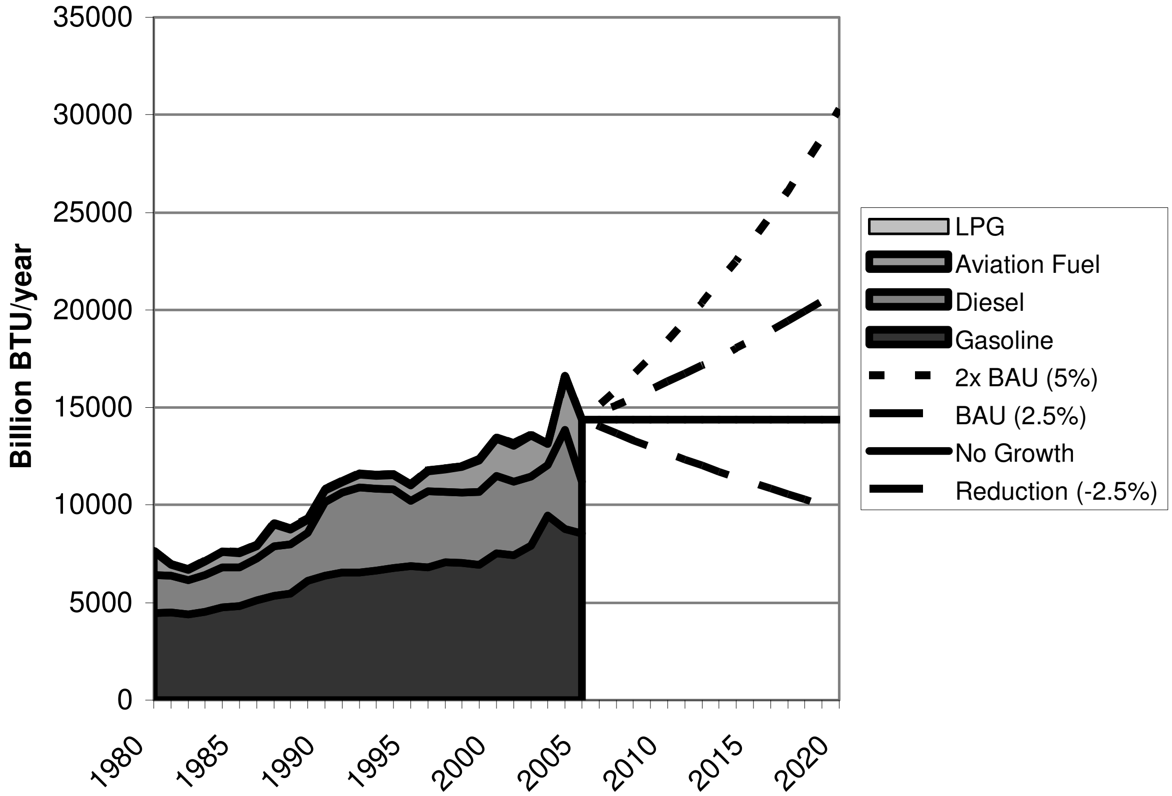


Figure 1.15: Liquid Fuels Demand Trend Scenarios to the Year 2020

Source: Hawaii Department of Taxation

2. Energy Supply and Generating Capacity

As described in the previous section, residents' and businesses' demand for energy determine the overall amount of energy that utilities and other providers must generate and distribute on the Big Island. It also governs the timing with which energy must be provided, and, to some extent, the form it must take (e.g., electricity vs. transportation fuels). Yet these considerations say little about what kind of fuels and infrastructure are actually used to produce this energy. In this section we will examine the island's energy supply system. Since all liquid fuels are currently refined off-island, our focus will be predominantly on electricity. We will first review the historical and current characteristics of Hawaii's fuel sources and electricity generation capital stock. Following that, we examine the environmental impacts of the island's energy use, and we conclude with a review and analysis of several existing scenarios for the Island's energy supply for the near future.

2.1 Evolution of Primary and Secondary Energy Supply

Hawaii is heavily dependant on imported petroleum-based fossil fuels. In 2005, 78% of electrical generation came from petroleum-based fuels. The island does, however, have a considerable amount of activity in renewable energy. The largest contributor is geothermal energy, coming from the Puna Geothermal Venture (PGV) plant. Table 2.1 lists sources of electricity for the year 2005.

Table 2.1: Hawaii County Electricity Production by Fuel Type, 2005

Source: HELCO

Source	1000 kWh/yr	% of total
Petroleum-based	950,500	78.0%
Diesel	192,500	
Residual fuel oil	326,600	
Naptha	431,400	
Geothermal	220,600	18.1%
Hydropower	39,800	3.3%
Wind	6,700	0.5%
Solar PV	930	0.1%
Total	**1,219,000**	**100.0%**

Although oil-based fuels have been the dominant source of electrical generation for decades, the portfolio has changed considerably over time. Figure 2.1 shows this evolution broken down by fuel type.

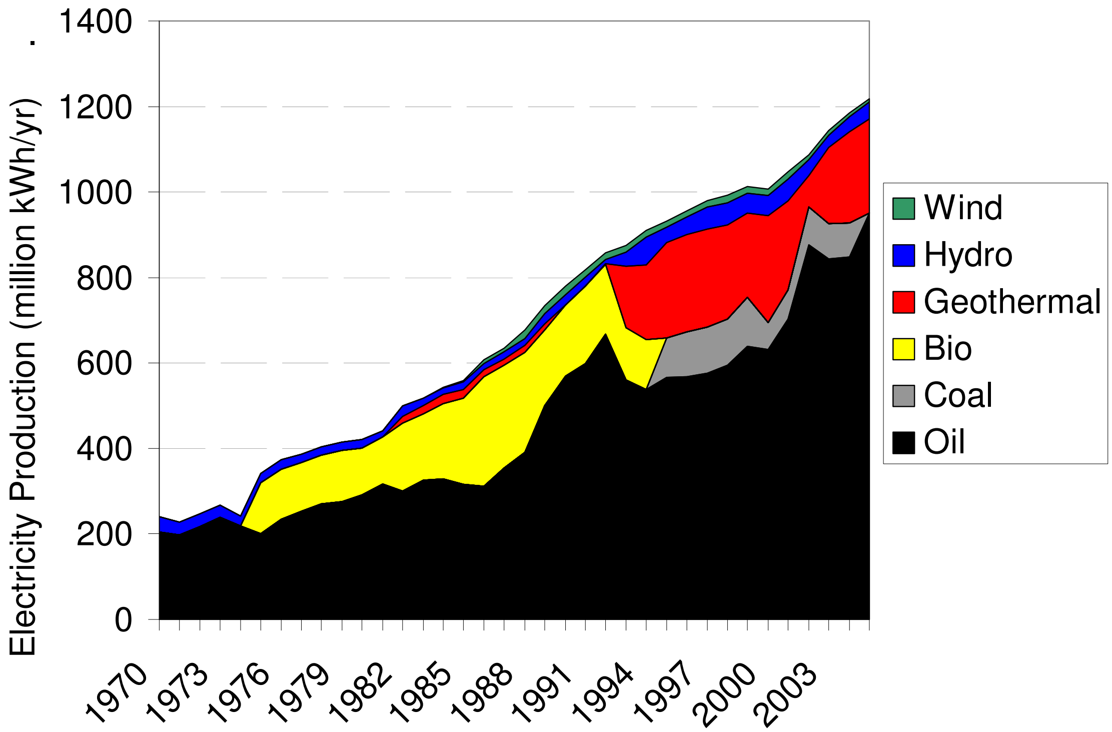


Figure 2.1: Electrical Generation on Hawaii Island by Fuel Type, 1970-2005
Sources: EIA database, HELCO, PGV

Over the thirty-five years evaluated in Figure 2.1, the CAGR in electricity production was 4.8%. During the 1970s and 1980s, the Pepeekeo plant utilized bagasse, a waste material from sugar cane processing. In 1994, following the collapse of the sugar industry, this facility began using imported coal as its fuel source. In 2004, these operations ceased and the plant was taken offline. The geothermal pilot plant in the Kilauea East Rift Zone (KERZ) accounts for the small blip in geothermal electricity production throughout the 1980s. The commencement of commercial operations at PGV in 1993 precipitated the major increase in geothermal electricity production. A large dip in geothermal output in 2002 was counteracted by increasing oil-based generation. Hydropower and wind power make up a small portion of the overall generation.

PV solar power, which is not shown in this diagram, is difficult to quantify with a high degree of certainty. There are several notable examples on the island, namely the Mauna Lani Bay Hotel with 674 kW of total capacity and Parker Ranch with 211 kW of total capacity. PV generation is discussed further in Section 3.2.4.

Figure 2.2 shows the evolution of the share of electricity generated from renewable sources. Several notable events are marked on this timeline. Biomass combustion and geothermal electrical production had the largest positive effects on the share of renewable generation. The biggest negative effects came from decreased geothermal production due to a temporarily blocked well at PGV and from the transition to coal from biomass at Hilo Coast Power following the collapse of the sugar industry, which had supplied the bagasse.

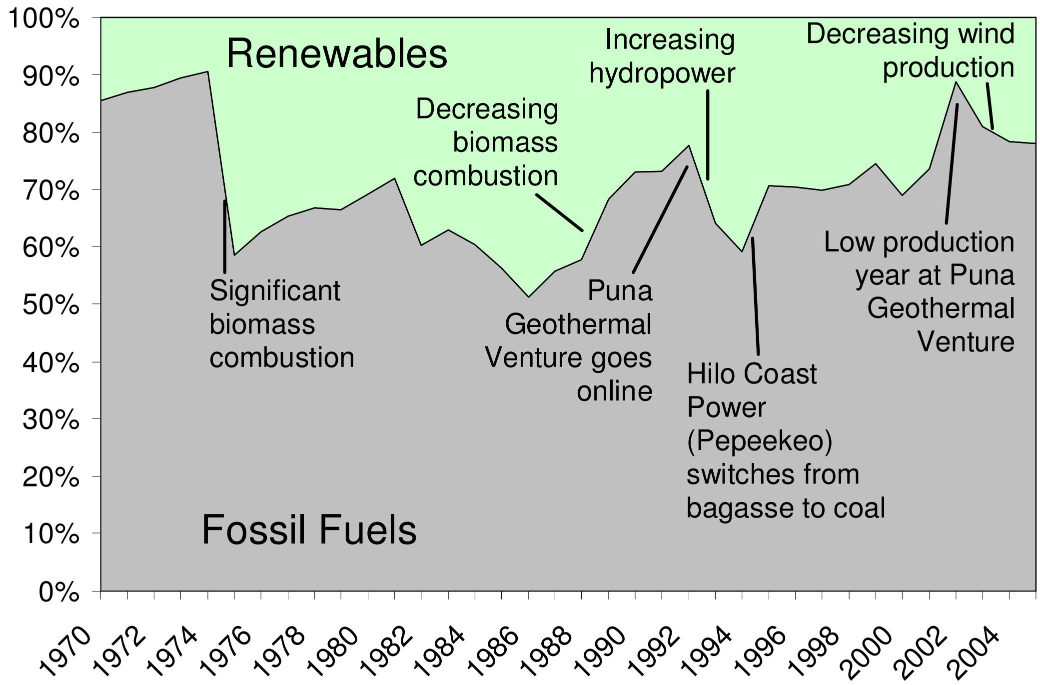


Figure 2.2: Share of Electricity Generation by Renewable and Fossil Fuels Sources, 1970-2005
Sources: EIA database, HELCO, PGV

Non-electrical fuel use is also significant. Because all transportation fuel is imported to the island, supply mirrors demand. For a detailed breakdown of liquid fuel supply, refer to Section 1.3.

Solar water heating (SWH) units have been installed in approximately 6,000 households, and are credited with displacing roughly 227 gallons of oil per year each.[27] Assuming 119,400 BTU/gal of oil and 35% generation efficiency, SWH created 57 billion BTU of final energy. This is equal to 1.5% of the electrical output in 2005.

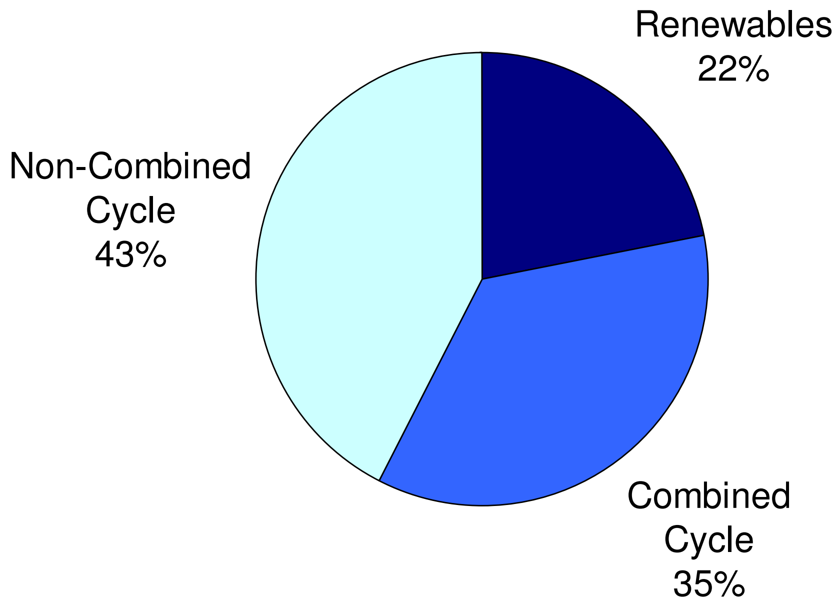


Figure 2.3: Combined Cycle Electricity Production, 2005

The use of combined cycle electricity production improves efficiency and reduces fuel consumption. Of the 1,219 million kWh of electricity produced in 2005, 35% was produced using combined cycle technology, all at the Hamakua Energy Partners naphtha plant (see Figure 2.3). The Keohole facility will be retrofitted to be combined cycle in 2009.

2.2 Evolution of Capacities and Age Structure of Capital Stock

Having discussed how the characteristics of Hawaii County's fuel mix have changed over time, we now turn our view to the evolution of the island's generation equipment. Figure 2.4 shows historical electrical generating capacity for Hawaii County. Data used to generate this figure is from the Energy Information Administration Generator Database EIA-860. Displayed are the summer and winter capacities – identical for all of these generators – spread between the in-service date and, where applicable, the retirement date.

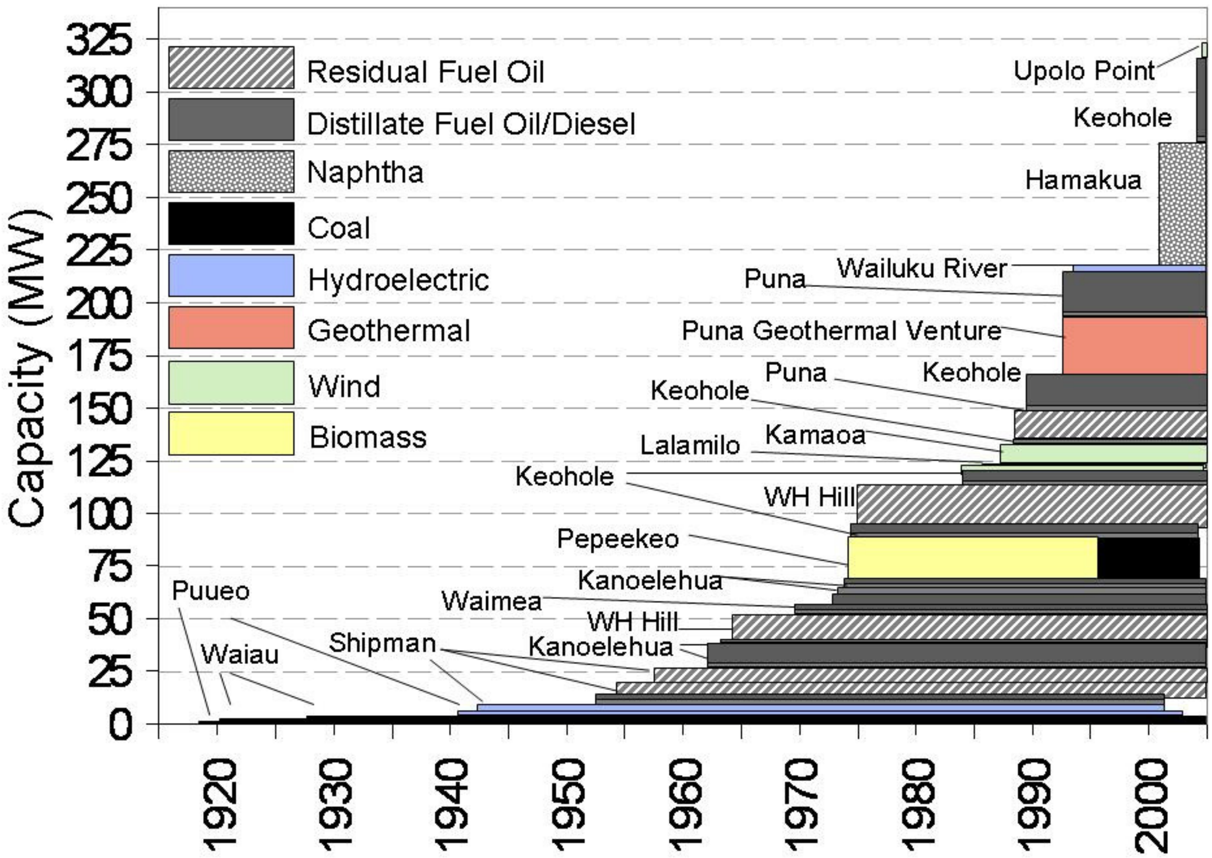


Figure 2.4: Electrical Generators in Hawaii County by Fuel Type
Data Source: EIA Generator Database

The fifty generators currently listed in the EIA-860 database have a combined capacity of approximately 325 MW. However, nine of these generators are currently retired, reducing the capacity to approximately 300 MW, including both firm and intermittent capacity. Among the retired generators is the Pepeekeo coal-fired power plant, with a capacity of 22 MW. Prior to the collapse of the Island's sugar industry, this plant ran on bio-based material. The primary sources of the currently operating generators are oil (79% of the operating capacity), geothermal (10%), wind (7%), and hydropower (4%).

More than a quarter (28%) of the Island's generators were permitted more than 30 years ago, and of these older plants, 98% are oil-fired. There was a gap in capital investment from 1976 to 1986, with only 2.5% of the current capacity built in that time frame. Between 1986 and 1996, 103 MW of capacity went online: 51% oil-fired, 30% geothermal, 10% hydro, and 9% wind. The past decade has seen similar levels of construction with the addition of 110 MW of additional capacity, all of which is oil-fired with the exception of the new Upolo Point wind farm.

The electrical transmission system has not been fully modernized to accommodate the increased level of supply. The majority of the system consists of 69 kV lines, and the long, cross-island distances between generators and customers result in considerable line losses. There is a spatial mismatch which exacerbates this problem: recent population growth, and thus electricity demand, has occurred on the west side of the island whereas the bulk of electrical generating capacity is in the east. HELCO estimates that 58% of the use occurs in the west, while 65% of the capacity is in the east. Consequently, any major capacity additions on the eastern side of the island with the intension of meeting peak-load demands on the western side would require substantial upgrades to the transmission system.[28] Since there is no inter-island transmission, the Big Island's grid must be completely self-sufficient.

There are currently no operating refineries in Hawaii County. Statewide, there are two, both located on Oahu. The Kapolei plant, owned by Tesoro, has a rated capacity of 95,000 barrels per day, producing gasoline, diesel, and aviation fuel. The second plant, owned by Chevron, supplies 60% of the state's gasoline. Both refineries were built in the 1960s. They must purchase light sweet crude oil, which costs up to $3 more per barrel than oil with higher sulfur content.[29]

2.3 Environmental Impact of Existing Energy Supply

Any method of producing energy for human use will create detrimental environmental impacts, and Hawaii County is no exception. The island's heavy reliance on fossil fuels raises a number of environmental concerns, mostly through the emission of airborne pollutants such as nitrogen oxides (NO_x), which contribute to smog and also have negative health effects; sulfur dioxide (SO_2), a precursor to acid rain; and carbon dioxide (CO_2), which contributes to global climate change. However, due to the island's relatively low levels of energy use (in absolute, per capita, and per area terms), these impacts are fairly modest. In this section, we describe the emissions resulting from both electricity and liquid fuel use. Other environmental concerns, such as ecological issues regarding the siting of power plants and the health effects of uncontrolled releases of steam at the geothermal plant, are addressed in Section 4.2 and 4.3.

Electricity

Estimated emissions of NO_x, SO_2, and CO_2 from each major electricity source on the island for 2005 are shown in Table 2.2. Actual electricity generation figures for the year were provided by HELCO; emissions were calculated by multiplying these numbers by the emissions factors for each respective pollutant reported in EPA's E-Grid database, which utilizes year 2000 data.

Table 2.2: Estimated Emissions from Grid-Distributed Electricity, 2005

Source: EPA E-Grid Database and HELCO.

Power Plant	Electricity (thousand kWh/yr)	NO_x (lbs/ thousand kWh)	SO_2 (lbs/ thousand kWh)	CO_2 (lbs/ thousand kWh)	NO_x (short tons)	SO_2 (short tons)	CO_2 (short tons)
Hamakua 1/	431,413	7	8	1,871	1,512	1,647	403,655
Hill	230,066	4	25	2,301	480	2,839	264,691
Kanoelehua	2,919	32	5	1,897	47	7	2,769
Keahole	157,391	22	5	1,987	1,711	407	156,421
Puna	115,367	8	16	2,260	457	925	130,369
Shipman	8,108	6	33	3,095	23	134	12,551
Waimea	5,136	35	4	1,710	90	11	4,394
PGV 2/	220,639	-	-	-	-	-	-
Puueo 3/	5,543	-	-	-	-	-	-
Waiau 3/	3,626	-	-	-	-	-	-
Wailuku 3/	29,726	-	-	-	-	-	-
Kamaoa 4/	4,841	-	-	-	-	-	-
Lalamilo 4/	1,697	-	-	-	-	-	-
Other	3,022	-	-	-	-	-	-
TOTAL	**1,219,494**	-	-	-	**4,320**	**5,970**	**974,850**

1/ CO_2 Emissions rate for this plant is 10x higher in the E-Grid database than shown here. Based on communications with utility employees this is believed to be a clerical error.
2/ Geothermal power
3/ Hydro power
4/ Wind power

The overall level of emissions is comparatively modest and well within regulatory limits. As of March 2, 2006, no county in the State of Hawaii was listed as a non-attainment area for any of the Clean Air Act's criteria pollutants. Some analyses have argued that limits on greenhouse gas emissions will be the most significant environmental constraint on energy generation sources in the coming years,[30] suggesting that conventional air pollutants are not perceived to be a major concern. Indeed, the County's General Plan notes that the island is known for its minimal air pollution, and that the clarity of the air has contributed to the worldwide prominence of the astronomical observatories located there.[31] The largest air pollution issue facing the island seems to be 'vog,' or smog caused by volcanic eruptions. During periods of sustained eruption, Kilauea emits as much as 2000 tons of SO_2 per day, dwarfing the contribution of all anthropogenic sources.[32]

Liquid Fuels

Emissions resulting from the use of liquid fuels in 2005 are estimated in Table 2.3. The emissions factors used to calculate these totals, along with the methodology and data sources used in generating these underlying rates, are found in the Appendix.

Table 2.3: Estimated Emissions from Liquid Fuels, 2005

Sources: see Appendix.

Pollutant Source	Fuel	Fuel Usage (gallons)	NO_x (short tons/yr)	SO_2 (short tons/yr)	CO_2 (short tons/yr)	CO (short tons/yr)	VOCs (short tons/yr)
Ground Vehicles	Gasoline	74,148,000	2,362	16	704,608	35,522	4,759
Ground Vehicles	Diesel	20,782,000	210	2	106,689	n.d.	34
Ground Vehicles	LPG 1/	10,900	0	0	59	0*	0*
Marine Vehicles	Diesel	28,000	1	0	250	26	6
Airplanes	Aviation Fuel	27,610,000	661	64	202,435	152	7
Direct Heating	LPG 1/	6,400	0	0	34	0*	0*
Total		**122,585,000**	**3,235**	**83**	**1,014,076**	**35,700**	**4,806**

1/ Due to data limitations, we assume that LPG is combusted completely, so that all carbon is emitted in the form of CO_2. Due to the minimal LPG usage on the island compared to other liquid fuels, any CO or VOCs emitted from LPG combustion would have an insignificant effect on the total numbers.

NO_x and CO_2 emissions from liquid fuels are comparable to emissions from electricity generation, while SO_2 emissions are substantially lower, presumably due to new EPA regulations mandating ultra-low sulfur content in transportation fuels. As noted before, the overall level of air pollution from anthropogenic sources does not appear to be a major concern currently.

2.4 Review of Energy Supply Scenarios

In this section, we briefly review some of the recently produced scenarios for the future of Hawaii's energy supply.

HELCO Integrated Resource Plan, 2006 (Preliminary)[33]

The electric utility's Integrated Resource Plan (IRP) is perhaps the most authoritative and certainly the most influential electricity supply scenario currently available. The IRP is a 20-year forward-looking supply plan used by the utility to help plan for additions to capacity, maintenance and upgrade of existing units, etc. Establishing an IRP is a multi-year process, and (as of the writing of this paper) HELCO's most recent plan had not yet been finalized. This review covers materials presented at their March 2006 advisory group meeting.

The most important change from previous versions of the IRP is a substantially revised forecast for petroleum product prices. Table 2.4 shows the Market Referenced Price Forecast along with HELCO's own price projections, both of which were used to evaluate the different scenarios.

Table 2.4: Projected Fuel Prices, in nominal $/barrel
Source: HELCO, Report to IRP Advisory Group

	Medium-Sulfur Oil ($/barrels)		Diesel Fuel ($/barrels)	
Year	HELCO	Mkt. Ref.	HELCO	Mkt. Ref.
2005	52.45	54.25	80.17	78.52
2010	48.27	59.43	74.85	85.41
2015	54.27	79.03	84.19	111.43
2020	64.89	91.03	100.47	127.45
2025	77.71	105.63	120.04	146.76

To guide the IRP process, a model was used to evaluate five different plans:

- Plan 1 – Least cost plan among all resources
- Plan 2 – Maximize renewables
- Plan 3 – Optimize distributed generation
- Plan 4 – Mix of renewable resources
- Plan 5 – Alternate timing of wind and pumped-storage hydro

Under the base case, each of the plans is modeled under an assumption of 1.6% annual growth in total annual demand and peak demand. An alternative analysis uses a higher forecast rate of 2.4% annual growth, but even this higher figure is below the ~3% growth rates the island has seen recently. This suggests that if demand continues to follow historical patterns or accelerates, HELCO may need to build or contract for more generation capacity than is currently planned under their scenarios. We have integrated HELCO's IRP supply scenario with these demand trends in order to evaluate this possibility.

The model results from HELCO's five plans are shown in Figure 2.5.

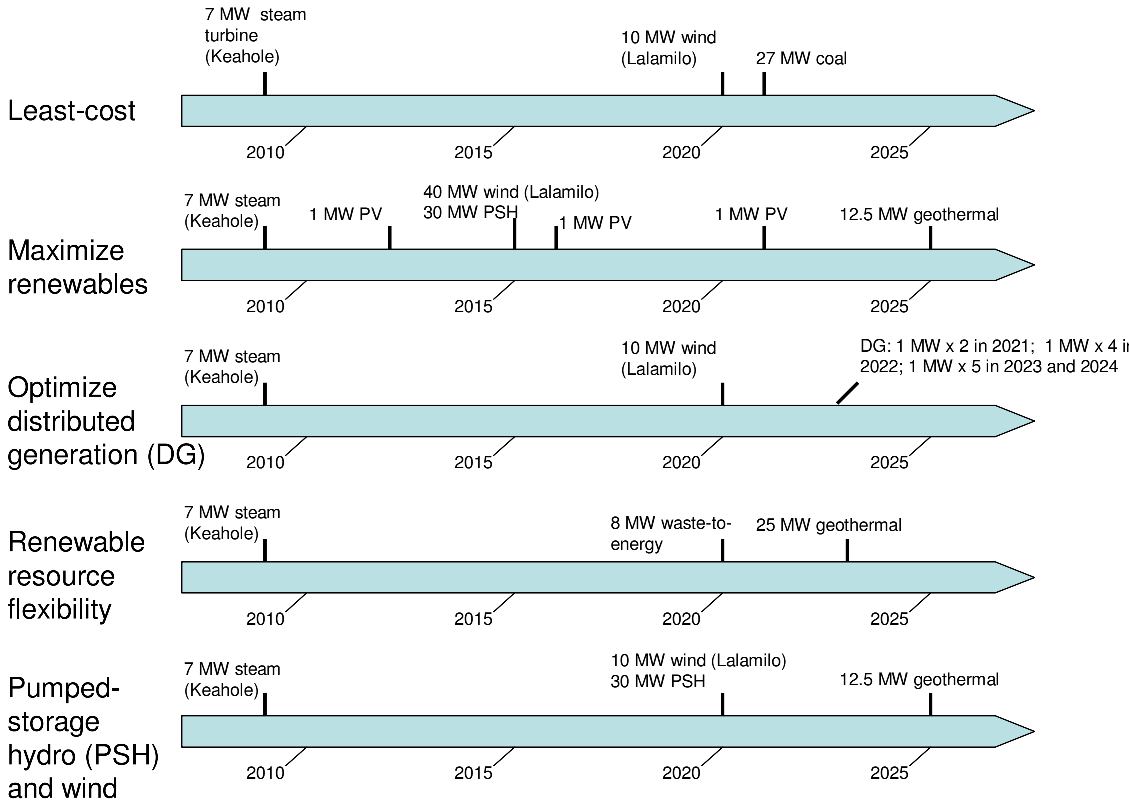


Figure 2.5: HELCO Integrated Resource Plan Scenarios

These projections were developed using HELCO's fuel price forecast. Using the Market Referenced Fuel Price Forecast produces identical results, with the exception being the fact that the beginning date for the coal unit under the least-cost plan is moved up to 2013.

There are a few details of the proposed plans worth highlighting. On a general note, the diversity of sources used in the different scenarios illustrates the flexibility the island is afforded by its relative abundance of wind, solar, and geothermal resources. Other notable features include changes since the previous iteration of the least-cost plan, brought about by the revised fuel cost estimations. Specifically, wind is now expected to become cost-competitive in the near future without relying on subsidies, prompting a substantial expansion of the existing 2.3 MW Lalamilo wind project to 10 MW. A new 27 MW coal unit is substituted for what had previously been a diesel-fired turbine. It is unclear how aggressively HELCO would actually pursue the coal plant considering the utility's recent public commitment to refrain from installing any additional fossil fuel-based capacity on the island;[34] its inclusion here may simply be an artifact of the way they have constructed their models. According to the utility, none of the existing power plants are scheduled for retirement over the 20-year window examined in this IRP; therefore, additions to capacity will need only to match increases in demand from their current levels.

Another interesting aspect of the plans concerns their comparative projected environmental impacts, some of which are rather counterintuitive. For instance, the Maximize Renewables option has significantly higher annual emissions of CO and NO_x, and slightly elevated levels of PM_{10}, when compared to the other options. CO_2 and SO_x are the only evaluated pollutants where the renewable plan shows a substantial advantage over the others. This perceived inconsistency apparently arises because the addition of intermittent renewables will necessitate more frequent dispatch of peak diesel-fired units, whose poor emissions performance more than offsets the emissions saved by the decreased use of baseload fossil units.[35] The environmental benefits of renewable energy therefore may not be as clear-cut as casual observers may believe. Thus, policymakers and other stakeholders should be clear on their objectives for increased renewable energy and consider whether their primary concerns are energy resource security, climate change, or local air standards. Prioritization of one goal over another may lead to different conclusions. The atmospheric emissions from each of the five scenarios are examined in Table 2.5.

Table 2.5: Atmospheric Emissions for Five Scenarios

Source: HELCO, Report to IRP Advisory Group

Avg. 2007-2026 (tons/yr)	Least Cost	Max Renewables	Optimize DG	Renewable Flexibility	PSH and Wind
CO_2	953,838	861,055	912,054	912,054	910,548
VOCs	148	144	148	143	147
CO	732	877	711	683	689
PM_{10}	696	715	705	691	701
NO_x	1,128	1,298	1,220	1,120	1,097
SO_x	5,150	5,014	5,273	5,168	5,274

The IRP also evaluates the annual revenue that would be required for the utility to fund the capacity changes under each of these scenarios. The Maximize Renewables plan, which involves more and larger-scale additions than any of the others, implies a need for roughly $1,058 million annually (in 2004 dollars) for the first ten years. Each of the other plans requires annual revenues of $1,031 million for the first ten years. The difference of $27 million implies a price difference of roughly two cents per kWh. The reason for this uniformity between the four non-renewable plans is that none of them call for any capacity additions prior to 2020. It is unclear why capacity needs to be added prior to 2020 in the Maximize Renewables plan, but not in the other four plans.

Combining the supply scenarios presented with various demand projections casts doubt on the reliability of the plans presented as long-term planning devices, however (Figure 2.6).

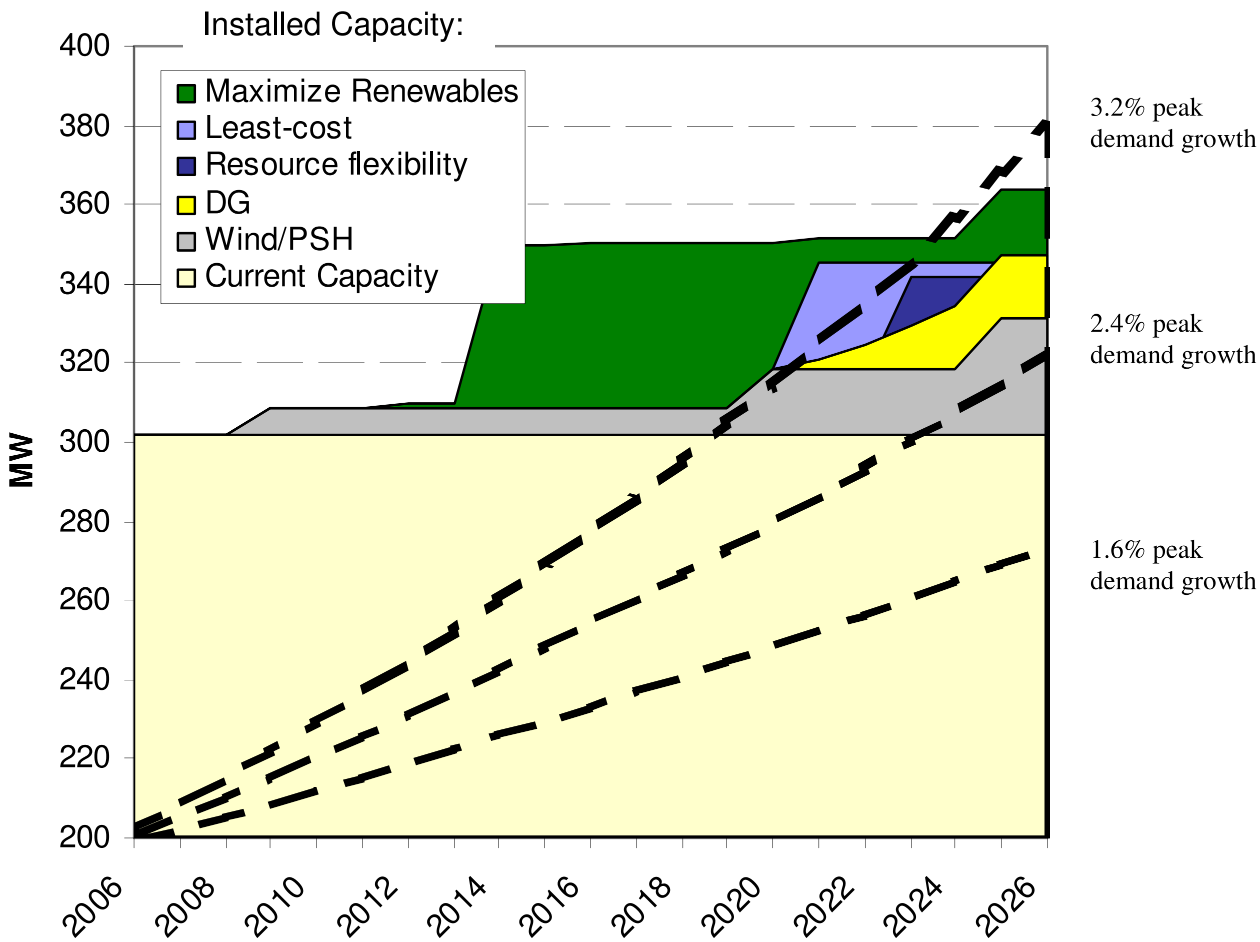


Figure 26: IRP Supply Scenarios vs. Projected Peak Demand Growth
Sources: HELCO, author calculations

The five scenarios are sufficient to meet peak demand growths rate of 1.6% or 2.4%, the figures used by HELCO in the planning process. However, none of the five plans can keep pace with a 3.2% growth rate throughout the entire 20-year planning period. Even the more modest 2.4% growth rate modeled by HELCO brings the system close to serious problems. For example, under the wind/PSH scenario, 2.4% peak demand growth would result in a scant reserve margin of less than 10 MW in 2026, or about 3% of the system's generating capacity (15% or greater is typically considered reliable). The inadequate level of capacity may, in fact, be due to the nature of IRP process, which does not include planned purchased production from independent sources.

In addition to the supply scenarios described above, HELCO has also developed a forecast of peak load reductions to be achieved through demand-side management (DSM) efforts and through use of combined heat and power (CHP). Such programs will undoubtedly help to bridge the projected gap between supply and demand, but even assuming they were as successful as the utility predicts, not all of the scenarios would be sufficient to meet the highest growth rate modeled, as shown in Figure 2.7. In sum, then, if observed trends in energy demand continue for the near future, HELCO's proposed capacity additions will be insufficient without additional capacity provided by IPPs. If any unexpected repairs would be needed – a likely prospect, given the age of much of the capital stock in use – such problems would be exacerbated even further.

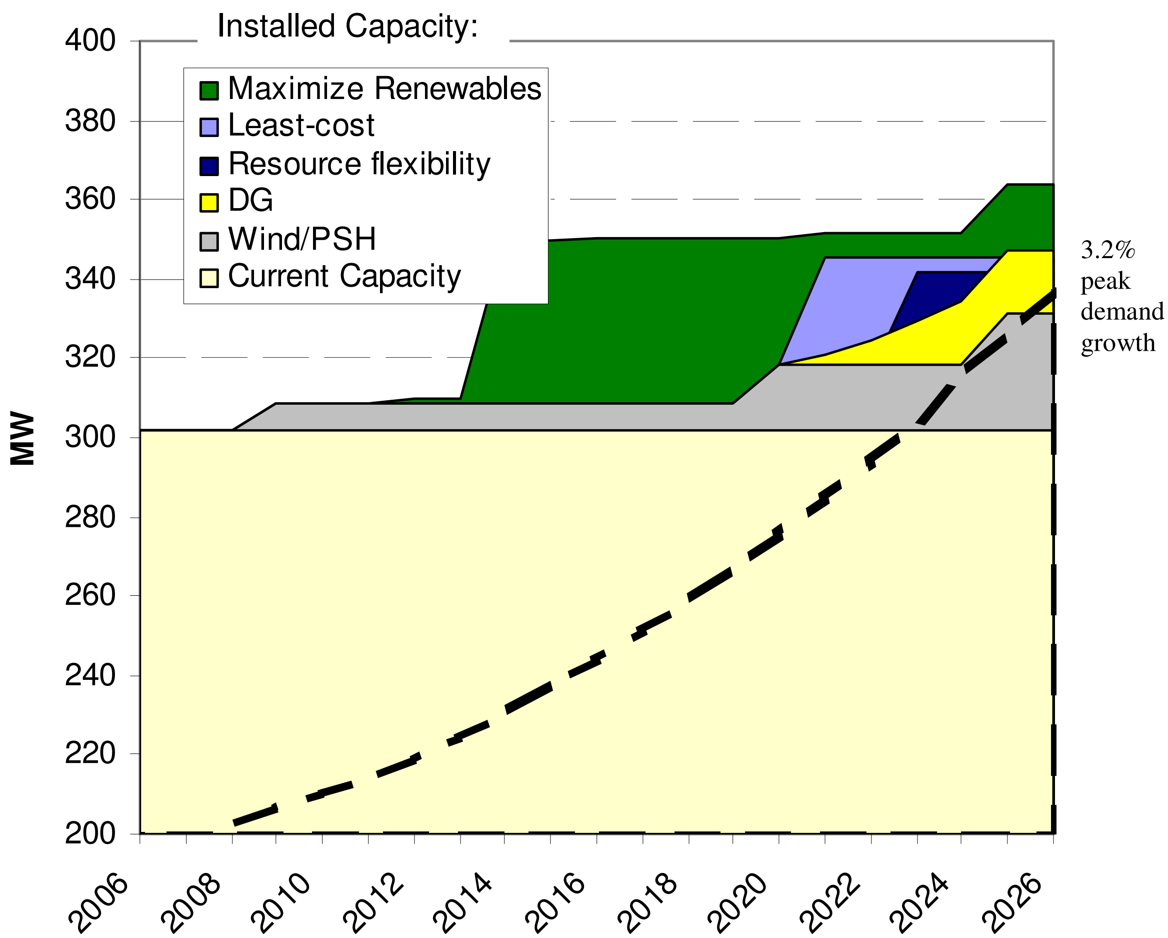


Figure 2.7: IRP Supply Scenarios vs. Projected Peak Demand Growth with DSM and CHP
Sources: HELCO, author calculations

Hawaii Energy Strategy 2000

The Hawaii Energy Strategy 2000,[36] completed in 2000 by the Energy, Resources, and Technology division of the DBEDT, was written as a guide for policymakers and other stakeholders to provide better insight into the state's energy system and to develop and analyze several future scenarios. It was intended to help support achievement of the State Energy Objectives. To that end, it was written with a number of specific policy goals in mind:

- Increase diversification of fuels and their sources of supply
- Increase energy efficiency and conservation
- Develop plans for regulated and unregulated energy development at least cost
- Enhance system of energy policy analysis
- Increase use of indigenous renewables
- Enhance contingency planning capabilities to allow effective future coping with supply disruptions.

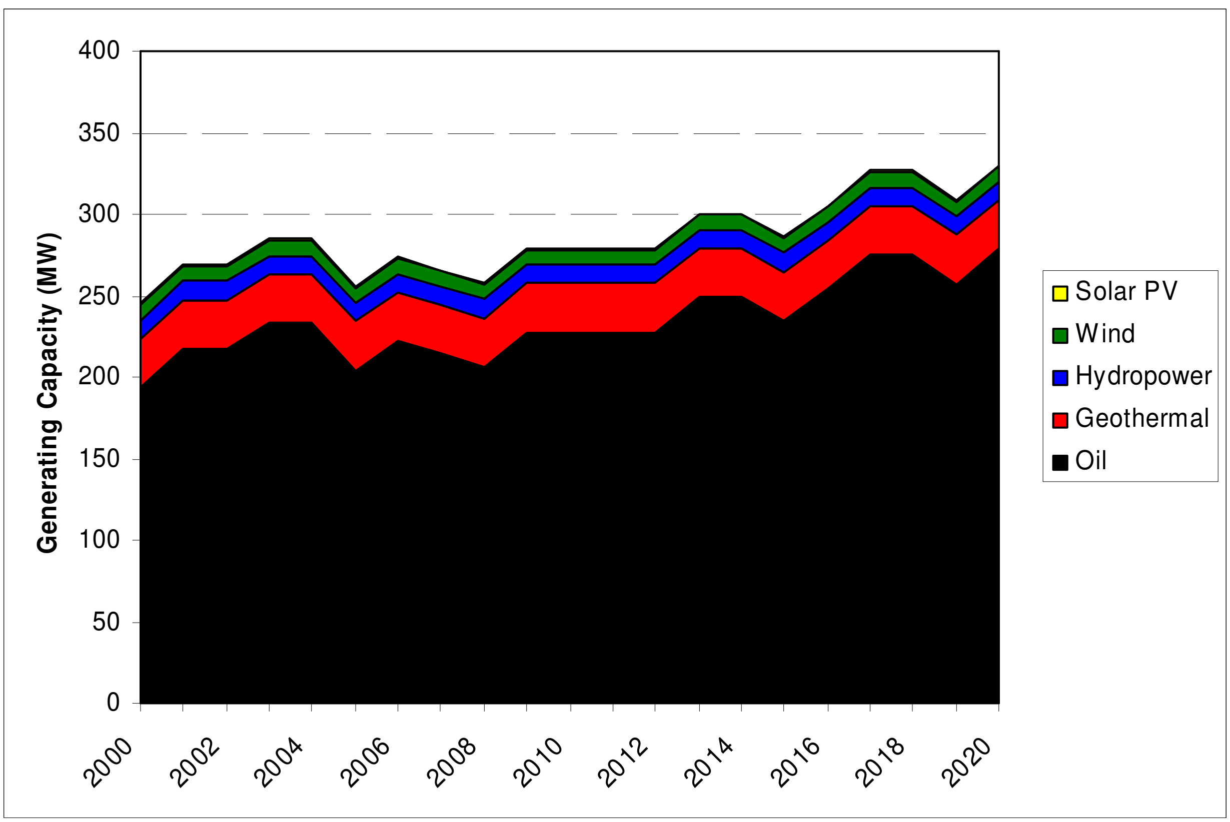
As part of the Energy Strategy, the ENERGY 2020 model was used to evaluate a number of different scenarios. In the base case, which extrapolates current trends in energy use, Hawaii County's total energy demand is forecast to grow by 24% between 2000 and 2020. This scenario is derived largely from HELCO's previous IRP, completed in 1998. With the exception of 18 MW generated by steam turbines installed on pre-existing oil-fired plants, all new capacity is expected to come from dual-train combined-cycle oil plants. In total, 119 MW of capacity are added by 2020 in this scenario. Planned retirements are not listed in this scenario, but based on the other scenarios we can assume that much of this added capacity would offset retirements of older plants.

Other scenarios, which included a 10% renewable scenario and a 20% renewable scenario, were originally designed to evaluate greenhouse gas reduction policies under the Hawaii Climate Change Action Plan. The percentage derived from renewable sources is statewide and does not refer to the Big Island specifically; due largely to its geothermal resource, the island already receives more than 20% of its electricity from renewables and is expected to contribute more than its share to the statewide total.

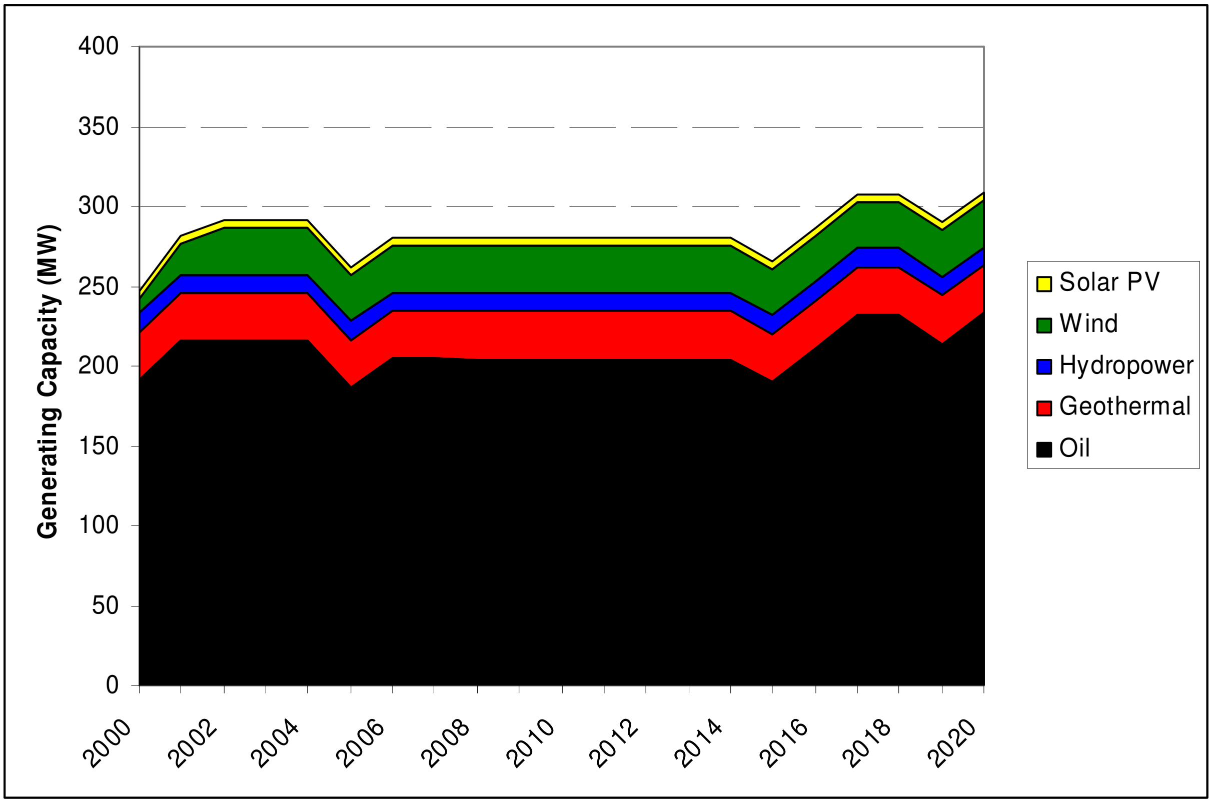
These scenarios were produced in 2000, and utilize data older than that. Fossil fuel prices were considerably lower at that time; it was also five years prior to HELCO's public statement that they would not build a new fossil fuel power plant on the island. Hence, these scenarios should not be interpreted as current predictions of the island's energy future. Rather, they are useful primarily in illustrating the range of possible ways in which energy needs could be met, and in showing how newly-developed scenarios have changed over time.

Figure 2.8: Hawaii Energy Strategy (a) Base Scenario (b) 10% Renewable (c) 20% Renewable

Source: Hawaii Energy Strategy 2000.

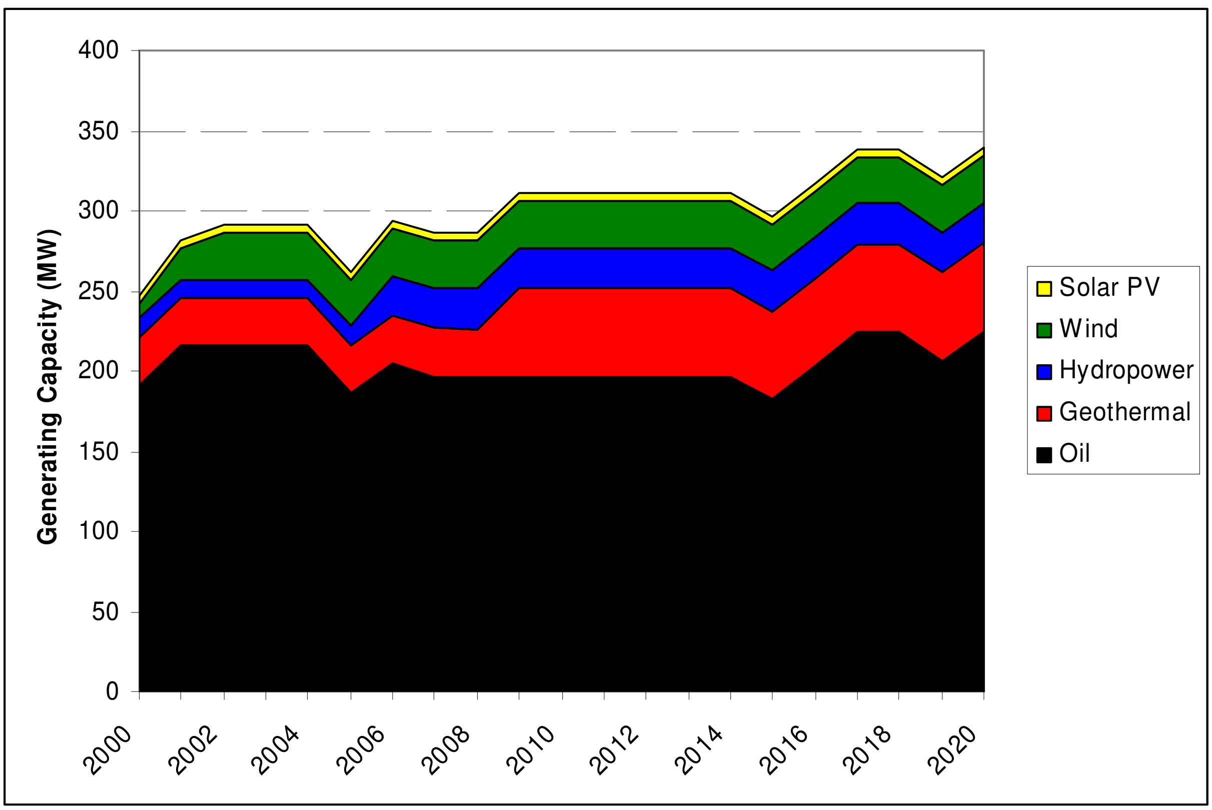


a)



Generating Capacity (MW)
400
350
300
250
200
150
100
50
0
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Solar PV
Wind
Hydropower
Geothermal
Oil

b)



Generating Capacity (MW)
400
350
300
250
200
150
100
50
0
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Solar PV
Wind
Hydropower
Geothermal
Oil

c)

The 20% scenario is remarkable in that it calls for 13.8 MW of additional hydropower capacity, a feat many observers believe would be politically difficult to achieve. The most striking aspect of the 10% scenario may be the fact that it does not envision any new renewables after 2002. In all three scenarios, all additional fossil fuel generators utilize combined-cycle technology.

Hawaii Energy Policy Forum Report on Renewable and Unconventional Energy[37]

The final supply scenario to be discussed was produced in 2003 for the Hawaii Energy Policy Forum, a collaboration of various stakeholders convened in order to "develop an energy vision for the year 2030 and to formulate a strategy to ensure its implementation." This report, which examined potential renewable electricity generation, was not intended to suggest a single course of action; rather, it aimed to identify all of the possible renewable projects that could feasibly be pursued in the foreseeable future.

Candidate projects went through a multi-step screening process to isolate the most feasible proposals. The authors started with a previously compiled list of potential projects, and updated it with regard to performance and cost. After this initial selection, three further screens were utilized. The first criterion was grid integration, which considered transmission constraints and other issues involved in the sale of electricity to the utility by Independent Power Producers (IPPs). The next screen, for land use, examined aspects such as compliance with zoning and environmental requirements. The final screen was community acceptance, although this was admittedly more subjective than the other screens. Projects that satisfied each criterion were divided into two implementation phases: near-term (2003-2008) and mid-term (2008-2018). A far-term analysis was also done, but it merely examined likely trends and did not discuss specific project possibilities or provide quantitative results.

Potential projects identified by the study are summarized in Tables 2.6 and 2.7. The researchers found potential for considerably more projects than HELCO identifies in its IRP, suggesting that as electricity demand continues to grow and older oil-fired power plants are retired, more of these renewable projects could enter the utility's portfolio.

Table 2.6: Potential Renewable Energy Projects 2003-2008

Source: Bollmeier et al., 2003.

Resource Type	Capacity (MW)	Notes
Wind	10	Hawi is operational as of March 2006.
Wind	20	Proposed expansion of South Point.
Wind (total)	30	
Solar (water heaters)	1.6	
Solar (residential PV)	0.15	
Solar (total)	1.75	
Biomass (total)	8	residue-to-energy
Total near-term	**40**	

Table 2.7: Potential Renewable Energy Projects 2008-2018
Source: Bollmeier et al., 2003

Resource Type	Capacity	Location	Notes
Wind	10	Kahua	Identified as a near-term possibility, but unlikely to go through in that timeframe if Hawi came online.
Wind	50	Lalamilo	
Wind (total)	60		Integration of this much wind would probably require pumped hydro or some other form of storage.
Solar (PV)	10	Keohole, Lalamilo, or Kawaihae	Identified as near-term possibilities, but more likely in mid-term.
Solar (Parabolic Trough)	30	Keohole, Lalamilo, or Kawaihae	Identified as a near-term possibility, but more likely in mid-term.
Solar (water heaters)	4		
Solar (residential PV)	1.9		
Solar (total)	45.9		
Biomass (total)	13		From dedicated energy crops - would require ~8000 acres.
Total mid-term	**118.9**		
Total (near-term & mid-term)	**158.9**		

3. Renewable Energy Technologies: Current Production and Potentials

The previous sections of this report have demonstrated Hawaii's reliance on petroleum products to meet its energy needs, but have also revealed the utilization of a variety of renewable energy sources. Spurred by rising fuel costs, heightened environmental awareness and concern, and federal- and state-level incentives, a number of stakeholders seek to accelerate this trend towards renewable energy. Indeed, one goal of this research project is to explore the feasibility of a long-term, complete transition to renewable fuels. In this section we will describe Hawaii's current use of renewable sources of energy as well as its renewable resource base, in order to evaluate whether they have sufficient resources to make complete displacement of fossil fuels possible.

Three important concepts that recur throughout this section bear defining here: theoretical, technical and economic potential of a resource. Theoretical potential is defined as the maximum potential supply available from a given source, such as solar radiation or kinetic energy from wind. A typical assumption in determining theoretical potential would be that every scrap of land on the island would be used solely to produce energy (leaving no room for homes or businesses). It is therefore useful mainly as a conceptual guide, demarcating an absolute upper bound. Technical potential includes restrictions based on land use and other feasibility issues, but excludes cost considerations. Finally, economic potential includes that portion of the resource which could be cost-effectively produced under current prices and policies.

It should be noted that we have not followed one particular methodology in estimating renewable resource potentials. In part this decision reflects the different circumstances surrounding different energy sources – land use may be a limiting factor for some renewables, but not all of them, for example – but it is also a result of data availability and time constraints. Theoretical and technical potentials are treated in a fairly consistent fashion, with our general approach being to consider the full hypothetical energy content of the resource for theoretical potential and relying on numbers from the literature or from expert opinion to determine how technical potential might relate to theoretical. However, our estimates of economic potential are somewhat less robust, and should therefore be interpreted as approximations, rather than definitive numbers. Suggestions for improvements in this regard in the course of future research can be found in Section 6.

Resource potentials for each of the major renewable sources are shown in Table 3.1.

Table 3.1: Renewable Resource Potential

	Current capacity (MW)	Annual production (1000 kWh)	Theoretical Potential (1000 kWh)	Technical Potential (1000 kWh)	Economic Potential (1000 kWh)
Wind	19.9	6,700	2,031,000,000	41,000,000	184,000
Biomass	0	0	26,035,300	719,300	320,300
Ethanol	0	0	22,000,000	498,000	224,000
Biodiesel (waste oil)	0	0	7,300	7,300	5,300
Bagasse	0	0	3,900,000	86,000	38,000
Waste-to-energy	0	0	128,000	128,000	53,000
Geothermal	30.0	220,600	11,618,000	7,124,000	1,498,000
Solar	0.9	17,930	9,239,000,000	1,359,000	159,000
Solar Thermal	n/a	17,000	6,840,000,000	159,000	159,000
Photovoltaic	0.9	930	2,399,000,000	1,200,000	unknown
Hydropower	11.4	39,800	152,000	86,000	unknown
Total	**61.3**	**285,000**	**11,308,000,000**	**50,288,000**	**2,161,000**

Geothermal dominates the contribution of the renewable sources to Hawaii's current energy mix, but there are sizeable inputs from solar thermal, hydropower, and wind as well. If we look at technical potential, wind appears to hold the most promise for future growth, although there is substantial room for expansion among most of the other energy sources as well. Most importantly, according to our calculations, there is easily enough economic potential for renewable sources to satisfy all of the island's electricity needs for the near future (recall that current electricity demand is roughly 1.1 billion kWh). Indeed, geothermal alone would be able to meet this need. Even if electricity demand were to grow by the projected 2006 growth rate of 3% for over 20 years, it would still be below the renewable energy economic potential of 2.15 billion kWh. Should electricity consumption grow at 4.8% (the average growth rate of the past 35 years), the current renewable energy economic potential could meet 100% of demand for nearly 15 years.

We now consider each potential source of renewable energy in more detail.

3.1. Wind

Installed Capacity and Production

In 2005, the Big Island produced 6,710,000 kWh of wind power, or about one-half of one percent of the total electricity demand. The vast majority of this came from two wind farms: Lalamilo, located in South Kohala, which produced 1,697,000 kWh, and Kamaoa, at South Point, which produced 4,840,000 kWh.[38] Both have been in operation for close to 20 years and use turbines that are quite small and out-of-date by modern standards. Parker Ranch also has an integrated wind-and-solar system. The wind portion of this array has a capacity of 50 kW, generating about 173,000 kWh of electricity per year. This is mostly consumed on-site, but some of it is fed back into the grid.[39]

The Lalamilo Wind Farm, located in South Kohala, opened in 1986. According to the Hawaii Energy Company's (HECO) website, it employs 81 wind generators: 26 17.5-kW turbines and 55 20-kW turbines, for a total capacity of 1.6 MW; however, HELCO lists its capacity as 2.3 MW. The wind farm has been owned by HELCO since 1996.[40] The Kamaoa Wind Farm at South Point, owned by Apollo Energy since 1994, has been operational since 1987. According to the HECO website, its 37 250-kW turbines offer a stated capacity of 9.3 MW.[41] However, the facility is in a state of disrepair and probably has a far lower capacity in actuality. On a recent site visit on a moderately windy day, only four of the 37 turbines were turning, while 11 were completely nonfunctional (e.g., rotors were missing). All of the turbines had substantial visible rust.[42] Indeed, HELCO claims its actual capacity to be 7 MW,[43] which may still be a generous estimate.

Another wind plant at Upolo Point, Hawi, began generating electricity in March 2006. Upolo Point is owned by Hawi Renewable Development and is rated at 10.5 MW, a capacity derived from 16 660-kW turbines.[44] According to HELCO's actual supply numbers, Hawaii County has a total installed wind power capacity of 19.86 MW, or about 10% of the island's peak demand of 197 MW.

Upcoming Projects

Apollo Energy has signed a Power Purchase Agreement (PPA) and announced its intention to undertake a dramatic expansion of its Kamaoa Wind Farm. By replacing the existing turbines with fourteen GE 1.5 MW turbines, they plan to scale the facility up to a total generating capacity of 20.5 MW, or about three times its current output. According to the utility's website, commercial operation is expected to begin in late 2006.[45] However, construction on the upgrades has not yet begun, and given the tight supply of wind turbines in the market currently, the expansion will probably not be realized within the next year.

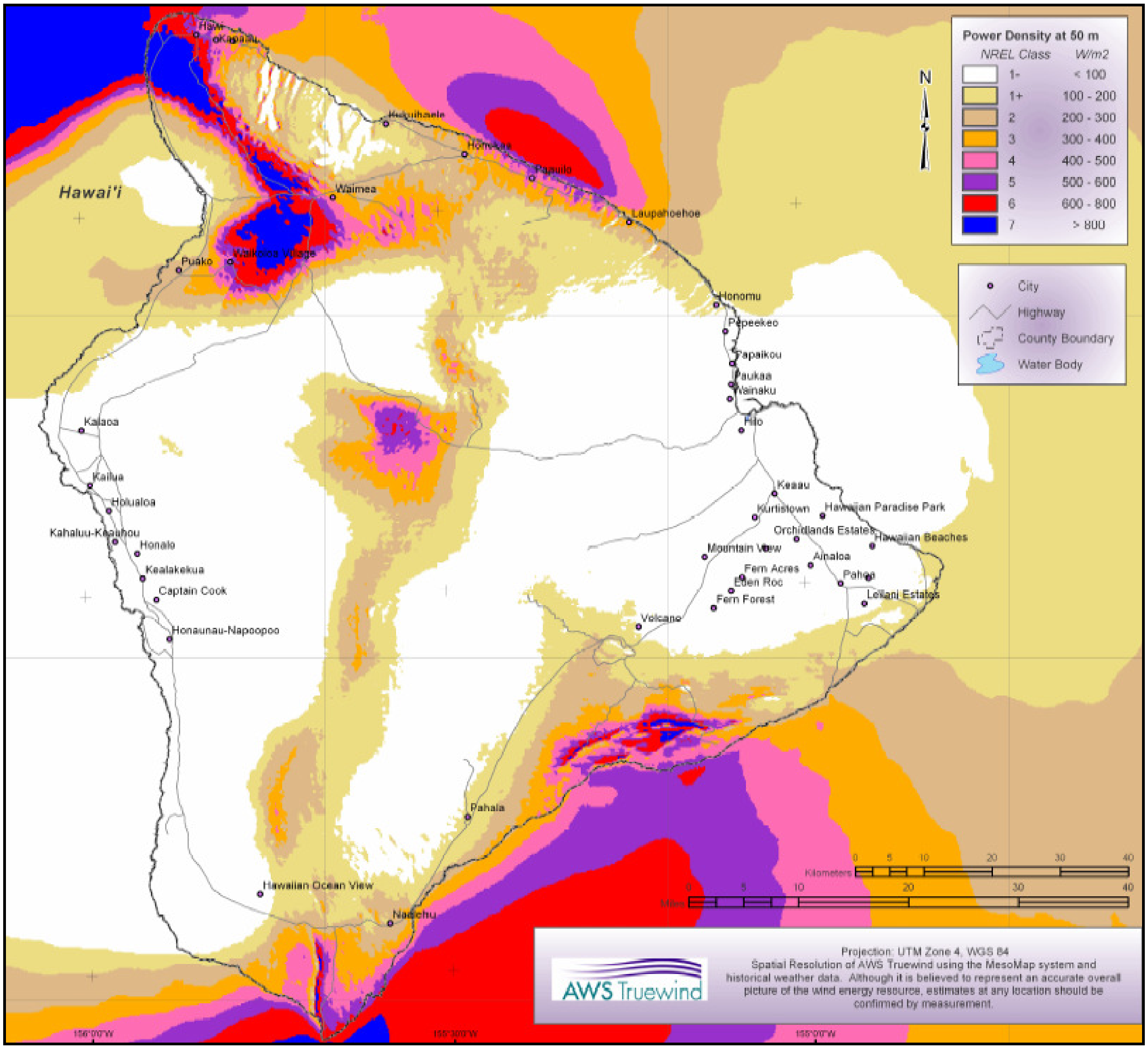
HELCO also has plans to expand its Lalamilo site to 10 MW, although it has not finalized a timeline for this.[46] In the latest IRP documents, the expansion is slated for 2020 under the least-cost distributed generation and pumped-storage hydro/wind scenarios (coupled with 30 MW of PSH in the final case). In the Maximize Renewables scenario, an expansion to 40 MW is scheduled for 2014 (also with 30 MW PSH), and in the Resource Flexibility scenario, no expansion is predicted to take place.

There was also an approved PPA for electricity from a proposed 10 MW wind farm at Kahua Ranch in North Kohala; however, after Hawi Renewable Development acquired the rights to the project, they terminated it, choosing instead to focus on their Upolo Point project. Nonetheless, it is evident that the site has good resource potential, and could probably be pursued in the future assuming grid interconnection and intermittency issues can be resolved, perhaps through increased use of PSH.

Resource Potential

Hawaii's major utilities partnered with NREL and DBEDT to fund the creation of high-resolution wind resource maps for the major islands in the state. The maps, produced by AWS Truewind, have a resolution of 200 meters and indicate wind speeds and power density at several different altitudes. We used the 50-meter altitude wind power map shown in Figure 3.1 to estimate a Hawaii County theoretical resource potential of 2,031,000 million kWh per year. The assumption guiding our estimate was that any part of the island with a wind power greater than 250-300 watts per square meter, which corresponds to class 3 of NREL's wind power classification scheme, could host a wind turbine.

Figure 3.1: Wind Map for Assessment of Wind Power Potential
Source: HECO website, 2006.[47]



Based on a detailed study of wind power potential in the United States and the Netherlands, the World Energy Council has suggested that 4% of the land area exposed to this wind resource could realistically be used for wind project development, a guideline that the World Energy Assessment utilizes in its review of worldwide wind energy potential.[48] It seems likely that Hawaii would face tighter constraints, in light of its high property values and numerous ecologically and culturally sensitive areas; therefore, a value of 2% is used here. Using that rule of thumb, technical potential for wind energy is estimated to be over 40,000 million kWh per year. This is still well over the island's current energy demand (total electricity generation in 2005 was approximately 1,219 million kWh), indicating that there is enough technical potential for wind to supply all of the island's energy needs for the foreseeable future. Of course, intermittency issues would have to be overcome to make this potential realistic.

Under current laws and power purchase contract standards, the economic potential for wind generation is essentially constrained only by the island's demand for electricity and the utility's ability to integrate wind into the grid. The Public Utility Regulatory Policies Act, or PURPA, requires utilities to purchase power from qualifying IPPs at a price set by state public utility commissions. In Hawaii, this purchase price has typically been set with an avoided-cost formula, which for Hawaii is tied very closely to the cost of oil. Under current oil prices, this formula has set a price well beneath the operating costs of a typical wind project.[49] The federal production tax credit (PTC) of 1.9 cents/kWh makes wind power even more attractive; however, as a regulated utility HELCO cannot qualify for the PTC on its own Lalamilo plant.

Under current economic and policy conditions wind is extremely competitive with oil generation, which produces the bulk of the island's electricity. However, the PTC is slated to expire at the end of 2008, and many analysts believe that PURPA will be repealed or modified in the near future. Furthermore, the presence or absence of pumped-storage hydro, which can be used to 'firm up' wind power by resolving intermittency problems, also has strong implications for the economic potential of wind on the island, as does the creation of new transmission infrastructure to connect any new wind sites into the grid.

Due to all of these variables, any estimate of economic potential is highly uncertain. Nonetheless, Dr. Karl Stahlkopf, Chief Technology Officer of the Hawaiian Energy Company (HELCO's parent company), said he believed that in addition to the 20-25 MW of wind already expected in the near term, an additional 25 MW could be integrated into the grid without too much difficulty, given enough pumped-storage hydro capacity to support it.[50] That would suggest a total economic potential of 70 MW of wind in the medium term (including the existing capacity). At a generating capacity factor of 30% (a standard figure on the mainland, but one that is considered conservative for the Big Island), this would translate into about 184,000,000 kWh per year. Kyle Datta, another analyst familiar with the Island's energy system suggested that wind, when coupled with pumped-storage hydro, could completely displace fossil generation as the Island's source of baseload power (along with geothermal), with fossil fuels providing intermediate and peak power as needed.[51] With a current baseload of approximately 100 MW, that would suggest an economic potential of 70 MW of wind capacity, confirming our previous estimate.

We must note, however, that all analysts agree that the creation of pumped-storage hydro infrastructure is critical to the expansion of wind power. As a general rule, most utilities believe that intermittent resources can only account for 20% of the system's power before threatening system stability. While the high capacity factor on Hawaii may mitigate this somewhat – the wind resource is steadier, with some potential sites believed to have a capacity factor of 60% – Hawaii Island's standing as a microgrid without interconnections to a larger system acts as a liability. In short, without pumped-storage hydro, it seems doubtful that the economic potential for wind power could exceed 20% of generation.

Table 3.2: Wind Potential

Wind	1000 kWh/year
Theoretical Potential	2,031,000,000
Technical Potential	41,000,000
Economic Potential	184,000
Current	6,700

3.2. Biomass

We will discuss three biomass to energy processes: ethanol production, biodiesel production from waste oil, and combustion of bio-based waste products. There are additional emerging biomass technologies that were not included due to data limitations, but, with technological development, may hold promise for development on the Big Island. Such processes include biodiesel production from dedicated energy crops and algae, lignocellulosic biomass utilization, and biomass gasification.

Ethanol

There are no active sugar plantations on Hawaii Island, but two plantations remain active statewide. Gay and Robinson operate one on Kauai and HC&S operate another on Maui. These two plantations cover 70,000 acres total and yield 340,000 tons of raw sugar annually.[52] In order to calculate the potential of ethanol production on Hawaii Island, it will be assumed that the Big Island's yield is 75% that of current operations on other islands,[53] resulting in 3.6 tons of raw sugar per acre. One benefit of sugar is the fact that refineries can operate under a self-sufficient energy state by burning the bagasse waste produced during processing. Over one year, one acre of land using integrated sugarcane to ethanol and power processes yields 1,100 gallons of ethanol and 3,200 kWh of energy from waste and bagasse.[54] A lower heating value of 76,000 BTU per gallon is assumed.

Global Power Generation Inc. plans to open a 10-million gallon per year ethanol plant in Hilo, Hawaii starting in December 2007.[18] To calculate the theoretical, technical, and economic potentials shown in Table 3.3, we had to make certain assumptions where sound ethanol research did not exist. The theoretical land area assumes that every piece of agricultural-zoned land on the island is used for sugar cane growth.[55] The technical potential was drawn from the Stillwater report, a study commissioned by DBEDT to evaluate the impact of a 10% ethanol mandate in gasoline. This study states that 27,000 acres are potentially available for the production of sugar cane. The lower bound for the economic potential comes from pending production levels at Global Power Generation's planned ethanol plant, which will produce the equivalent of 12% of the Island's gasoline consumption when operating at maximum capacity. We have adopted this as our base case because we believe this plant is capable of meeting the entire ethanol demand, which at this point stems primarily from the recent state directive requiring that 85% of gasoline contain at least 10% ethanol.

Table 3.3: Potential for Ethanol Production in Hawaii County

	Land used (acres)	Ethanol produced (gallons/yr)	Energy content (billion BTU/yr)	Percent of Gasoline Use
Theoretical	1,220,000	1,000,000,000	76,000	100%
Technical	27,000	22,300,000	1,700	20%
Economic	12,000	10,000,000	750	8.8%

Biodiesel from Waste Oil

There are currently no major operations on Hawaii Island that produce biodiesel. Pacific Biodiesel, which operates a facility on Maui and one on Oahu, does take a small amount of cooking oil from the Big Island. Total annual production for these two facilities is 150,000 and 400,000 gallons of biodiesel, respectively.[56] The amount of waste oil from the Big Island could not be disaggregated, but is assumed to be quite small. A study by University of Hawaii at Hilo students – conducted on behalf of the Solid Waste Division of the Hawaii County Department of Environmental Management – found that 60% of respondents reuse or recycle their waste oil, 21% (totaling 2,000 gallons per month) use Pump Truck

Services for disposal, and 15% (300 gallons per month) dispose of their waste oil through municipal solid waste (MSW) or wastewater treatment. An estimated 800 tons of waste oil per year are being generated by the target population. Recycling and collection costs are approximately $1.13 per gallon, while proper waste disposal in West Hawaii Sanitary Landfill would be $1.91 per gallon. They estimate that 320 to 475 tons of used oil are being improperly disposed in Hawaii County. The study also asserts that the waste oil generation in Hawaii County is comparable to that of Maui County, implying that biodiesel production would be viable on the Big Island.[57]

The following assumptions were used in calculating the potential for biodiesel:

- 87% of the inputs into the process are waste fats
- 88% of the outputs of the process are biodiesel
- Lower heating value of 118,000 BTU per gallon;
- 75% of waste oil can be collected economically
- The density of waste oil is 0.92 g/cm^3.

The potentials listed in Table 3.4 consider only biodiesel from waste oil, and not that from dedicated energy crops. Because ethanol production is considered to be a more efficient use of energy crops, we assumed energy crops would be dedicated to ethanol production over biodiesel.

Table 3.4: Potential for Biodiesel Production from Waste Oil in Hawaii County

	Tons of waste (oil/yr)	Biodiesel production (gal/yr)	Energy content (billion BTU/yr)	Percent of Diesel Use
Theoretical	800	208,000	25	0.6%
Technical	800	208,000	25	0.6%
Economic	600	156,000	18	0.5%

Combustion of Bio-Based Waste Products

We considered two possible sources of bio-based combustion energy: agricultural waste and MSW. To determine the energy potential from agricultural waste, we relied on a case study of bagasse from sugar cane production. While our results show the potential for energy generation, much of this energy may be used internally by agricultural processing and therefore would not necessarily be available for distribution. Using the assumptions listed above (under *Ethanol*) and an energy generation of 3,200 kWh per acre, we calculated the potentials listed in Table 3.5.

Table 3.5: Potential for Bagasse Waste in Hawaii County

	Land used (acres)	Trash & Bagasse (tons)	Energy content (1000 kWh/yr)	Energy content (billion BTU/yr)	% of Current Electricity Production
Theoretical	1,220,000	32,000,000	3,900,000	13,000	100%
Technical	27,000	980,000	86,000	290	7.1%
Economic	12,000	440,000	38,000	130	3.1%

There are currently no waste-to-energy facilities on the Big Island, but due to landfill constraints there may be a growing need, regardless of energy generation potential. However, the dispersed nature of the population centers and the relatively low population density of the island make collection challenging.

The Yale Materials group estimated that the West Hawaii landfill took in 135,000 tons of waste in 2005, while the East Hawaii landfill took in nearly 86,000 tons. There is a proposed waste-to-energy plant in Hilo that, if approved, will be able to process 250 tons of waste per day.[58] To calculate the theoretical and technical potentials, we assumed that all combustion of all Big Island waste. The economic potential assumes that the proposed Hilo plant is all that is economically feasible. We have also assumed that 63% of waste is combustible, that this combustible waste has a lower heating value of 4,000 kWh per ton, and that an electricity generation efficiency of 23% of achieved.[59]

Table 3.6: Potential for Municipal Solid Waste Combustion in Hawaii County

	Mass of waste (tons/yr)	Mass of combustible waste (tons/yr)	Electricity Generation Potential (1000 kWh/yr)	Energy content (BBtu/yr)	Percent of Electricity Produced
Theoretical	221,000	139,000	127,880	0	11%
Technical	221,000	139,000	127,880	0	11%
Economic	91,000	57,000	52,900	0	4.3%

3.3. Geothermal

Installed capacity

The Big Island currently has only one geothermal operation actively generating power: PGV,[60] which is located 21 miles south of Hilo in the lower KERZ. It is now owned and operated by Ormat Technologies.

The plant occupies 13 acres of a 500-acre site. The energy source is geothermal liquid, brought to the surface through production wells drilled to a depth of about 4,500 feet. The liquid is separated and the condensed steam is routed to one of ten electrical generating units. The system is closed, meaning everything extracted from the reservoir is eventually reinjected back into the resource area.[61]

After years of experimentation and numerous test wells, PGV began commercial operation on April 30, 1993. The plant consists of four production wells, five reinjection wells, and ten electrical generators with a combined capacity of 30 MW. Capacity has fluctuated occasionally due to well blockages, even temporarily dropping as low as 5 MW in 2002 due to heat and corrosion-caused casing failure.[62] At present, though, PGV is fully operational with a total capacity of 30 MW. Typically, geothermal energy production has a capacity factor of 95%, meaning it can operate for 95 hours out of 100.[63]

Upcoming Projects

The Puna site is permitted for up to 60 MW of capacity, and in 2000 PGV stated it plans to double its generation capacity to 60 MW.[64] However, more recent conversations with Ormat representative Barry Mizuno revealed the company's discussions with HELCO to potentially deliver another 8 MW by the end of 2007. While the 30 additional megawatts are still possible, the demand does not exist at this point so they plan to proceed in smaller increments.[65]

Resource – Theoretical and Technical Potential

The youngest island in the Hawaiian chain, Hawaii County has by far the most significant geothermal potential. The numbers in Table 3.7, from a September 2005 GeothermEx study commissioned by the DBEDT,[66] present the theoretical and technical potential of the resource.

Table 3.7: Geothermal Potential by Region

	Capacity (MW)	
Zone	**Low**	**Mean**
Kilauea East Rift Zone	291	778
Excluding National Park/Forest land	181	438
Kilauea Southwest Rift Zone	133	393
Excluding National Park/Forest land	64	193
Mauna Loa Southwest Rift Zone	35	125
Mauna Loa Northeast Rift Zone	22	75
Hualalai	7	25
Total (all potential)	**488**	**1,396**
Total (excluding National Park/Forest land)	**309**	**856**

There are 5 main areas of geothermal activity on the Big Island, each of which is listed in the table above. The "low" numbers represent the 10th percentile estimate, meaning there is a 90% chance that actual geothermal energy reserves exceed this level. The "mean" numbers represent the most likely estimate of current reserves. Thus, the GeothermEx study estimates the most likely theoretical potential to be almost 1,400 MW for the Big Island. The technical potential of 856 MW excludes all federally-protected parkland (much of the Kilauea Rift lies within Hawaii Volcanoes National Park).

Note that the above reserve estimates address only the amount of heat recoverable at present from drillable depths, assuming a time horizon of 30 years. The numbers do not speak to the commercial viability of any of the sites. In fact, significant portions of the identified resources may be unsuitable for electricity generation at this juncture.

Resource – Economic Potential

An island grid cannot afford to have too much of its generation capacity in one location, especially considering the threat of extended disruption due to volcanic eruptions, which occurred as recently as 1955 at the PGV site.[67] The fact that most load growth is occurring on the western side of the island, away from the geothermal reserves, thereby limits the realistic potential of the resource.

In considering economic potential, the upper KERZ and upper Kilauea Southwest Rift Zone (KSRZ) resources are not included because they reside within Hawaii Volcanoes National Park or state natural reserve areas. The lower KSRZ and Mauna Loa Northeast Rift Zones are also not included, because they are subject to the same transmission constraints as the lower KERZ, where PGV is assumed to take priority.[68]

The remaining zones, the Mauna Loa Southwest Rift Zone and the Hualalai Rift Zone, could potentially present further electricity generation of 65 MW and 25 MW, respectively, by 2025. The Hualalai site, given its proximity to the rapidly growing Kailua Kona load center, is most promising from an economic perspective.

Given the above constraints, the upper geothermal capacity limit for the Island of Hawaii, according to the GeothermEx study, is 180 MW by 2025.[69] GeothermEx notes that this is the realistic upper bound, and should be regarded as such in future planning.

Resource – Other Uses and the Future

Finally, it is important to note that there are other potential benefits that can be derived from the waste heat and off-peak energy generation potential. These uses include serving as an energy source for hydrogen production, ice production, food drying, and even district heating where necessary.

As discussed in Sections 4.2 and 4.3, geothermal energy generation has been and continues to be a highly charged issue on the Big Island. While the resource could supply an increasingly large portion of the island's total electricity use, important spiritual and land use concerns must be considered.

Table 3.8: Potential for Geothermal Production in Hawaii County

	Capacity (MW)	**Potential** 1/ **(1000 kWh/yr)**
Theoretical	1,396	11,618,000
Technical	856	7,124,000
Economic	180	1,498,000
Current	30	220,600

1/ Assumes a capacity factor of 95%

3.4. Solar

<u>Direct Solar</u>

Installed Capacity

The primary use of direct solar energy in Hawaii is SWH. HELCO has funded the installation of over 4,000 residential SWH systems on the Big Island and estimates that there are at least 6,000 installed systems in operation.[70] HELCO estimates that each system offsets 227 gallons of oil per year. On average, conversion from oil to electricity is 35% efficient, which means that one SWH unit offsets roughly 2,800 kWh of electricity consumption (assuming an energy content of 35 kWh per gallon of fuel oil).[71] Under these assumptions, current use of direct solar energy offsets 17 million kWh of electricity.

Resource Potential

This energy resource has the theoretical potential to offset nearly 7×10^{12} kWh/yr of electricity demand, or six orders of magnitude greater than the current electricity use of the island as a whole (see Table 3.11). The specific statistics used to calculate this estimate are listed in Table 3.9. The estimate is based on the following assumptions:

- The average household size on the Island of Hawaii is 2.75 people[72]
- The rule of thumb for sizing SWH in the "Sun Belt" is 40 square feet for the first two family members and an additional 8 square feet for each additional family member.[73]

Table 3.9: Direct Solar Theoretical Potential

	Land Area (mi^2)	Avg unit (ft^2)	Total Units	Energy Offset per Unit (kWh/yr)	Final Energy (1000 kWh/yr)
Theoretical Potential	4,028	46	2,441,178,000	2,800	6,840,000,000

The major limit to the technical and economic potential of harnessing direct solar energy to heat water on the Island of Hawaii is the actual demand for hot water. Table 3.10 illustrates the assumptions used to estimate the potential total demand for SWH. Since roughly 10% of households currently have SWH, the economic and technical potential is an order of magnitude greater than current use, or 159,000,000 kWh/yr (Table 3.10). The gallons of oil avoided per household value is based on empirical testing of residential usage. To our knowledge, similar studies do not exist for commercial operations on the Island of Hawaii. Therefore, for the purpose of this estimate we used the same value for gallons offset for both residential and commercial. Considering that direct solar energy is also useful for the production of electricity (by concentrating the energy to produce steam) or to dry food the actual technical and economic potential of this resource is likely greater than our estimate.

Table 3.10: Direct Solar Technical and Economic Potential

Source: US Census Bureau

	Households & Commercial Operations	Electricity Offset per Unit (kWh/yr)	Final Energy (1000 kWh/yr)
Technical/Economic Potential	56,838	2,800	159,000

Table 3.11: Direct Solar Potentials and Current Use

Direct Solar	1000 kWh/yr
Theoretical Potential	6,840,000,000
Technical Potential	159,000
Economic Potential	159,000
Current	17,000

Photovoltaic Solar

The current documented production of electricity from PV systems amounts to less than 0.5% of the total electricity demand on the Island of Hawaii. Table 3.12 lists all the major documented PV installations and their capacity and estimated production of electricity. To calculate the estimated net generation of all the PV systems a 10% efficiency factor is assumed. Two privately owned systems supplied 91% of capacity: Parker Ranch and the Mauna Lani Resort. The installation at the Kona gym has since been removed. The Mauna Lani Bay Hotel has 674 kW of total capacity, including 288 kW of sun tracking solar panels powering their water pumping facility, 217 kW on the hotel roof, 140 kW on the golf facilities, 23 kW on the golf carts, and 6 kW on their massage bath. The water pumping facility likely achieves the highest percentage of electrical output based on maximum potential, at 14%.[74] Assuming 10% generation for the other cells, the Mauna Lani produces approximately 700,000 kWh/yr in PV solar power.

Small "off-grid" residential applications are not included in this list because their exact number or capacity is unknown. However, we have attempted to estimate the currently installed residential capacity. Hawaii DBEDT estimates that there are only 500 homes with PV systems in the entire state.[75] If we assume that there is an even distribution of PV systems among all people across all the islands of Hawaii, it is possible to estimate the number of systems on the Big Island. The total population of Hawaii is 1,275,000, and the population of Hawaii County is 167,000, or 13% of the state.[76] Therefore, the number of PV systems in Hawaii County, given our assumption, is 13% of all systems, or 65. We will assume that the average residential PV system has a capacity from 1.2 to 5 kW. Thus, we estimate the total capacity of currently installed Hawaii County residential PV systems to be between 78 and 325 kW and the total production to be between approximately 68,000 and 285,000 kWh. Thus, residential systems could be anywhere between 7% and 30% of the total documented PV electricity production on the Island.

Table 3.12: Major Photovoltaic Installations in Hawaii County

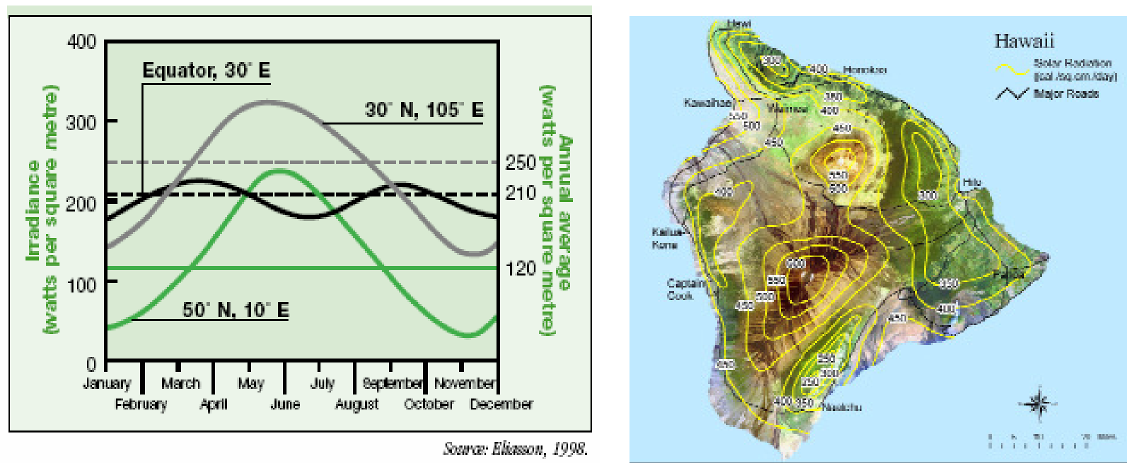
PV Systems	Capacity MW	1000 kWh/yr 1/
Mauna Lani	0.674	700
Parker Ranch	0.211	185
Hapuna Prince Hotel	0.020	18
Kona Gym	0.015	13
NELHA Gateway Center Project	0.010	9
HELCO Engineering Office	0.005	5
Total	**0.935**	**930**

1/ Calculation assumes a 10% efficiency factor except for a fraction of the Mauna Lani system which is 14% efficient

Similar to SHW systems, the theoretical potential of PV far exceeds the current energy production, again by a factor of six (Table 3.14). The major difference between the two solar technologies is that PV systems are far less efficient in their conversion of primary energy to final energy than SWH. The best PV systems on the market are able to convert only 10 to 15% of the solar radiation they intercept into electricity.[77] The theoretical potential from PV is roughly 2.5×10^{12} kWh/yr. To calculate this potential the following assumptions were made:

- The average solar insolation in Hawaii County 0.21 kW/m^2/year (see Figure 3.2a)
- The net conversion efficiency (sunlight to electricity) of PV systems is 12.5%[78]
- The entire land area of Hawaii County is covered with PV panels

We made another calculation to verify this theoretical potential estimate. This time the average insolation value was derived from the average radiation, 400 calories/cm^2/day, displayed on the State of Hawaii's solar radiation Geographic Information System (GIS) maps (Figure 3.2b).[79] The theoretical energy production potential was calculated to be 2,399,000 million kWh/yr, or only 8% less than our first calculation. The variables used and the results of this calculation are shown in Table 3.13.



(a) (b)

Figure 3.2 (a) Variations in Average Monthly Insolation Over the Year in Three Locations and (b) Map of the Average Solar Insolation on the Big Island of Hawaii.
Source: WEA and Hawaii Statewide GIS program.

Table 3.13: Photovoltaic Solar Theoretical Potential

	Land Area (m^2)	Avg. Irradiance (watts/m^2/yr)	Avg. Insolation (kWh/sq meter/yr)	Generation (kWh/sq meter/yr)	Annual Energy (1000 kWh/yr)
Theoretical Potential	10,432,472,000	210	1,840	230	2,399,000,000

The limits to the technical potential of PV are the demand for electricity and the availability of energy storage. Assuming unlimited storage capacity, satisfying the Big Island's total annual demand for electricity (1,217 million kWh) would require about 5.3 km^2 of PV panels, or 0.05% of the Island's land area. To put this in perspective, there is at least 6.5 km^2 of roof area on the Island[3]. Storage at any one time – likely in the form of water head, hydrogen, and/or batteries – would need to be equal to the peak electricity demand (~200 MW) to ensure a reliable system.

Table 3.14: Photovoltaic Solar Potentials

PV Solar	Net 1000 kWh/yr
Theoretical Potential	2,399,000,000
Technical Potential	1,200,000
Economic Potential	unknown
Current	930

[3] There are 65,605 housing units on the island (US Census) and for the purpose of this estimate it is assumed that each unit has 100 m^2 of roof area.

3.5. Hydropower

On the Big Island, there are three major run-of-the river hydroelectric power plants and several smaller grid-connected independent operations. In 2005, the total production from hydroelectric power was nearly 40 million kWh, or 3% of the total electricity production on the Big Island.[80] A single plant owned and operated by the Wailuku River Hydroelectric Power Company generated 75% of the total electricity production from hydropower (see Table 3.15). The maximum capacity of all the plants combined is estimated to be 11.4 MW or 6% of the peak load.[81] Because its output is highly dependent on rainfall and other climatic conditions, run-of-the-river hydropower must be viewed as an "as available" resource. In other words, the maximum capacity may not necessarily be available year round.

Table 3.15: Hydropower Output, 2005

Current Hydroelectric	Max Capacity (MW)	Net 1000 kWh/yr
HELCO		
Waiau	1.1	3,630
Puueo	2.3	5,540
IPP's		
Wailuku	11	29,700
Other	0.4	910
Total	**11.4**	**39,800**

In recent years, there have been numerous resource assessments of the potential for hydroelectric power in Hawaii County. The Army Corps of Engineers (1978), the U.S. Army (1981), and the US Department of Energy and The Hawaii Department of Planning and Economic Development (1981) all completed assessments. More recently, the Idaho National Laboratory (INL) created the Hydropower Evaluation Software to map and model the theoretical and technical potential of hydroelectric power in every state.[82] Table 3.16 lists the undeveloped hydropower sites covered by the INL assessment.[83] The Name Plate rating, developed by The Federal Energy Regulatory Commission (FERC), is equivalent to the theoretical potential capacity of the resource and the annual energy rating represents the theoretical annual production. The Project Environmentally Suitable Factor (PESF) energy rating is equivalent to the technical potential to produce electricity given physical and social constraints.[84]

Table 3.16: Idaho National Laboratory Assessment of Undeveloped Hydropower

Source: Idaho National Laboratory

Stream/Plant Name	Name Plate Rating (kW)	PESF	PESF*KW	Annual Energy Rating (1000 kWh)	PESF Energy Rating (1000 kWh/yr)
HONOLII	14,600	0.10	1,460	35,000	3,500
HONOLII(GARRATT)	2,400	0.90	2,160	10,200	9,180
HONOLII(GARRATT)	2,400	0.90	2,160	10,200	9,180
UNION MILL	500	0.90	450	4,100	3,690
WAILOA	2,900	0.90	2,610	12,300	11,070
UMAUMA	13,800	0.25	3,450	40,200	10,050
Total	**36,600**		**12,290**	**112,000**	**46,670**

The theoretical potential for additional production is 112 million kWh or three times the current production of hydroelectric power. The technical potential for additional production is 46 million kWh, which would nearly double current production (Table 3.17). Not all the potential hydropower sites were modeled and therefore the INL assessment is likely an underestimate.

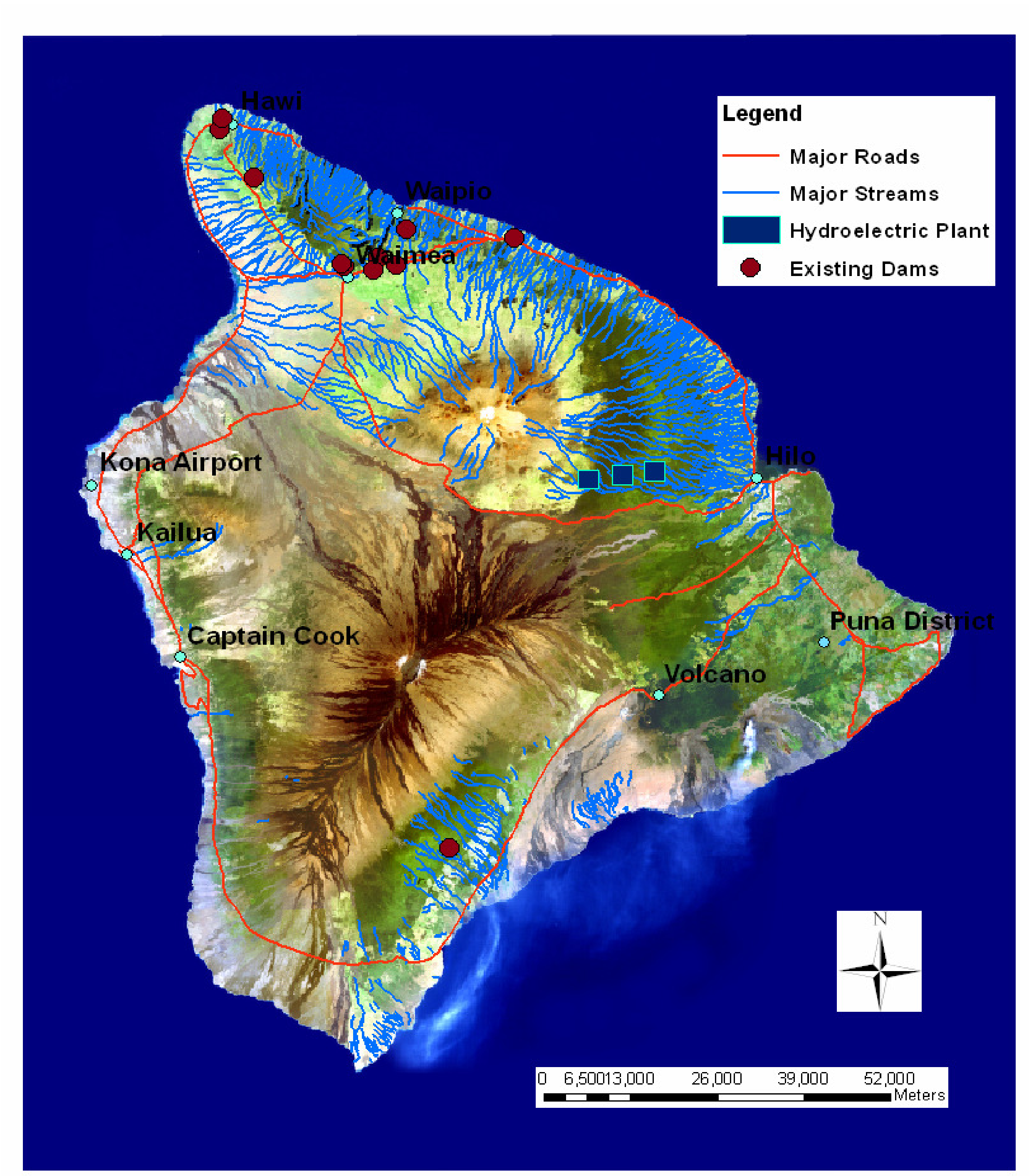


Figure 3.3: Major Streams, Existing Hydroelectric Power Plants and Dams on the Big Island of Hawaii
Source: Hawaii Statewide GIS Program

Table 3.17: Hydropower Potentials

Hydro	Peak Capacity (MW)	Net 1000 kWh/yr
Theoretical Potential	52	152,000
Technical Potential	27	86,000
Economic Potential	unknown	unknown
Current	11	39,800

3.6. Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) makes use of the temperature difference between the warm surface water and the cold water in depths below 2,000 feet. Most of the U.S. OTEC experimentation has taken place in Hawaii, where year-round sun and near shore depths make it an attractive location. A number of designs have been tested, with varying degrees of success. There have been promising discoveries throughout, and the theoretical potential is virtually limitless. However, OTEC does not appear to be a near term solution to Hawaii's oil dependence in the electricity sector.

There are three basic types of OTEC procedures:[85]

- Closed-cycle – Warm surface water vaporizes a working fluid such as ammonia—which has a very low boiling point—and the vapor drives a turbine which creates electricity through a generator. The cold deep water then acts to condense the vapor back into its liquid form, at which point the cycle repeats.
- Open-cycle – Here, the warm surface water itself is the working fluid. The water vaporizes in a surface vacuum and is fed through a low-pressure turbine attached to an electricity generator. The vapor can then be condensed back into a liquid by exposure to colder water. Alternatively, the system can take advantage of the desalination of the vaporization process, routing the desalinized water to irrigation, aquaculture, or drinking water needs onshore.
- Hybrid-cycle – Hybrid cycles use both open and closed systems to optimize the electricity generation and fresh water creation of the OTEC process.

The world's first successful OTEC operation took place at sea off Keahole Point in 1979,[86] and since then there have been several experimental developments. Between 1992 and 1998, a 210 kW open-cycle OTEC Experimental Apparatus operated at the Natural Energy Laboratory of Hawaii Authority's (NELHA) Keahole Point facility, providing significant data. The highest electricity production levels were 255 kW (gross) during late summer, when the surface water was warmest. In addition, the system produced about 6 gallons of desalinated water per minute, providing a potential input for terrestrial aquaculture or irrigation needs.

However, the electricity losses due to the system's pumps are high, resulting in net generation of only 103 kW under optimal conditions. DBEDT estimates that this ratio of net to gross electricity generation could be reduced to 0.7 using commercial-sized plants,[87] but a larger operation must be constructed to prove that the gains of scale can be realized. In spite of the promising developments since 1979, the state's plans for a 1.4 MW (gross) plant have stalled due to NELHA's inability to find financially viable solutions.[88]

According to Dr. Karl Stahlkopf, Chief Technology Officer of HECO, there may not be enough of a temperature gradient above 7° latitude to make OTEC work effectively. The temperature difference needed for an efficient process is about 40°F, so even Hawaii's 76-81°F surface water may not present enough of a temperature gradient given the 43°F deep water.

Clearly, Hawaii's OTEC efforts are in their nascent stages. While OTEC's potential to develop completely clean energy – coupled with its ability to provide fresh water to adjacent operations – may well point to a promising future in Hawaii, it likely cannot be counted on for significant economically-viable electricity generation in the near term.

3.7. Energy Storage

The future of increased renewables use on the Big Island relies heavily on the potential to store energy. The development of viable energy storage options is particularly important as the system seeks to firm up intermittent resources such as wind and solar. Storage could also serve as a valuable complement to geothermal, whose high output capacity and low variable costs could make it a viable source of energy for off-peak hydrogen production.

Storage options are designed to provide one of three different functions:[89]

1. Power Quality – Stored energy can be used for seconds, as needed, to ensure continued power quality
2. Bridging Power – Stored energy can be used for seconds to minutes, to ensure a constant power source while switching from generation source to the next
3. Energy Management – Storage is designed to facilitate load management, typically leveling the load curve by charging when relative demand and generation costs are low and dispersing power when demand and generation costs increase. Energy management applications can run for extended periods of time, allowing consumers to remain grid independent for hours to days at a time.

While all applications certainly apply in Hawaii, for the purposes of this paper we will discuss only the major energy management options. We discuss the potential impacts and costs associated with four technologies: PSH, hydrogen, batteries, and compressed air energy storage (CAES). The first two options are more frequently discussed with respect to the Hawaii grid, but all offer intriguing potential at least in the long-term. Because the theoretical and technical potentials for these sources are nearly unlimited, we refer only to proposed installations and economic considerations here.

Figure 3.4, from the Energy Storage Association, shows approximate capital costs (as of 2002) per unit of energy and power for the principal storage technologies. Costs vary according to application and scale, so this chart should be used as a guide rather than a rule.

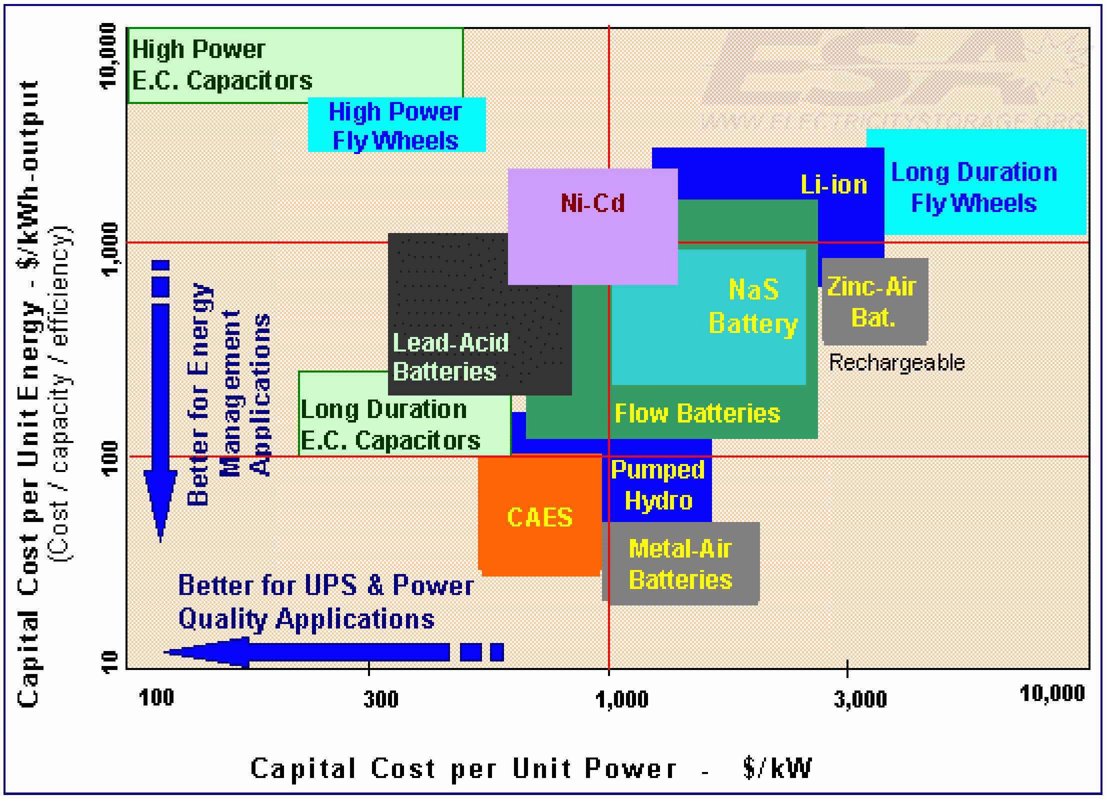


Figure 3.4: Capital Costs by Storage Technology[90]

Figure 3.5 provides approximate capital costs on a per cycle basis. Because these estimates incorporate cycle life and efficiency considerations, this method of examining costs may be most representative when considering load leveling technologies. Note that these figures do not include disposal, replacement, and operations & maintenance costs, all of which bear consideration before an ideal technology option can be identified.

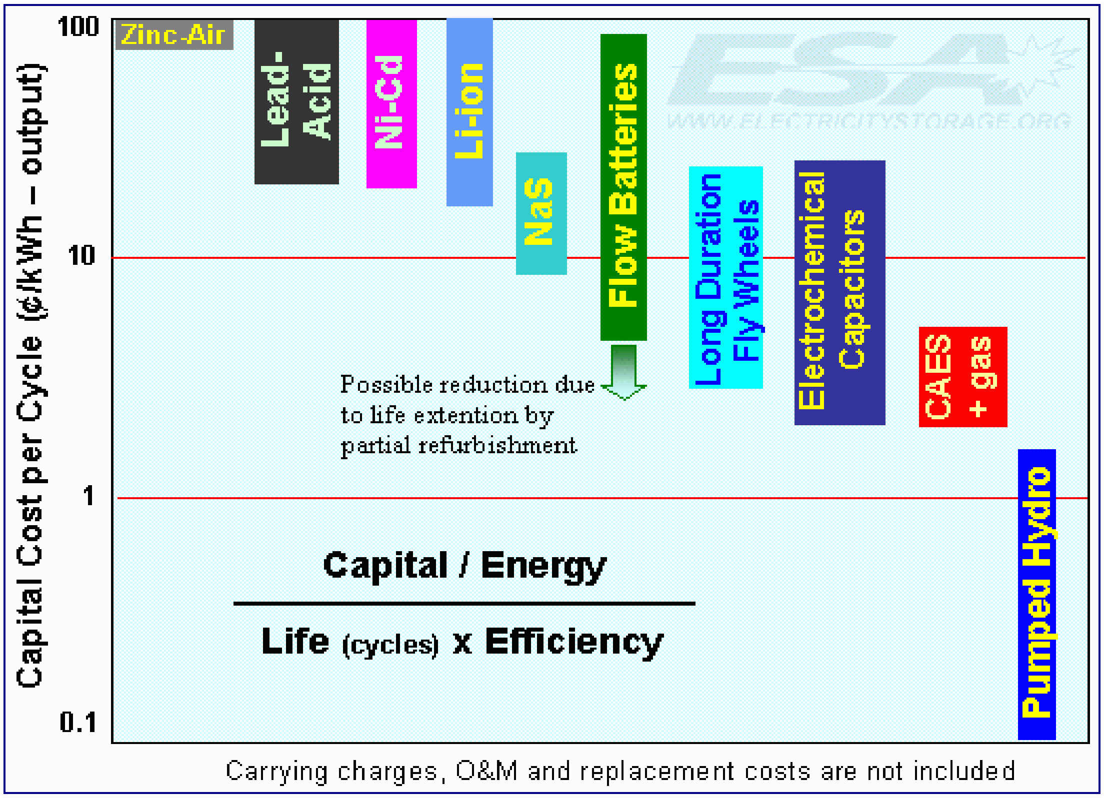


Figure 3.5: Per Cycle Capital Costs by Storage Technology[91]

Pumped-Storage Hydro

PSH is the world's most widely used storage technology on power networks. Pumped hydro can function on almost any scale, delivering firm energy generation for anywhere from a couple hours to several days. The principal requirement is two reservoirs – water is pumped up to the higher reservoir during off-peak hours, where the hydroelectric resource remains available as needed. While most Big Island proposals involve brackish groundwater, it is technically possible to use seawater as well, as evidenced by the 30 MW plant built in Yanburu, Japan, in 1999.[92] One advantage of using groundwater, however, is the fact that the relatively fresh reservoirs also double as fire-fighting resources, an environmentally friendly alternative to the predominant current practice of extinguishing wildfires with seawater.[93]

Round trip efficiency levels range from 75 to 80% on the Big Island, meaning for every 100 kWh required to pump the water to elevation, the system can expect to recover 75 to 80 kWh on the way down.[94] In spite of the net loss, PSH has a very bright future on the Big Island. The advantages include load leveling, frequency regulation, and system reliability. The most import contribution from PSH, however, is the ability to leverage non-dispatchable revenue generating assets – intermittent energy generation from wind and solar does not coincide with peak demand – in off-peak periods. For instance, overnight wind energy could fill the reservoir, which could later be emptied to help satisfy the next day's peak load.

Big Island PSH sites require 500-1400 feet of head (elevation change) and an accessible water source near existing transmission lines. According to Karl Stahlkopf, HELCO has identified an undisclosed site where they plan to construct a 200 million gallon reservoir that could provide 50 MW of capacity for 8 hours by 2010 or 2012.[95] Another recent study indicates a near-term Big Island potential of 30 MW, with 6 hours of available storage at 3 sites: Puu Waawaa and Puu Anahula in North Kona, and Puu Enuhe in Kau.[96]

PSH capital costs are high, though, ranging from $2432 to $2842 per kWh according to a November 1, 2005 presentation by Art Seki to the Maui Electric Company IRP-3 meeting.[97]

Hydrogen

The "Hawaii Governor's Energy Plan – 2006" contains the following vision: "Establish a world-class renewable energy-to-hydrogen program in Hawaii, and through the development of hydrogen as an energy carrier, provide for the long-term energy security of the State."[98] Hawaii plans to invest heavily in hydrogen development, and the Big Island, with its ample renewable resources, will play a major role in this.

Hydrogen is often discussed as the energy carrier of the future. It has a high energy density by weight compared to other liquid fuels, converts to electricity at a higher efficiency than combustion processes, and emits only water when it is used to generate energy. Furthermore, hydrogen can be produced using energy from intermittent resources such as wind or solar power and then used for power generation at a later time, providing greater stability and control over the electricity system. These advantages are viewed quite seriously on Hawaii, which has become a nationwide center of hydrogen research and development.[99]

Hydrogen does not occur naturally, but it can be isolated in a number of ways, most notably by reformation of hydrocarbons in fossil fuels or by electrolysis. The most frequently discussed process for the Big Island – and the most environmentally-friendly due to the lack of carbon emissions – is electrolysis, in which an electric current is used to split water into hydrogen and oxygen molecules. The pure hydrogen can then be used as a transportation fuel or in conjunction with fuel cells to produce electricity.

Since electrolysis can be driven by solar, wind, or geothermal power, the theoretical potential of the resource is essentially infinite (the water used as an input is recreated when the hydrogen combines with oxygen during use, so there is no overall depletion of resources). Similarly, because the equipment to drive these processes is already in existence and well-proven, the technical potential exists for hydrogen to meet all of the island's energy needs.

Electrolysis is very energy intensive, however. The production of each kg of H_2 requires anywhere from 53 to 70 kWh of electricity, depending on the scale of the operation.[100] Lower heating values and higher heating values for hydrogen average 113,600 and 134,500 BTU/kg, respectively. By way of comparison, these numbers are approximately three times as high as that of gasoline.[101] Thus, even at lower heating values, large-scale electrolysis plants can produce 113,600 BTU of hydrogen from 180,843 BTU (53 kWh) of electricity, for a total minimum conversion efficiency of 63%.

Capital costs are extensive, as discussed, but as operations get larger, fuel costs represent an increasing percentage of total costs. Consider the following example from the U.S. Department of Energy, where electrolysis cost breakdowns were considered assuming modest electricity costs of 7.89¢/kWh (recall that Big Island electricity currently retails for about 28¢/kWh). In the average small-scale operations, which produce only 20 kg (or 2.272 million BTU) of H_2 per day, energy costs account for only 17% of total costs, with capital costs accounting for the vast majority of the remainder (O&M accounts for about 10%). In large-scale operations (1,000 kg or 114 million BTU of H_2 per day), electricity costs account for 58% of the total costs. Even with a large-scale operation and those modest electricity costs, a single kg of H_2 would still cost approximately $4.10 to produce, for an average cost of 0.36¢/BTU.[102] Gasoline, at 4/24/06 wholesale prices of $2.48 per gallon (125,000 BTU) – this includes crude oil input costs plus refiner costs and profits – can be valued at $0.0019¢/BTU, approximately 190 times cheaper than hydrogen. It is worth noting that crude oil prices, which account for 69% of the cost of gasoline production at this price, were greater than $70/barrel on April 24, 2006![103] This should give the reader an idea of the relative expense of hydrogen production.

Because the current costs of producing, storing, and transporting hydrogen are prohibitively high, it is not economically competitive with existing energy sources.[104] As of now, hydrogen is only used for energy in research and demonstration projects, in heavily subsidized applications, and in niche markets that do not exist on the Big Island. We therefore consider the current economic potential on the island to be zero. Furthermore, use of the fuel on a large scale will necessitate the development of a storage and transportation infrastructure; such a system will not likely be implemented until costs drop significantly. Developments in hydrogen generation technology, as well as the ability to use off peak geothermal, wind, or solar energy to fuel electrolysis, should make this an increasingly attractive storage technology as Big Island renewable energy efforts continue to mature. Hydrogen could eventually become the dominant energy source, not just for Hawaii but worldwide.

While hydrogen is not currently being used on the island, there is a pilot project under development to create a "Hydrogen Power Park." Funded by the U.S. Department of Energy and overseen by DBEDT and the Hawaii Natural Energy Institute (HNEI), the project's goal is to create a small, integrated system comprised of electrolysis for hydrogen production, hydrogen storage, and grid-connected fuel cells. Renewable energy sources would be used as the driving source of power. Since the effort is still in the planning stages, further details as to expected costs, energy use or hydrogen production are not yet available.[105]

Compressed Air Energy Storage

CAES applications consist of a peaking gas power plant that consumes less than 40% of the gas used by conventional gas turbines to produce the same amount of electricity. The reason for the increased efficiency is that a conventional gas turbine uses about 2/3 of its input fuel to compress air at the time of electricity generation. CAES relies on low cost, off-peak energy sources to pre-compress the air, which can then be used with a gas fuel to generate electricity as needed.[106]

While CAES represents a promising storage provider for intermittent renewable energy produced at low demand times (wind at night, for example), due to the current lack of a gas infrastructure on the Big Island, its reliance on gas fuel presents an obstacle that cannot currently be overcome. However, it is possible that imported liquefied natural gas (LNG) could meet this need, as could hydrogen gas (with relatively minor burner modifications). Lastly, it is not clear that adequate underground compressed air storage options – such as salt caverns – exist on the Big Island. Storage tanks can be used in lieu of airtight geologic options, but that option significantly raises the capital costs involved in any CAES system.

Batteries

Sodium sulfur (NaS), metal-air, and various flow batteries are all in use as energy management options at select locations throughout the world. However, issues such as low energy densities, short life spans, and high production costs have plagued each of them to varying degrees.[107] As a result, batteries are not yet an economically realistic storage option worthy of discussion here.

4. Regulatory and Social Context

The nature of an energy system is not determined merely by such factors as fuel prices, infrastructure, and economic growth. Energy systems are also in large part a reflection of personal and societal values. In this section we will explore this human dimension of Hawaii's energy use, looking at how it has shaped the island's energy system and how it may continue to do so in the future. There are two major components in our analysis. The first is political, and consists of a review of a number of relevant federal and state policies addressing energy use. The second is social and cultural, and concerns how the general public as well as different stakeholders have supported or resisted changes in the energy system. In Hawaii County, this social mobilization has been manifested predominantly in response to the use of geothermal energy, so we will present a case study on the history of geothermal operations on the island in order to highlight the phenomenon. We end the section with an analysis of the major social and political constraints that may play a strong role in shaping the future development of energy trends on the island.

4.1. Renewable Energy Policy

4.1.1. Federal

Public Utility Regulatory Policies Act of 1978

In response to the 1970s oil crisis the United States Congress passed the Public Utility Regulatory Policies Act (PURPA) of 1978. PURPA's intent was to encourage efficient electric power production while simultaneously regulating the rates consumers pay for electricity.[108] The basic concept was to force utilities to purchase power from independent generators in the hope that healthy competition would provoke greater efficiency and lower rates. FERC created a new class of power producers called Qualifying Facilities (QFs). To gain QF certification, a wholesale power generator must either be 1) a small power producer, or 2) a cogeneration plant that meets a series of requirements regarding fuel use, fuel efficiency, and reliability.[109] Utilities are required to purchase power from QFs within their service area at a rate determined by "avoided cost" which is in theory a reflection of the operating costs the utility itself incurs to produce a comparable amount of electric power.

PURPA is a federal law; however, implementation and enforcement are left to individual state governments to achieve its goals as they see fit. Historically the level of enforcement of the law and the interpretation of "avoided cost" has varied considerably among states.

PURPA and its avoided cost provision have created a great deal of tension and difference of opinion among the major players in the electricity market on the island of Hawaii. Current crude oil prices are above $70 per barrel, and the resulting high cost of producing electricity are reflected in the high "avoided cost" paid to IPPs. From HELCO's point of view, the utility is forced to overcompensate QFs (IPPs supply more than half of HELCO's power) for their electricity, while at the same time often inheriting the burden of adopting additional intermittent power sources (in the case of wind power, for instance). Consequently, they would like to see the rates they pay for renewable energy de-linked from the cost of fossil fuel.

Somewhat paradoxically, IPP owners do not necessarily disagree outright with this viewpoint. While those who are able to sell electricity into the grid may make a handsome profit, many believe that the ability to offer discounted rates closer to their marginal costs would enable them to sell (and thus produce) more clean electricity.

According to John Cole, the Executive Director of Hawaii's Division of Consumer Advocacy, the state's consumers understandably take issue with the artificially higher rates which stem from the avoided cost legislation.[110] Rate payers, who currently pay the nation's highest electricity rate of 28 cents per kWh, do not see the cost savings associated with renewable energy on the Island of Hawaii.

4.1.2. State and Local

Competitive Bidding

In order to address the problems associated with PURPA's requirements and its avoided cost payment formula, the Hawaii PUC is currently examining a proposal (Docket 03-0732) to allow, and indeed to require, competitive bidding to be the primary mechanism determining from whom the state's electric utilities buy their power. As the law now stands, PURPA's purchase requirements do not apply in competitive wholesale electricity markets. Therefore, regulation mandating competitive bidding would allow the utility to negotiate lower prices for wholesale electricity, and the resulting savings would ultimately be passed on to consumers.

According to the Division of Consumer Advocacy, competitive bidding would have several important benefits:

- "Expand the resource options considered in meeting an identified need, thereby increasing the range of products that are available to consumers;
- "Create an opportunity for consumer savings by imposing price competition among resource options and removing the link between prices paid for incremental resources and utility avoided costs;
- "Increase efficiency in the allocation of Hawaii's resources by allowing non-utility providers to develop creative responses to specific resource needs;
- "Improve resource supply markets in Hawaii by fostering a healthy competitive climate that encourages the introduction of innovative resource options; and
- "Improve the responsiveness of utility resource plans to achieve environmental, fuel diversity and other public policy goals by removing barriers to developers with innovative resource proposals."[111]

The major players, including the utilities, appear to be in broad agreement regarding these potential benefits of competitive bidding, although the utilities seem to believe that an additional round of rulemaking would be required in order to more explicitly state the requirements of the Request for Proposal (RFP) process that would ultimately guide competitive bidding. The Division of Consumer Advocacy rejects this position, pointing out that the Kauai Island Utility Cooperative has already engaged in a competitive bidding procurement process, and that the HECO companies themselves believe that the utilities should play the dominant role in setting resource requirements.[112] The exact timeframe is as yet unknown, but it appears quite likely that competitive bidding for electricity generation capacity will become a legal requirement in the near future.

While renewable power producers will undoubtedly receive lower profit margins under a competitive bidding scheme, the nature of the free market all but guarantees that project developers will nonetheless compete to produce Hawaii's electricity. Furthermore, by giving utilities like HELCO more control over the procurement process, the state would vastly increase the utility's incentive to seek out the cheapest sources of power available and might provide them with a greater ability to address their concerns regarding intermittency, system stability and grid integration. Of course, given the varying forces at play, it is unclear exactly how such a system would influence the future penetration rates of renewable energy on the Big Island, particularly if oil prices were to dip substantially.

Renewable Energy Legislation

In the 1970s the State of Hawaii passed a series of acts in response to the oil crisis. These acts helped pave the way for the development of more renewable energy production on the islands, but none of them had a significant impact on the energy industry in Hawaii. A series of acts passed in 1974 focused primarily on research and development and coordination. These include Act 237, which created a State Energy Resources Coordinator position, Act 235, which created HNEI, and Act 236, which established NELHA.[113] In 1976 a more direct approach was adopted with Act 189, which established a tax incentive for the installation of "solar energy devices" and "alternative energy improvements."[114]

Since 2000, there has been increased interest in increasing the Big Island's energy independence. The remainder of this section will focus on the series of resulting laws designed to stimulate new growth in the renewable energy market and industry in Hawaii. We will also examine recently proposed policies deemed viable by popular opinion, but will not consider the numerous past bills that have failed.

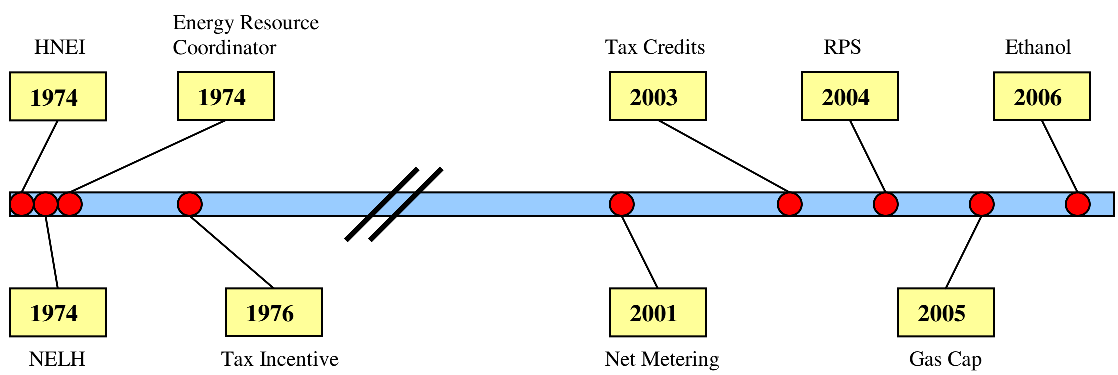


Figure 4.1: Hawaii State Level Renewable Energy Policy Timeline

Net Metering

Since 2001, four acts passed into law regarding net metering in the State of Hawaii. Net metering refers to a two-way metering system where grid-connected customers who also produce their own electricity can run their meter forwards or backwards depending on their "net" electricity draw, in effect selling their surplus generation back to the utility. Acts 272 (2001), 99 (2005), 69 (2005), and 104 (2005) each built on this net metering law. While the original laws supported only small residential and commercial customers, the general trend in the law's provisioning has been towards encouraging greater generation capacity from an ever-broadening range of customers.

The Net Metering law, as it stands in 2006, contains the following provisions:

- The system is typically limited to electricity production from renewable energy sources, usually solar, hydro, and wind.
- Residential, commercial and government entities with production capacities of under 50 kW qualify for net metering (up from 10 kW in the earlier laws) and can "bank" excess production for up to one year.

- Total output capacity of net metering subscribers may not exceed 0.5% of the electricity grid's total peak load.
- While maintaining the values established by earlier laws, Act 104 in 2005 gave the PUC the authority to amend the capacity ceiling (50 kW) and load percentage requirement (currently 0.5%).

However, the net impact on the percentage of electricity produced from renewable energy is likely to remain minor.

In 2003, to further promote residential and commercial production of electricity from renewable energy, the State of Hawaii enacted Renewable Energy Tax Credits (Act 207). The incentive-laden law, slated to run through January 1, 2008, establishes state tax credits for installing SWH, PV systems, or wind power systems. The credits are awarded based on a fixed percentage of the cost of the system or a fixed dollar amount, whichever is less. Table 4.1 lists the eligibility requirements and the value of each tax credit.[115] Between federal and state tax credits – equal to 20% and 35% of the system cost, respectively – and HELCO rebates of up to $1,000, the typical $5,100 cost of installing a new solar hot water system can be reduced by 75%.[116]

Table 4.1: Summary of Available State Tax Credits for Installation of Renewable Energy Systems

System Type	Tax Credit (%)	Dollar Amount ($)
Solar Water Heater		
single-family	35	1,750
multi-family (per unit)	35	350
commercial	35	250,000
PV Systems		
single-family	35	1,750
multi-family (per unit)	35	350
commercial	35	250,000
Wind Power		
single-family	20	1,500
multi-family (per unit)	20	200
commercial	20	250,000

Renewable Portfolio Standard

To date, twenty states have enacted Renewable Portfolio Standards (RPS).[117] In 2004, the State of Hawaii joined this group when Governor Lingle signed Act 95 into law, calling for a set percentage of all generated electricity in the state to come from renewable energy sources. The Hawaii RPS sets the following increasingly aggressive goals: 8% by 2005, 10% by 2010, 15% by 2015, and 20% by 2020. To provide context, note that in 2003 8.3% of the statewide electricity portfolio was from renewable energy.[118] It is interesting to note that in addition to electricity from conventional renewable sources, the RPS calculation also includes the displaced use of fossil fuels through more alternative means, such as solar hot water, seawater air conditioning, and small scale cogeneration, is included in the calculation used to determine if the RPS is met.[119] While the RPS in its current form sets a nonbinding goal, there has been discussion of strengthening this act into an enforceable requirement.

Gasoline – Wholesale Price Controls

The state of Hawaii consistently has the highest retail fuel prices in the nation; as of April 8th, 2006, average rates were $2.97 for regular unleaded gasoline and $3.33 for diesel.[120] The high cost of transporting fuel to the island contributes to the high gasoline retail prices, but there are other factors as well.

First, the taxes in Hawaii are higher than average. Big Island federal, state, and local taxes add up to $0.432 per gallon.[121] Many contend that a greater factor, however, is the market power resulting from the Hawaiian market's isolation. Some speculate that the limited wholesale competition allows the state's two refiners, Tesoro Corporation and Chevron Corporation, to keep wholesale gas prices high even as crude prices drop.[122] By contrast, the retail market has six major marketers – Chevron, Texaco, Tesoro, Shell, ConocoPhillips, and Aloha – presenting a somewhat more competitive environment,[123] with typical pre-cap margins of only about $0.12 per gallon.[124]

As a result, Hawaii instituted the nation's first price cap on gas prices since the 1970s energy crisis.[125] Under the new law, which went into effect on September 1, 2005, the Hawaii Public Utilities Commission (PUC) sets a weekly pre-tax wholesale price cap based on the spot prices in three mainland markets: New York Harbor, the Gulf Coast, and Los Angeles.[126] If and when prices on the mainland fell, so would prices in Hawaii.

In an early comparison of the price behavior of gas versus that of diesel, which remains unregulated, former Hawaii Governor Ben Cayetano presents some evidence that gas prices are lower than they might otherwise be without the cap (see Table 4.2). As retail prices on the mainland fell from their Katrina high of $3.06 to $2.25 on February 24, 2006 – a drop of 26.4% – Hawaii gas prices fell by a similar 25.7%. Over the same period, mainland diesel prices saw a 21.2% decrease, while those in the unregulated Hawaiian diesel market fell by only 5.3%.[127]

Table 4.2: The Effect of the Price Cap on Gasoline[128]

	U.S. Reg. Unld	HI Reg. Unld	U.S. Diesel	HI Diesel
Katrina high	$ 3.057	$ 3.594	$ 3.239	$ 3.403
Feb. 24, 2006	$ 2.249	$ 2.670	$ 2.552	$ 3.222
Decrease (cents/gal)	$ 0.808	$ 0.924	$ 0.687	$ 0.181
Decrease (%)	*26.4%*	*25.7%*	*21.2%*	*5.3%*

One cannot assume that retail prices will drop with the newly capped wholesale prices. In addition, opponents of the cap, including Governor Linda Lingle, worry that it will lead to supply shortages in the future as the Hawaiian market becomes less appealing to current and potential future suppliers.[129]

[Editor's note: as of May 5, 2006, the gas cap has been repealed after being in effect for eight months.]

Ethanol Legislation

In the 1990s, the Hawaii state legislature passed a law requiring that 85% of the gasoline sold in the state contain 10% ethanol, but the law was never enforced. The reason most commonly cited is that there is no ethanol production in the state to meet the requirement, and that importing ethanol has never been a popular idea. In 2004, Governor Lingle signed a rule to implement the neglected law. The ethanol requirement went into effect on April 1, 2006. Hawaii will be one of three states, including Minnesota and Montana, to have an active 10% ethanol requirement, though many other states have heavily subsidized ethanol programs.

Approximately 34 million gallons of ethanol per year will be required statewide to meet the new demand.[130] In 2004, seemingly in an effort to prepare the state for the impending ethanol law, Governor Lingle signed Senate Bill 3207 and House Bill 1944 into law. The first law provides tax credits for producing and investing in ethanol production in Hawaii, and the second extends the option for state financing, through $50 million in bonds, of an ethanol project for another five years.[131] Currently at least two companies, Worldwide Energy Group and Maui Ethanol LLC, have plans to build major ethanol facilities in conjunction with sugar cane plantations on the Islands of Kauai and Maui respectively.[132]

4.2. Case Study in Multi-Stakeholder Process: Geothermal

The history of geothermal electricity generation on the Big Island is very contentious, with fierce opposition to development arising as a result of health concerns, land use questions, and cultural differences.

History

Geothermal development began in 1976 when a public-private partnership developed a well (HGP-A) in the lower KERZ. Six years later, a 3 MW power plant went online at this site. Although it was originally intended to be a two-year experimental plant, HGP-A remained online for eight years and generated between 15 and 19 million kWh per year. Before its closure in 1989, HGP-A's lack of maintenance damaged the reliability of the plant, and costs began exceeding revenues. The community and various regulatory agencies found the pollutant treatment (both gaseous and brine) unacceptable.[133]

In the 1980s, the Campbell Estate sought to drill for geothermal resources in an area called Kahauale'a, which was conservation-zoned. This drew opposition from local residents, led by Russell Kokubun, who is now a State Senator. A compromise was reached that allowed for a land swap, giving Campbell Estates control over 27,800 acres of Wao Kele 'O Puna Natural Area Reserve and Puna Forest Reserve. True Geothermal's efforts to develop this land were not welcomed by local residents, who formed the Pele Defense Fund to challenge the swap.[134] Ultimately, after several years of unsuccessful exploration amid decreasing political support, efforts were abandoned.[135]

One additional piece of the geothermal history involved the potential to harness the Big Island's with the goal of helping meet the electricity needs of other Hawaiian islands. Due to the high potential for geothermal production on the island and the relatively low population density, feasibility assessments were conducted to determine if such inter-island transmission would be possible. These studies, conducted throughout the 1980s at a cost of over $26 million in federal and state funding, found that the Hawaii Deep Water Cable would be technically feasible but economically impractical without government subsidies. Efforts by the state to gain research funds triggered a lawsuit by the Sierra Club Legal Defense Fund against the U.S. Department of Energy, with the goal of forcing a full environmental impact analysis to be conducted for the proposed 500 MW facility. Efforts to create an impact assessment failed to meet the demands of the opponents, and the government withdrew their support for the project.[136] Currently, the political will to support this project does not exist, with the common mindset being that energy production that occurs on the island should be used exclusively on the island.

Health Concerns

The major potential health threat resulting from geothermal development stems from the hydrogen sulfide (H_2S) present in the geothermal steam. H_2S is a poisonous gas that can be detected by humans (it smells like rotten eggs) at levels as low as 10 parts per billion (ppb). At low levels of 50-100 parts per million (ppm), it can cause dizziness, coughing, headaches, and eye irritation. Exposure to higher levels – usually exceeding 600 ppm – can be fatal.[137] Hawaii's geothermal sources have significantly more H_2S than most other geothermal sites, with concentrations around 700 ppm present in the steam used for power generation.[138] The toxic gas disperses quickly in the open air, though, so it typically poses more of a nuisance than a health threat to those outside the immediate vicinity.

In 1990, experimental efforts at the PGV facility replaced those at HGP-A,[139] and after an uncontrolled blowout in 1991 released considerable amounts of H_2S, local health concerns mounted. The blowout prompted a health risk assessment by the state Department of Health. Their report concluded that residents would not experience any adverse health effects from accidental releases, and would be exposed to a maximum concentration of about 12,700 ppb of H_2S for less than one hour[140] – above the 8-hour OSHA permissible exposure limit, but still well below the concentration necessary to cause any harmful impacts other than unpleasant odors.[141] A later investigation into unplanned releases in 1996-1997 found that concentrations never exceeded 500 ppb during this period.

While the Department of Health's Health Risk Assessment stated that the public would not experience any adverse health effects from accidental releases, other experts disagreed. The state commissioned Goddard and Goddard Engineering to conduct a micro-meteorological assessment, which found that concentrations at the center of a discharge plume would remain high. Wilson Goddard wrote to the US EPA that "scenarios result in severe significant impacts exceeding federal regulations."[142] His opinion about geothermal energy is not patently negative, however, as shown in his statement to the Houston Chronicle that "if it's done right and in the right location, it can be benign…The history of [PGV] development, unfortunately, has not been good."[143]

In 1996, Dr. Marvin Legator, an environmental toxicologist from the University of Texas, interviewed locals near the plant with the goal of assessing the impact of long-term exposure to low levels of H_2S. In 2001, he and his colleagues published a report that showed high self-reported numbers of hydrogen sulfide-related ailments in the affected community.[144] The study acknowledged, though, that it "may be susceptible to response enhancement bias (i.e., an increase in reported symptoms resulting from the fact that respondents are aware of, and sensitized to, the fact that they are exposed). Our study was vulnerable in this area given the rather intense political controversy that characterized the history of H_2S exposure in the Puna community."[145] Thus it is unclear to what degree the reported symptoms may reflect genuine health impacts.

PGV continues to operate today and Barry Mizuno, the owner's public relations representative, claims that PGV has made strides towards containing the unpleasant gas leaks and improving community relations, particularly with the 100 residents who live within 3,500 feet of the plant.[146]

Cultural Issues

Cultural issues play an important role in the opposition to geothermal development. The volcanoes are highly important to Native Hawaiian culture and spiritual leaders believe that harnessing geothermal energy is effectively taking from Pele, the Goddess of volcanoes, which violates their spiritual beliefs. Ulu Kanaka'ole, a Native Hawaiian leader, claimed that nature was not ready for these geothermal projects. When asked whether there would be room for discussion if future projects were handled with more respect towards native Hawaiian beliefs, she responded, "The island is not ready for this. In the future, it may be, but now it is not." This family places a high value on environmental stewardship, but feels quite strongly that renewable energy generation can be achieved through technologies other than geothermal.

Land Use

In addition to religious beliefs, another important consideration centers around the siting of power plants in ecologically sensitive areas, a concern that can be especially powerful given Hawaii's diverse and sometimes fragile ecosystems. This was most evident in the failed attempt by the True Geothermal Energy Corporation to develop a power plant in the Wao Kele 'O Puna rainforest, the last major lowland tropical rainforest in the United States. Although there were other social and cultural sources of opposition for the project, one point of contention was the environmental importance of the area:

> "'Kilauea is one of the most active volcanoes in the world. Being a small volcano, that means its surface is covered frequently,' notes biologist Rick Warshauer of the U.S. Geological Survey's Biological Resources Division, who knows the rainforest well. 'In order to maintain the native vegetation, there has to be a lot of seed sources of older kipukas [patches of rainforest among the lava fields]…What you need is to have a large critical mass of diverse native vegetation to keep vegetation on Kilauea's flows native,' he maintains. 'Otherwise it will be snuffed out by aliens.' Wao Kele 'O Puna, he says, is 'as good [a rainforest] as you're going to find.'"[147]

The proposed power plant was also problematic in that "Native Hawaiian residents from ancient times to the present had customarily come to the Wao Kele 'O Puna area for such products as kukui, ginger, taro, ti leaf and awa, as well as for hunting and cultivation of mala'ai, or dryland garden patches…[The Puna community's] continuing dependence on subsistence hunting and agriculture has persisted over time."[148] Restricting the availability of these traditional food sources would almost certainly have had negative consequences for native communities. The Native American Rights Fund, in operation with the Pele Defense Fund, is seeking to "regain Native Hawaiians' access rights to rainforest lands traditionally exercised by Native Hawaiians before those lands were exchanged in 1983." In September of 2005, it was announced that the Trust for Public Land will acquire more than 40 square miles of Wao Kele 'O Puna rainforest from the Campbell Estates. This piece of land is near Hawaii Volcanoes National Park and is expected to be conveyed to the Office of Hawaiian Affairs. If the goals of the Pele Defense Fund are met, this land will be shielded from geothermal energy production and other non-forest uses.[149]

There are persuasive arguments supporting geothermal production on the Big Island: reduction of soaring electricity costs, the ongoing ability to meet growing baseload capacity needs, and mitigation of greenhouse gas emissions. (To date, PGV's operations have displaced the combustion of 200 million gallons of oil.) However, opinions on geothermal development are strong and polarized. Resistance to the current operation at PGV has probably diminished somewhat over time, but should the Big Island revisit plans to develop other areas of the island, the critics would certainly resurface. Any future plans must honestly consider the concerns and incorporate the diverse needs of the many stakeholders involved.

4.3. Social and Political Constraint Analysis of Major Energy Options

In this section we present a qualitative analysis of the dominant social and political constraints on the major energy forms. We address economic and technical issues only indirectly. We have summarized the dominant constraints in Table 4.3 and explained each in more detail below.

Table 4.3: Major Social and Political Constraints on Energy Options

Energy form	Constraint type	Major actors involved	Factors underlying opposition
Fossil fuels	Social	NGOs, public	environmental concerns; resource security; cost to consumers; past
Wind	Social	windfarm neighbors	visual impact
Wind	Political/regulatory	HELCO, PUC/state legislature	grid stability concerns; lack of financial incentive
Biomass	regulatory	County Planning Department, public	zoning regulations (restrictions on land use)
Geothermal	Social	NGOs, public, traditional religious communities	religious beliefs; public health concerns; community relations; land
Solar	Regulatory	State legislature	'wheeling' prohibited under current law; subsidies set to expire in 2008

Fossil Fuels

Discussions with various stakeholders and members of the general public revealed a widespread distaste for increased fossil fuel use in electricity generation, a solution regarded as unnecessary by many in light of the island's abundant renewable resources. This aversion comes on various grounds: environmental (concerning climate change as well as more localized impacts), resource security, and financial (revealing a largely justified belief that renewable sources of electricity will be cheaper than oil for Hawaii in the long run). The community displayed its commitment to this stance during HELCO's recent efforts to expand the Keahole oil-fired power plant. Due in part to the NGO and public response to these efforts, HELCO made a public commitment that after expanding the Keahole plant they would avoid building any new fossil fuel capacity on the island:

> "HELCO's president, Mr. Warren Lee, recently stated in HELCO's announcement of its plans to seek a rate increase in 2006 that: 'At this time, I can foresee no circumstance under which we would seek to construct a new fossil fuel plant. We now move formally and decisively to make renewable energy, energy efficiency and conservation our future.' Therefore, we have been analyzing options that are consistent with this statement."[150]

The utility did proceed to present a least-cost plan at their next IRP advisory group meeting that included 27 MW of new coal capacity. As noted above, it is unclear whether this represents an option that the utility is seriously pursuing or merely a result of the way in which they constructed their least-cost model. If HELCO did ultimately attempt to move forward with the plant, they would undoubtedly face stiff resistance from community groups, the public, and the county and state legislatures.

Even if the coal plant were to come on line, however, this would probably be the upper bound of increased fossil fuel consumption for electricity on the island. Indeed, in all five of HELCO's IRP scenarios, the only additional fossil fuel-derived power (other than the coal plant) comes from adding a steam turbine to an existing oil-fired plant, which would in essence produce a greater electrical output from the same level of input.

Wind

General public opinion seems to regard wind as the key to the island's energy future. As a result, wind energy enjoys broad public support. Social opposition does not appear to have been a decisive factor in the success or failure of any wind power projects to date on the island. Kahua Ranch, the only proposed and subsequently cancelled windfarm for which information was available, was only withdrawn because its project developer, Hawi Renewable Development, chose to instead pursue an alternative project at Upolo Point.[151]

However, there have been after-the-fact aesthetical complaints from neighbors of the recently completed Upolo Point windpower plant. Area residents have complained that the turbines interrupt their view of the coastline. Furthermore, blinking red lights installed on the windmills for aviation security reasons have left adjacents homeowners dismayed. Because the facility was still in its first few weeks of operation as of the writing of this report, it is unknown how persistent or serious these concerns will prove to be, but the experience does suggest that siting issues may be an important ongoing factor in future wind development plans. While relatively remote areas with wind promise do exist, there are also wind-rich areas – such as that between Waimea and Waikaloa Village – where future development plans could prove problematic.

A more important constraint on increased wind use is opposition from HELCO. Systems engineers and other employees indicated a great deal of concern regarding the implications of the wind's intermittency issues. They discussed the resulting frequency concerns and their potential effect on system stability, as well as the high costs associated with establishing new grid connections. Stability issues are especially acute in the Big Island's electricity distribution system because it is a micro-grid without any interconnections to a larger network, leaving it more vulnerable than a mainland grid with viable neighboring grids. These concerns are while valid, but could likely be addressed through increased use of PSH or other backup power as well as improved systems communication and control abilities.

A more fundamental problem underlying their opposition is the fact that the existing regulatory framework compels HELCO to purchase power from IPPs at price well above operating costs while they are unable to realize any profits themselves from this purchased electricity. This constraint was discussed in greater detail in Section 4.1.

Bioenergy

The most likely constraint on bioenergy would be land availability for large-scale production of dedicated energy crops, whether for ethanol or electricity. Perhaps as an effort to safeguard Hawaii's ecological diversity, or perhaps simply because of bureaucratic red tape, the zoning regulations in Hawaii are perceived to be far-reaching and difficult to circumvent. While there is available land from the former sugar plantations that could presumably be devoted to bioenergy crops, it seems likely that it would be administratively (and perhaps politically) difficult to expand production beyond these areas into previously undeveloped land.

Geothermal

As discussed above, the history of PGV and its predecessors reveals that geothermal energy is undoubtedly the renewable option with the most intense social opposition. Opposition comes in many forms. One constituency, represented by the Kanaka'ole family, includes those people who believe the volcano to be the incarnation of the goddess Pele and consider any interference with her to be sacrilegious. This group appears to be a small minority on the island, but one that is powerful and well-respected nonetheless. The family is well-known for its efforts to strengthen island communities and preserve native culture, most notably through the Edith Kanaka'ole Foundation, and their successes in these areas have left them in great standing on the island.

Community-based opposition is centered on environmental justice concerns and NIMBY (not in my backyard) activism. The potential health risks of uncontrolled emissions from PGV remain a sensitive topic among many neighboring residents, and one that is certainly not helped by the sulfurous odor of otherwise harmlessly low background H_2S gas levels. There is also public opposition based on land use, for fear of both disturbing fragile ecosystems and denying native people access to their traditional lands.

All three of these strains – religious, community, and environmental – have combined to form a powerful bloc of geothermal opponents, as evidenced by the tumultuous history of geothermal development of the Big Island. This is not limited merely to the public at large: several state- and county-level politicians rose to prominence during the early struggles and likely count themselves as opponents of increased geothermal energy use. While PGV's announced plan to increase its capacity has not met with significant pushback, we believe this absence of conflict stems from the fact that any increased power generation at PGV will be occurring on land that has already experienced geothermal development. In other words, the major battles there have already been fought. However, development efforts in other locations would likely face much stiffer, potential unbeatable, opposition.

It is also worth noting that, as with wind, geothermal power has been heavily pursued by IPPs. HELCO thus has no real incentive, outside of the technical benefits presented by its firm baseload characteristics, to advocate for expanded geothermal use.

Solar

Interviews with a variety of stakeholders revealed no social opposition to an expansion of the Big Island's solar energy use. In fact, it appears to be perceived as a very positive option. For example, the utility's residential SWH program has proven quite popular, with an estimated 6000 units installed on the Big Island.[152] As for larger installations, in contrast to wind power plants, large solar arrays such as that as NELHA facility seem to have garnered widespread support.

One constraint that is already in evidence lies in the regulatory structure of the energy system. While net metering, which allows a customer to sell surplus electricity back to the utility, is encouraged, this electricity garners a pre-established price.[153] In contrast, 'wheeling' is an arrangement by which electricity generated from solar PV (or another distributed resource) on one customer's property could be fed into the utility distribution system and sold to a third party. In this way, resorts or other customers with insufficient land area to devote to solar arrays would still be able to reap the reputational and pricing benefits of solar PV. Wheeling is currently prohibited in the state of Hawaii. The Mauna Lani Resort, which boasts the most solar electric generating capacity of any resort in the world, has the land available to expand its solar generation and potentially sell electricity to other resorts on the island should wheeling be legalized. There is legislation pending before the state legislature, perhaps as a result of this interest, to allow wheeling in the future.[154] Until that happens, however, the combination of land constraints on the property of large commercial customers and the current wheeling ban will limit the amount of solar PV installations.

It should also be noted that PV's economic attractiveness at present depends on several subsidies. Chief among these are the corporate and residential income tax exemption for 35% of the cost of an installed system. The tax credits are currently slated to expire on January 1, 2008; if they are not extended, Hawaii County's interest in solar PV will likely drop precipitously.[155]

5. The Total Systems Approach to Industry, Materials, and Energy

The Yale study of Hawaii Island is comprised of two parts: this energy analysis and a study by another team of students on the island's industry and use of materials. Both parts employ a systems approach, with the goal of capturing all relevant information within the boundaries of the study (i.e., the island's activities). The utilization of systems analyses captures all activities throughout the entire life cycle of the observed activity. By considering both energy and materials systems in concert, one can identify opportunities to use waste energy to drive industry or use local materials to generate energy. The field of industrial ecology aims to create such linkages, "closing the loop" on material and energy use and lessening the environmental impact of industrial activity.

Electricity production often produces a considerable amount of waste heat and other waste byproducts, so it is important to consider potential uses for this waste stream. In 1985, the Noi'i O Puna research center was created next to HGP-A, the geothermal pilot plant, with the goal of developing uses for waste heat. The following year, the Community Geothermal Technology Program was launched with the aim of fostering small businesses near the plant. Ten projects were funded in two rounds of funding. Several focused on potential uses for geothermal heat, such as the drying of lumber or green papaya powder. Direct use of heat was also employed by such projects as a tilapia fish farm, a greenhouse heating system, and a media sterilization project. Use of non-heat waste products include glass manufacturing from waste silica, the use of silica as a refractory in bronze artwork casting, cloth dyeing utilizing the chemical composition of the steam, and electrodeposition of minerals such as calcium carbonate.[156] These projects serve several beneficial goals: they increase employment in value-added sectors, boost the local economy, and do not appreciably increase virgin energy demand due to their use of waste energy. In some cases, they also decrease the reliance on foreign imports.

While these pilot projects spurred creative solutions to utilizing waste heat and byproducts, there are considerable opportunities for larger scale projects. The overall electricity generating efficiency of oil-burning plants is 31%, with 69% of the energy lost primarily to waste heat. This means that over 7×10^{12} BTU is lost as low-value heat that could provide an inexpensive and environmentally-friendly source of energy. Although it is not technical feasible to harness the majority of this energy, a tremendous theoretical potential exists. For example, if this waste heat were to be used for low-grade water heating, the energy contained therein could theoretically warm 32 million gallons of water each day by 40°C.

Local materials also serve as potential sources of energy, whether it be in waste materials (waste oil for biodiesel production and bagasse and other agricultural combustion) or dedicated energy crops. The use of these local materials effectively reduces foreign dependence on energy sources, increases the share of renewables in the energy portfolio, creates employment opportunities, and reduces net greenhouse gas emissions. When the sugar industry was active, the Pepeekeo plant (operated by Hilo Coast Processing Co.) burned the bagasse waste from sugar cane processing, generating a significant amount of electricity and heat. When the sugar industry collapsed in the mid-1990s, this plant remained online but relied on imported coal as its energy source. Its operations ceased in 2005, but the potential for future use of this site still exists.

Much of the sugar plantation land is currently lying fallow. One possible use for this land would be to revive the sugar industry and utilize the sugar cane for ethanol production and the bagasse for heat or electricity production. The heavy dependence on imported liquid fuels could be reduced with local ethanol production, which is being realized with the 10% ethanol mandate in gasoline and the 10-million gallon ethanol plant which is slated to open in 2007. A full discussion of the potential for energy generation from all material-based sources is provided in Section 3.2.

6. Conclusions and Recommendations for Future Research

The work presented here is intended to serve as a baseline energy analysis for Hawaii Island. Included in this report are comprehensive details of current and historical energy use, by source and end use. By understanding the demand, the drivers of energy use have been isolated, giving a solid foundation for future discussions on altering the energy portfolio. This report also addressed the cultural, regulatory, and political climate in which the energy system operates; this is essential information for anyone who wishes to truly understand this county's energy use.

Hawaii Island is remarkable for its natural beauty and wealth of natural resources. Renewable resources are used extensively in electricity generation, providing 22% of the net production. Geothermal generation is the renewable leader, followed by significant hydropower production, and modest wind and photovoltaic solar operations. Direct use of solar thermal energy is significant as well. The potential for increased renewable use is quite high, and Hawaii Island is expected to lead the state in the transition to "greener" energy. With the highest unit costs of electricity in the country, Hawaii is uniquely poised to increase renewable energy production within the limits of current prices.

Looking at electricity generation only tells part of the story, however. Approximately 71% of the final energy use is utilized for transportation. This accounts of 51% of the energy content in the imported fuels and renewables used each year. Currently, nearly all of the transportation energy comes from non-renewable fossil fuel sources. This will change, however, with the advent of the ethanol mandate, which will likely use domestically produced ethanol from local sugar plantations. This will serve to increase the use of renewable resources and decrease foreign dependence on energy.

The low population density of the island exacerbates the energy situation on two fronts: 1) long travel distances and little public transportation increase liquid fuel demand, and 2) poor cross-island electrical transmission and a demand-generation spatial mismatch lead to line losses. As tourism and demand increase on the western side of the island, the ability to meet this demand will require more generation in that area or increased long-distance transmission coupled with high line losses and, often, resentment from areas generating this power.

Central to the energy discussion on the island are the cultural issues, some of which are unique to this state. Geothermal development has proven to be a very contentious issue with a group of native residents in opposition due to spiritual reasons and locals in opposition claiming that it is a health and environment risk. Others see it as an opportunity to decrease foreign dependence on energy and reduce greenhouse gas emissions. The current geothermal developer has permits that would allow for a doubling of current operations. Any development beyond this would likely be met by strong opposition.

This report lays the foundation for more detailed studies and analyses of the energy system in Hawaii County. Here are several suggestions for future study:

Detailed Analysis of Economic Trends and Projections

Big Island economics clearly contribute to energy use, peak electricity loads, and general welfare. For future studies, we recommend establishing statistically significant correlations between various economic indicators and energy use metrics.

Transportation

We have not completed a detailed examination of trends in the transportation industry. Future teams should consider looking more closely at fuel economy of the Big Island vehicle fleet, rental car growth, inter-island transportation, etc.

In addition, public transportation, or relative lack thereof, continues to be a critical issue relating to high liquid fuel usage on the island. It would be worth surveying the population to investigate a possible expansion of the existing public transit system. Factors to consider are average commutes, population centers, economics of public transportation,etc.

Energy Impact of Inter-Island Boat Transportation

Currently, all inter-island transportation occurs via air, with air travel consuming 19% of the final energy. Keep in mind that this only includes fueling that occurs on the Big Island and refueling on other islands will also increase the statewide energy consumption. Plans are underway to offer inter-island transportation by water vessels, a change that will have significant impact on the consumption of liquid fuels.

Cumulative Load Duration Curve

Due to the confidential nature of the data, we were unable to obtain a cumulative load duration curve for all 8,760 hours in 2005. Using the two sample days that we had, we constructed a 48-hour version of this plot. Obtaining or creating a full graph would provide increased insight into the capacity requirements, and in particular into the peak and base load requirements.

Clearly, a great deal of work remains to be done in order to fully understand the Big Island's current energy system and the different ways in which it might evolve in the future. This paper presents an important first step in this regard, and we hope that it will provide some insight into ways in which the island's energy system can also be made more environmentally, socially and financially sustainable.

End Use of Energy

Although it is clear that water heating and air conditioning are among the most important end uses of energy on the island, additional detail is needed in this area. Energy demand for water heating, air conditioning, and all other end uses should be quantified to the greatest extent possible. Such information would make it clear what proportion of electricity demand could be substituted by solar power or liquid fuels. Information regarding the thermal characteristics of the Island's housing stock would also provide valuable insight into the end use of energy and highlight the potential for efficiency improvements to decrease demand.

Another important aspect of the end use of energy is transportation. Ground transportation accounts for a majority of the final energy demand on the island, but beyond a cursory examination of the vehicle fleet we have done little to examine this in detail. Future research should develop this assessment in more detail and furthermore consider the potential impact of expanded public transportation or changes to the vehicle fleet (such as increased use of hybrid cars). It should also examine the impact on transportation fuel use of land use changes that develop compact, walkable communities.

Transmission Losses and Costs

We recommend conducting a more detailed analysis into cross-island transmission losses and their associated economic and environmental costs. This could be coupled with scenarios to determine the possible economic breakeven point that would justify major transmission line improvements. This analysis could also be used to inform future placement of generation systems.

Sugarcane and Gasoline

With current gasoline prices at near-record levels and significant potential for sugar-cane based ethanol, an economic analysis could highlight the potential for ethanol production as a function of gasoline price. For example, if gasoline prices top $4.00 per gallon and current ethanol subsidies remain in place, how much ethanol could profitably be produced? The analysis would need to include the likely constraints, such as a shortage of cheap labor, the inability of cars to take high ethanol blend without retrofitting, and competition from other ethanol producing states and nations.

Improving Estimates of Renewable Energy Potentials

As noted in the body of the report, in this study we have not followed one particular methodology in estimating renewable resource potentials. Future research should address this shortcoming. We recommend the following approach:

Theoretical potential should be determined by considering the maximum available energy output from each energy source: for instance, assuming that all land on the island is used solely for the purpose of housing renewable generation equipment. However, theoretical potential should take account for the limits imposed by technology; one should not assume that PV panels can convert sunlight into electricity with 100% conversion efficiency, or that wind turbines can work with very low-speed winds. Thus, theoretical potential can be seen as acknowledging technological realities, but nothing else. If possible, such values may be drawn from the existing literature, as we have done with our hydropower and geothermal estimates; in cases where no prior estimates exist, more on-the-ground research will be needed.

Technical potential narrows down theoretical potential by regulatory, environmental and land use constraints. A robust estimate of technical potential should consider the following factors: restrictions on land use within national parks and other protected areas, as well as cities and resorts; other site availability concerns, including the total proportion of land that could realistically be allocated to energy production; regulatory conditions which may limit potential supply; and, if readily quantifiable and reasonably certain, any social or institutional limitations. For intermittent resources such as wind, constraints on the availability of storage technologies should also be examined. To integrate all these considerations, a detailed spatial analysis of the island will be necessary. Current demand should not be used as a proxy for technical potential, because this approach implies that there is no room for growth in resource beyond present conditions. Such concerns are best addressed through economic potential.

Economic potential should be calculated under a number of different circumstances. The first such analysis should determine the level of energy production that is economic under current prices and conditions, from the point of view of the project developer. This estimate would assume the continued existence of current subsidies, taxes, and other price-setting mechanisms such as avoided-cost pricing. A second calculation would maintain current (or projected near-term) prices but remove the regulatory distortions just mentioned. Following that, economic potential should be calculated at several different price points, in order to make it clear how the resource mix could develop under different scenarios of technological improvements and economic changes. This would facilitate comparisons between the availability of one resource and another at different demand levels. If it is believed that the resource has potential to meet the island's full demand, it should be made clear how much additional growth in demand could be accommodated.

Scenario Development Using Renewable Energy Potentials

Building off of and improving upon the renewable energy potentials in this report, a set of scenarios could be developed. These scenarios could answer such questions as "What would a 100% renewable Hawaii Island look like and how would they get there?" and "What are the environmental impacts of different development trajectories?"

Impact of Plant Retirement in Sustainability Transition Scenario

According to HELCO, no fossil fuel plants are slated for retirement within the next 20 years. Yet a major goal of this study is to examine the feasibility of a transition to sustainable energy within this approximate time horizon. Therefore, the transition scenario should address not only the technical viability of such a shift, but should also provide an economic/financial analysis of how premature plant retirements could impact the utility and the island's consumers. The costs of any planned maintenance and repairs to existing plants should be accounted for as well.

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Appendix

Methodology for Calculating Emissions from Liquid Fuels

For each liquid fuel, an emissions factor was calculated for each pollutant in grams per gallon of fuel. Data sources and methodology for each factor are described briefly below.

Table A.1. Estimated Emissions Factors for Liquid Fuel Use

Pollutant Source	Fuel Type	NOx (g/gallon)	SO2 (g/gallon)	CO2 (g/gallon)	CO (g/gallon)	VOCs (g/gallon)
Ground Vehicles	Gasoline	28.9	0.2	8623.1	434.7	58.2
Ground Vehicles	Diesel	9.2	0.1	4652.3		1.5
Ground Vehicles	LPG	5.5	0.6	4924.4	0.0	0.0
Marine Vehicles	Diesel	32.0	0.1	8105.3	853.0	209.3
Airplanes	Aviation Fuel	28.0	2.7	8575.3	5.4	0.3
Direct Heating Applications	LPG	5.5	0.6	4924.4	0.0	0.0

Emissions factors for automobiles were taken from EPA year 2000 estimates, available at http://www.epa.gov/otaq/consumer/f00013.pdf. Based on Hawaii's vehicle fleet, an average fuel efficiency of 20.8 miles per gallon is assumed, following the Hawaii Energy Strategy 2000. This estimate is in line with nationwide numbers; EPA estimates average fuel use of cars at 21.5 mpg and light trucks at 17.2. A density of 6 lbs/gal is used.

Although the county provides separate numbers for diesel use from highway and non-highway (e.g. construction) vehicles, due to data limitations we use a single emissions factor for each pollutant here. Emissions factors are taken from a variety of government sources, which are compiled at http://www.cfs.co.uk/sustainability2003/ecological/conversions.htm. The exception is that diesel is assumed to have a sulfur content of 15 ppm, in keeping with a recently promulgated EPA mandate.[157] Density of the fuel was assumed to be 7.26 lbs/gal.

For LPG, as with diesel, a lack of available data forces us to use the same emissions factors for stationary as for mobile sources. In the case of LPG, we use emissions factors based on stationary, direct heating applications. These factors were produced by the Department of Energy's office of Energy Efficiency and Renewable Energy and are available online at http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/k-2.pdf. We used an energy content of 22.16 MJ/L. Furthermore, we assume complete combustion, meaning that all carbon contained in the fuel is emitted in the form of CO_2 rather than CO or VOCs. While neither of these assumptions are ideal, due to LPG's small contribution to the overall fuel use of the island (around 1/100th of 1%), the error in our total estimated emissions resulting from these shortcomings will be negligible.

Emissions factors for marine vehicles are taken from EPA's widely-used NONROAD 2005 emissions inventory model and can be found at http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2005/420r05019.pdf. For the sake of simplicity, all boats are assumed to be powered by 2-stroke, direct injection, 60-hp engines. These specifications fall in the midrange of EPA's values and are believed to be fairly typical of boats actually in use. Since all fuel reported in this category was produced for small boats, significantly larger ships are not a concern here. The same assumptions made above regarding the sulfur content and density of diesel fuel were carried through here.

Finally, aviation fuel emissions factors are taken from a study by the European Environmental Agency, which can be found at http://reports.eea.eu.int/EMEPCORINAIR4/en/B851vs2.4.pdf. We used the emissions factors reported for use with the simple methodology, reflecting an average-aged domestic plane fleet. A density of 6.84 lbs/gallon was used. It is important to note that different emissions factors are associated with LTOs (the landing/takeoff cycle) as with normal cruising. Therefore, we determined the number of LTOs on the island using information on flights onto and off of the island from the Hawaii County Data Book,[158] multiplied the average amount of fuel used in LTO by the emissions factors and the number of LTOs in the county over one year, and then multiplied the remaining fuel by the cruising emissions factors. The most recent year for which data on the number of flights on the island were publicly available was 2003; utilizing that information, we used a figure of 109,313 LTOs. While using multiple years for our data sources undoubtedly produced some small amount of error, we did calculate emissions using the correct total amount of fuel used in 2005. Thus, the only discrepancy in total emissions would result from slightly differing proportions of fuel being used during LTO as with cruising between 2003 and 2005. Fortunately, the emissions factors for these two activities are quite close to each other with respect to every pollutant other than carbon monoxide and VOCs. We are confident, therefore, that our numbers represent a very reasonable approximation of the expected emissions.

Table A.2. Emissions from Aviation Fuel Use

	NO_x (g/gallon)	SO_2 (g/gallon)	CO_2 (g/gallon)	CO (g/gallon)	VOCs (g/gallon)
LTO	31.2	3.0	9780.6	44.4	1.9
Cruise	32.0	3.1	9775.9	6.2	0.3

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