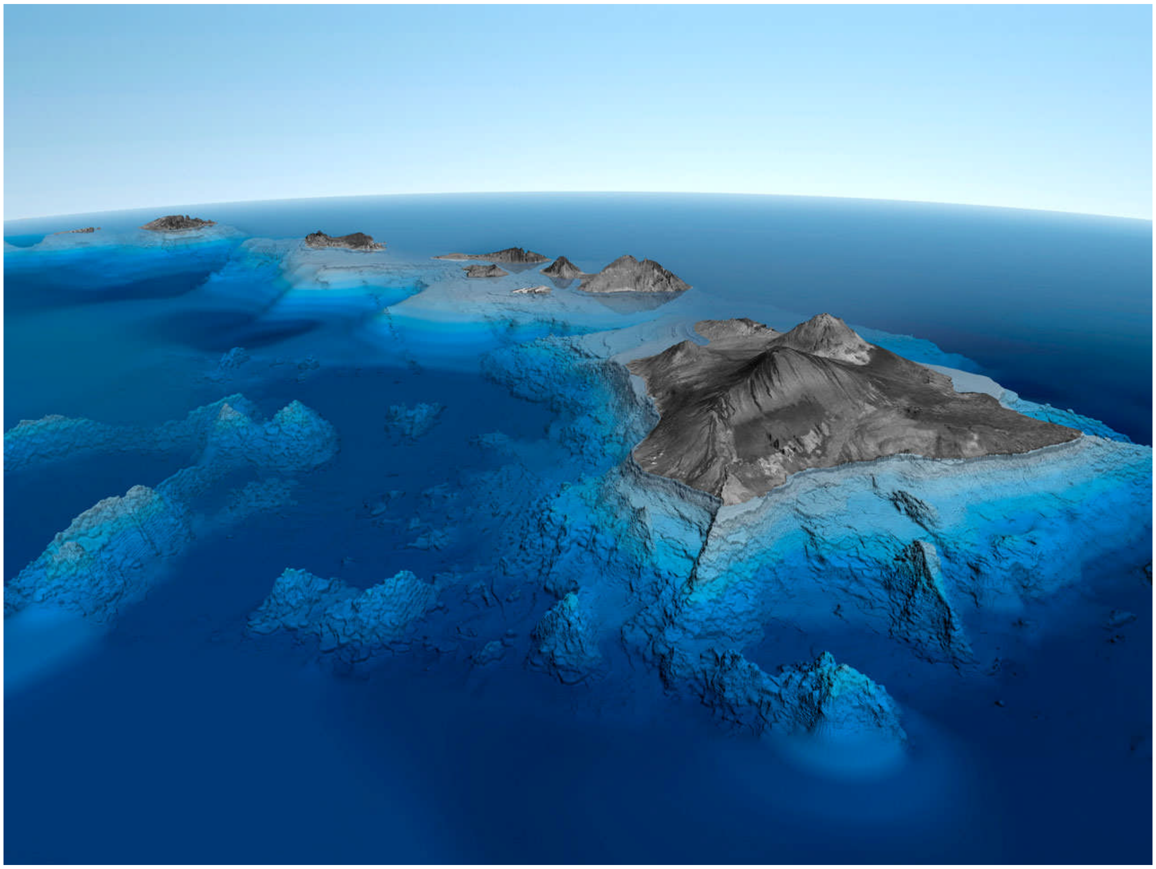


Life of the Land's

Energy Independence for Hawai`i (2030)

An Integrated Approach to Economic Revitalization in a Culturally and Environmentally Sensitive Way

Written by Henry Curtis

(February 25, 2011)

EXECUTIVE SUMMARY

With this document, Life of the Land lays out a plan whereby each island would be 100% energy self-reliant by 2030. The chief baseload energy would be Ocean Thermal Energy Conversion (OTEC). Pacific Biodiesel would focus on the production of Jet Bio-Fuel.

Chapter 1 focuses on the key energy issues that need to be understood in discussing energy projects. There is often confusion in public discourse between load and peak load, between megawatts and megawatt-hours, between costs and financial costs and between intermittent and continuous power. Key mechanisms for delivering non-utility power to the grid are also discussed.

Chapter 2 focuses on energy efficiency. It is often, but erroneously, described as the low hanging fruit. Energy efficiency is primarily an economic tool, not an energy tool.

Chapter 3 focuses on the major types of renewable energy. We include Sea Water Air Conditioning in this section, although it is a displacement technology and not a renewable energy. That is, it diminishes the need for renewable energy rather than providing renewable energy.

In Chapters 4 we lay out the vision of what we want to accomplish. The key is recognizing that energy facilities are part of, and not separate from, the community. They need to be integrated into the educational system and there must be transparency at every level; data must be collected and shared.

OTEC systems utilize a number of specific technological components including very lengthy underwater pipes, and special heat exchangers, and they move around substantial amounts of water. The facility must be in waters 4000 feet deep. Underwater transmission lines are needed to bring the power to shore. To avoid the coastal reefs, the transmission line should be buried using Horizontal Directional Drilling (HDD).

While the oil industry brought us global warming, it also brought an understanding of oil rigs and other offshore platforms. Unlike oil operations, which tap into huge underground oil and gas fields that can leak or explode, the oil platform technology can serve as relatively benign platforms for renewable energy systems such as OTEC and wave energy facilities.

In Chapter 5 we discuss solutions for transportation.

Chapters 6-11 examine the impacts from various perspectives: environmental, cultural, social justice and economics.

The amount of electricity that could be generated is measured in megawatts (MW). The actual amount of electricity that is generated is measured in megawatt-hours (MWhr). The combined total of all electricity generating power plants operating in Hawai`i is about 2300 MW. Table I lists the amount of Renewable Energy that could be brought on line now, at today's prices and using current technology

Table 1: Potential Renewable Energy Systems (MW)

Type	Technology	Kaua`i	O`ahu	Maui	Moloka`i	Lana`i	Hawai`i	State
Baseload Power (MW)	Ocean Thermal Energy Conversion (OTEC)		1550				100	1650
	Geothermal			30			30	60
	Biomass	30		40	2	2		74
Semi-intermittent Power (MW)	Concentrated Solar Power	100	200	100	5	5	100	510
	Blowhole Wave Energy Conversion (BWEC)	30	200	10				240
Variable Power (MW)	Wind Farms		500	100	2		100	702
	Rooftop Wind		1					1
	Photovoltaic	20	200	20	2	2	100	344
	Hydroelectric	5					5	10
TOTAL (MW)		185	2651	300	11	9	435	3591

TIME LINE (2011-2025)

The large systems proposed within this document should be built over a 20-year period. Table 2 lays out a reasonable timeline for installing these future systems.

Table 2: Installation of Future Baseload Renewable Energy Facilities

Year	Kahe	Pearl Harbor	Kaneohe	Kailua-Kona
2015	Kahe Marine Research Park I (OTEC: 150 MW)			
2020	Kahe Marine Research Park II (OTEC: 200 MW)		Kaneohe Marine Facility (Wave Hub 200 MW)	NELHA Marine Research Park (OTEC 100 MW)
2025			Kaneohe Marine Facility (OTEC 400 MW)	
2030		Pearl Harbor I & II (OTEC 800 MW)*		

* Photovoltaic systems, algal biodiesel, micro-geothermal and/or batteries may displace need for OTEC.

TABLE OF CONTENTS

FREQUENTLY ASKED QUESTIONS

Who is Life of the Land?

Life of the Land (LOL) is a Hawaiʻi-based, Hawaiʻi-focused environmental and community action group. Founded in February 1970, its mission is to preserve and protect the life of the land through sustainable land use and energy policies and to promote open government through research, education, advocacy and, when necessary, litigation. LOL has intervened in dozens of utility regulatory actions over the past four decades; it prevailed in the 1971 HECO Rate Case before the Hawai`i Supreme Court, and convinced the Board of Land and Natural Resources to reject the Wa`ahila Ridge 138-kV Transmission Line.

During the past fifteen years Life of the Land successfully sought to codify Cultural Impact Statements into State Law and fought for passage of Environmental Justice legislation.

- Former U.S. Secretary of the Interior Stewart Udall (1961-1969) stated in 1970: "Life of the Land is waging a vigorous fight against polluters in and out of court."
- The November, 1973, cover story for Hawaii Business News reported: "The remarkable thing about Life of the Land is the fact that it has succeeded as well as it has against such a broad and potent array of opposition."
- The May 13, 1975, Honolulu Star-Bulletin Editorial stated: "Life of the Land fills a near-vacuum in the State in terms of a citizens' lobby to challenge the establishment's policy decisions ...particularly in the all important areas of land use and environmental protection."
- Honolulu Weekly's Earth Day edition in April, 1996: "Life of the Land has become synonymous with environmental activism in Hawaii."

Why is LOL writing about this issue now?

For thirty years Life of the Land has actively advocated for the use of Ocean Thermal Energy Conversion as a baseload renewable energy source. We advocated for OTEC in a contested case proceeding before the Hawai`i Public Utilities Commission, and presented a number of expert witnesses who specialize on OTEC related issues.

The Hawaii Department of Business, Economic Development and Tourism (DBEDT) recently published the Big Wind Environmental Impact Statement Preparation Notice (EISPN). This proposal involves an undersea high voltage transmission cable connecting O`ahu to industrial-scale power plants on Lana`i and/or Moloka`i. DBEDT maintains that there are only two alternatives worthy of evaluation: the two wind farms together or separately; no other renewable energy sources are considered.

In response, Life of the Land filed comments in December 2010 noting that there are more than ten reasonable alternatives currently available in Hawaii, among them biofuels, geothermal and ocean thermal. Hawaii's major utility, Hawaiian Electric Company (HECO) favors biofuels (although a new start-up company, Ku`oko`a is seeking to buy out the utility and move to geothermal), and LOL believes this does a significant disservice to the people of Hawai'i. While we write about several alternatives, our focus is on ocean thermal.

Who is this written for?

Life of the Land has produced this document for the lay person concerned about our present energy path. Some believe we face a threat of climate change. Some believe that peak oil is around the corner and oil prices will rise back to $140/barrel and then keep going up. Some believe that we should support the local economy by promoting local sources of energy. Some believe that we should remove the volatility in the price of energy. There are many reasons we need to change direction. We are writing this report for those individuals interested in understanding one path forward: the OTEC path.

Why ocean thermal?

The majority of power supplying an electric grid must be continuous power, that is, it must always be available. Wind, wave, photovoltaic and concentrated solar are not continuous sources. Garbage-to-energy, although "firm", can only supply a small fraction of our needs.

On the other hand, the tropical oceans of the world can supply 10,000 times the total energy used by mankind, indefinitely, at all times of the day and the year. Ocean thermal systems have limited greenhouse gas emissions, and a smaller footprint and fewer impacts than other continuous energy sources.

Doesn't ocean thermal heat up the ocean?

No, it cools the ocean, but in a very small way. However, a majority of the existing fossil fuel power plants in Hawai`i do heat ocean waters.

If the impacts are so low, why don't we have ocean thermal plants today?

The fossil fuel industry has become a trillion dollar a year industry, and despite fears that oil has "peaked", there remains $100 trillion dollars' worth of economically and technically recoverable oil in the ground. There are also significant amounts of coal and natural gas that can be pulled out of the ground. Ocean thermal can displace all of it, and the fossil fuel industries know that.

For example, HECO proposed a biofuel peaking unit for Campbell Industrial Park in 2005. Life of the Land countered with a robust and detailed ocean thermal proposal. Neither the utility nor the regulators showed any interest.

While ocean thermal can easily be integrated into a grid in areas (1) in the tropics, (2) without a continental shelf, (3) where there is a grid that can handle the load, economy of scale would require a facility that could produce 50-100MW of power, at a cost of $600-800 million dollars. It also requires a stable government and a utility that is willing to accept ocean thermal energy.

LOL continues to believe that Hawai`i is an ideal place to demonstrate that OTEC works.

When will ocean thermal energy systems become a reality?

The HECO-State Energy Agreement (Oct 2008) states that Sea Solar OTEC will build a 25 MW system in 2015 and expand it to 100 MW in 2020, to be located somewhere off the O`ahu coast.

Lockheed Martin is working with the Navy at Pearl Harbor to build a 10MW OTEC pilot plant off Pearl Harbor (~2012), and then will build a 100 MW system in 2020 off the Kalaeloa-Kahe Coast.

Ocean Engineering and Energy Systems (OCEES) International, Inc. is working to build a 1MW OTEC facility at NELHA, along the Kailua-Kona Coast of Hawai`i Island.

As the price of fossil fuels rise, there is renewed talk worldwide regarding ocean thermal energy.

Why should ocean thermal be built on a barge instead of on land?

If ocean thermal energy conversion (OTEC) systems are built on a barge at sea, a small transmission line is required that would run under the reefs and the shoreline to interface with the grid. If it is built on land then a several foot wide cold water pipe needs to be brought through the reef and coastline.

What is the difference between the Big Wind undersea cable and one supplying OTEC?

The Big Wind project involves 70-200 miles of undersea cable, which would be laid through the Whale Sanctuary. The OTEC cable system would have 7 miles of cable. The cable would avoid the Whale Sanctuary, and would go under the reefs and the beach area.

Don't we need a basket of energy choices?

Absolutely, Hawai`i should have multiple energy choices, including wind sources, rooftop wind, wave energy, photovoltaic energy, and concentrated solar. While renewable, none of these sources are "firm" or continuous.

Hawai`i's peak energy use occurs between September and December from 6-8 p.m., typically on a dark windless evening. Relying only on intermittent sources means we have to keep all of our fossil fuel units ready for those few occasions when they are needed. The cost to operate them so infrequently would significantly increase the cost of operation.

A solution to this is batteries, which fall into three categories: (a) those that smooth out second-to-second fluctuations, (b) those that smooth out minute-to-minute fluctuations, and (c) those that shift several hours' worth of electricity from the morning to the evening. Hawai`i would need the last option and these are extremely expensive.

Therefore we should have a basket of intermittent renewable energy backed by OTEC as a firm continuous energy source.

Will an undersea transmission line impact the coral reefs?

Regardless of who builds the cable, the current approach to laying all offshore electric and telecommunication cables in Hawai`i is to either go in areas without reefs, or to go underneath the reefs. Using horizontal directional drilling a cable can be built below the ground and seabed floor from the mauka side of the coastal highway to an area of the ocean beyond the reefs.

Aren't transmission lines difficult to install due to the steepness of the seabed?

Yes. Hurricane Iwa damaged some but not all of the transmission cables in the area. A lot has been learned about how to install cables in the past three decades.

What will an OTEC platform look like?

An OTEC Platform would occupy several acres. Several visual examples are discussed in Chapter 4.

What about wave energy?

Wave energy systems are less intermittent than solar and wind systems, but also are less proven. Wave energy systems remove some of the energy of the wave, decreasing damage to shorelines and decreasing wave action for surfing. We propose installing a blowhole wave system operating at a wave farm off the Kaneohe Marine Air Corps Station.

Will OTEC Companies put us at risk?

There are risks with any option, including remaining on the course of energy use set decades ago. In Chapter 6 we discuss the environmental benefits of switching from fossil fuel to OTEC. Obviously we need safeguards, insurance bonds, reputable companies, oversight, etc. What is to be avoided is the approach being advocated by Big Wind, a corporate approach that asks a community to accept the risk, but not share in the profit.

What is the major risk from OTEC?

The major risks are injury and death to marine life and eggs/offspring. This is why scientists, regulators and environmental monitors should be stationed on-site with full access to underwater video and continuous data monitoring systems. This is provided for in our plan.

How will rates be affected?

The goal is to produce electricity for 20-25 cents/kWh.

ABBREVIATIONS

AC	Alternating Current
BA	Biological Assessment
CC-OTEC	Closed-Cycle OTEC
CRRC	Coastal Response Research Center at the University of New Hampshire
CWP	Cold Water Pipe
DBEDT	Hawai`i Department of Business, Economic Development and
DC	Direct Current
Delta T (ΔT)	Difference between the hot water and cold water temperatures
DOE	U.S. Department of Energy
DPED	Hawai`i Department of Planning and Economic Development (DBEDT)
EMF	Electromagnetic field
EIS	Environmental Impact Statement
FEIS	Final Environmental Impact Statement
HECO	Hawaiian Electric Company
HIREP	Hawai‘i Interisland Renewable Energy Program
HRS	Hawai’i Revised Statutes
HVDC	High Voltage Direct Current
HX	Heat Exchanger
KMRP	Kahe Marine Research Park
kW	Kilowatt
kWh	Kilowatt-hour
MW	Megawatt
MWh	Megawatt-hour
NELH	Natural Energy Laboratory of Hawaii (now NELHA)
NELHA	Natural Energy Laboratory of Hawaii
NIOT	National Institute of Ocean Technology, India
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
OC-OTEC	Open-Cycle OTEC
OPEC	Organization of Petroleum Exporting Countries
OTA	Congress Office of Technology Assessment
OTEC	Ocean Thermal Energy Conversion
OTECA	Ocean Thermal Energy Conversion Act of 1980
PEG	Public, Education and Governmental
SOEST	School of Ocean and Earth Science and Technology

CHAPTER 1: INTRODUCTION TO ENERGY

Energy

Energy can neither be created nor destroyed, but it can change forms. All energy options in the world are derived from three sources: the sun, the earth, and the moon. Sun energy includes solar, wind, biomass, biofuels, ocean thermal, coal, hydroelectric, oil, ocean waves, and natural gas. Earth sources includes geothermal and nuclear (uranium). The moon causes tides.

Electricity is simply a useful form of energy, from whatever source derived, that can be transmitted to customers via a transmission and distribution grid.

Renewable energy can be either intermittent (solar, wind, ocean wave energy, biomass, hydro) or firm (ocean thermal, geothermal, garbage, biomass, hydro).

Intermittent or variable sources are those that are available only part of the time, so when electricity is needed the fuel source may or may not be available to produce it. For example, solar panels will produce a lot of electricity when the sun is overhead, some electricity at dawn and dusk, and no electricity at night.

Firm electric power, also called "baseload" power, is power that is always available because the fuel source is always available to be converted to electricity. Firm fuel sources include coal, oil, gas, nuclear, geothermal, and ocean thermal energy conversion (OTEC).

Note that both biomass and hydro can be intermittent or firm.

Maintaining reliable grids requires mostly baseload energy. The exact percentage that can be renewable depends on the characteristics of the grid, the intermittency of the energy sources, and their interplay.[1]

It is better to not need energy in the first place (conservation) but if it is used, to use less of it (energy efficiency). Sometimes "energy efficiency" is used to mean both conservation and efficiency. Energy efficiency can also mean the production of electricity for local use, for example, solar electric panels used for household consumption.

A solar (photovoltaic) panel converts sunlight into electricity. The efficiency rating of a solar panel refers to the *maximum* percentage of sunlight converted into electricity. The capacity factor of the solar panel refers to the *average* percentage of sunlight converted into electricity. The capacity factor averages sunlight conversion at noon, dusk and night.

[1] Further analysis requires knowledge of advanced mathematics, physics and electronics.

Economics

Hawai`i's gross state product, a measure of the total value of all goods and services produced in Hawaii, is about $60 billion.[2] Each year we export $6 billion to buy foreign energy: petroleum, coal, and tropical biofuels.

Similar to the way a rock dropped in a pond creates waves rippling across the surface, each dollar spent in Hawaii generates $3-4 of local economic activity (also known as the economic multiplier). Keeping the $6 billion in Hawai`i that is currently spent on foreign energy would therefore add $20 billion to the state economy.

How did we become so import-dependent, so dependent upon foreign fuel sources? In the late nineteenth century Hawai`i energy and electricity systems were based on locally available resources, including biomass, bagasse (sugar waste) and hydropower (stream-water powering turbines). The twentieth century was the fossil fuel era, both in the U.S. and in Hawai`i, by which point reliance on petroleum, coal and natural gas had become the backbone of the U.S. economy. And although Hawai`i did not have any petroleum, coal or natural gas, the price remained relatively low.

That changed in 1973 during the fourth Arab-Israeli war when the Organization of Petroleum Exporting Countries (OPEC) launched the Arab Oil Embargo. The oil price shocks propelled energy issues onto the front burner around the world.

At that time certain visionaries laid out bold new initiatives based on energy conservation, energy self-sufficiency, and alternatives to fossil fuels. Nowhere was the vision stronger than in Hawai`i, where advocates suggested that we become the international model for sustainability. The Hawai`i State Constitution was amended in 1978 to add an energy self-sufficiency clause.

Shortly thereafter, the backlash of *status quo* forces regained the upper hand. President Reagan ripped out the recently installed solar panels at the White House, and Hawai`i sought to diversify away from oil by turning to coal. Coal is now Hawai`i's number two fuel source.

In 1988-89 AES Corporation (a multinational power production company) built a 180 megawatt coal plant in Campbell Industrial Park; this plant currently supplies 20% of O`ahu's electricity. The Hawaiian Commercial & Sugar Company's (HC&S) Pu`unene power plant on Maui consumes 60,000 tons of coal per year. Gay and Robinson (Kaua`i) has proposed using coal and biomass to produce ethanol. Coal was also used at the Hilo Coast Power Company (1985-2004). Hawai`i's number three and four fuel choices became garbage-to-energy and geothermal.

In 2008 oil peaked at $140/barrel. This affected transportation everywhere but electricity in very few places. Oil accounts for only 2% of the nation's electricity but accounts for over 75% of Hawaii's electricity; hence, Hawai`i felt twice the impact.

---

[2] Hawaii Gross Domestic Product (GDP) in 2006 ($61.2B); 2007 ($64.4B); 2008 ($66.1B); 2009 ($66.4B). http://www.usgovernmentspending.com/Hawaii_state_spending.html

Load

Two terms which are sometimes confused are watt and watt-hours. Watt (a unit that measures the rate of energy conversion) refers to the size of the system, that is, what is the maximum amount of electricity that a system can produce. Watt-hours refers to the actual amount of electricity produced. If a one-watt system is always turned on, it will produce 24 watt-hours of electricity per day. A kilowatt equals 1,000 watts, and a megawatt equals one million watts. Rooftop solar energy systems are usually in the kilowatt (kW) and kilowatt-hour (kWh) range, while utility scale renewable energy systems are usually in the megawatt (MW) and megawatt-hour (MWh) range.

Load is the average amount of electricity that is used over a period of time. Peak load is the maximum amount of electricity that is used, and minimum load is the least amount of electricity that is used. The O`ahu grid currently has a minimum load of approximately 600 MW, a maximum load of approximately 1,300 MW, and an average load of approximately 900 MW.

When a utility company provides information about load, it almost always refers to peak load since that is what drives the need for additional generation and transmission. Waikiki's peak load in 1998 was 8%; that is, Waikiki's maximum load divided by O`ahu's maximum load (which may not be on the same day but is in the same year) was 8% for 1998.

Generation that is produced and used in the same general area is called Distributed Generation (DG). Generation that is produced in one area, and is then sent on transmission lines to another area, is called Central Generation (CG). Central Generation requires transmission lines to be built between where the electricity is produced and where it is consumed. The location of the generation and the transmission lines raise Environmental Justice issues which are discussed in Chapter 9.[3]

[3] Many pose the question as: why should one community, often economically-challenged and in the racial minority, assume most of the undesirable infrastructure for electric generation that is designed to benefit distant, better-off communities? Environmental Justice is part of the field of externalities: benefits and risks which are not reflected in prices.

The charts below delineate system peak load by Company[4] (MW). The peaks on different islands occur at different times, so the total does not refer to the amount actually being generated at one specific time.

Utility	2008	2007	2006	2005	2004
HECO	1186	1216	1266	1230	1281
HELCO	198	203	201	197	195
MECO	206	216	218	214	218
Total	1590	1635	1685	1641	1694

HECO Peak and Minimum Loads[5]

Year	Peak Demand (Net MW)	Minimum Load (Net MW)
2005	1230	531
2004	1281	538
2003	1242	513
2002	1204	502
2001	1191	520
2000	1164	496
1999	1120	502
1998	1131	487
1997	1176	483
1996	1157	475

Costs

Specific financial data on energy systems is very difficult to obtain. In practically all regulatory proceedings data is considered confidential and is only made available to other parties who are non-competitors and who sign a Protective Order, a legally-binding, court-enforceable, non-disclosure document. "Back-of-the-napkin" cost estimates vary greatly and are highly dependent upon the assumptions used. Since 2001, the utility has used national security laws to restrict public knowledge of the transmission and distribution grid. This includes the amount of load carried by different transmission lines, distribution lines, and the amount of electricity delivered to different communities. The specific characteristics of each line determine the amount of intermittent energy that the line can carry.[6]

Many elements factor into a financial analysis of a utility's system. Current and future governmental actions have an enormous impact on the viability of new electric generation projects, as do income and property tax rates, production tax credits, and depreciation rates. The "cost" of money is also a key issue determined by the percentage of debt, interest rates, and discount rates. The cost of the project itself is critical, and includes capital purchase costs, the cost of land, engineering, installation, insurance, and interconnection.

[4] HEI 2008 statistical supplement and utility forecast, p.19. http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9MzMzNTM5fENoaWxkSUQ9MzE2MTc0fFR5cGU9MQ==&t=1
[5] http://www.heco.com/vcmcontent/GenerationBid/HECO/HECOSystemOverview.pdf
[6] Introductory electronics is based on fifth semester calculus and is beyond the scope of this paper.

Finally, the revenue stream can vary greatly. There are two major commercial wind facilities on the Big Island, one at South Point and one at Hawi. The former has an average output of 61% of its maximum output, while the latter has an average output of 37% of its maximum output. Thus for an average hour, for each 1 MW of capacity, the South Point facility produces 0.61 MWh while the Hawi facility produces 0.37 MWh. Finding sites that allow high capacity factors are much sought after, and thus location-based data is very valuable and highly protected.

Electric Utilities

HECO, and its subsidiaries Hawai'i Electric Light Company (HELCO) and Maui Electric Company (MECO), provide electricity for ninety-five percent of Hawai`i's residents. The three associated companies operate a total of sixteen petroleum-fueled power plants distributed throughout the main islands of Hawai`i (except for Kaua`i, which maintains its own electrical cooperative). These sixteen HECO plants, along with independent alternative renewable energy facilities, have a power-generating capacity of approximately 2,400 MW. Of the total sale of electricity, the percentage from renewable energy sources currently ranges from HECO's 15% to HELCO's 39% on the Big Island.

Regulation

Utilities are regulated companies serving the public good. Utilities include water, wastewater, electric and gas companies. The Public Utilities Commission in Hawaii (PUC) regulates privately-owned and member-owned utilities, and also the contracts they sign with private companies. The PUC does not regulate utilities owned by municipalities.

Utilities can be owned by investors (HECO), customers (Kauai Island Utility Coop), Municipalities (Honolulu Board of Water Supply), other utilities (HECO owns the electric utilities on Mau`i and Hawai`i Island), or they can operate under contract to the Public Utilities Commission (Hawaii Energy[7]).

The Public Utilities Commission must approve all utility expenditures exceeding $2.5M in order for the utility to pass the cost onto their ratepayers.

On O`ahu, there are three energy utilities: (a) Hawaiian Electric Company (HECO) which provides electricity; (b) Honolulu Gas Company, which supplies gas for home heating systems; and (c) Hawaii Energy, an independent energy efficiency utility. Each of these three entities are non-interlinked companies, they do not share board members or invest in each other.

[7] Hawaii Energy: www.hawaiienergy.com/

Net Energy Metering (NEM)

Net Metering essentially allows a self-generator to use the grid as a battery. During the day when a customer generates more energy than he or she needs, the excess is "sold" to the grid, and at night the customer takes energy back from the grid. The system uses one meter and at the end of the month the customer pays only for the net energy used. At the end of the year the system is zeroed out – any excess energy placed on the grid by the customer goes without compensation. Installation of a net metering system, therefore, is sized to minimize the amount of free electricity given to the utility.

Feed-In Tariffs (FiTs)

Feed-in Tariffs (FiTs) have been successfully used in Germany and Spain, and were just adopted in Ontario and Gainesville, Florida. The utility uses two meters: one which buys energy from the grid at the retail rate, and one which sells electricity to the grid at an established FiT rate. This allows self-generators to size systems to maximize profits.

Third Party Power Purchase Agreements (TPPPAs)

Under a TPPPA, a third party designs, builds, owns, operates, and maintains the solar system and sells back solar-generated electricity to the end-user. This model removes the burden of significant upfront costs from the end-user, and also allows the solar contractor, who has significantly greater expertise than the end-user, to assume the responsibility for system installation and maintenance. Tax credits and accelerated depreciation for the solar systems help to drive down their cost, as well as reducing the electricity price charged to the end-user.

As the United Nations noted in 2008: "One of the main financing tools used [to finance the installation of renewable energy facilities] is the third-party power purchase agreement (TPPPA), which by some estimates drove 60% of the solar capacity installed in California in 2007."[8]

In 2008 SunEdison financed, constructed, and will now maintain a 0.283 MW solar power system on the roof of Sam's Club on Keeaumoku Street in Honolulu. It will build three more systems on WalMart rooftops in the state as part of an agreement to build twenty-two such systems in Hawaii and California at Wal-Mart stores, Sam's Clubs, and distribution centers in Hawaii and California. The systems are being installed under a Third Party Power Purchase Agreement (TPPPA) which SunEdison

---

[8] Energy Investment: Analysis of Trends and Issues in the Financing of Renewable Energy and Energy Efficiency. (United Nations Environment Programme and New Energy Finance Ltd. page 22. Authors: Rohan Boyle, Chris Greenwood, Alice Hohler, Michael Liebreich, Virginia Sonntag-O'Brien, Alice Tyne, Eric Usher. ISBN: 978-92-807-2939-9, DTI/1066/PA). This report was commissioned by UNEP's Division of Technology, Industry and Economics (DTIE) under its Sustainable Energy Finance Initiative and was produced in collaboration with New Energy Finance Limited.
See:www.unep.fr/shared/publications/pdf/DTIx1066xPA-GlobalTrends08.pdf

calls a Solar Power Services Agreement (SPSA).[9] Sample Solar Power Services Agreements are available on the web.[10]

SunEdison and SunPower are two leading TPPPA proponents. SunEdison first used the model in 2004 on a commercial installation, and has since installed 34MW of systems for commercial users, all financed via TPPPAs (or SPSAs - solar power services agreements, as SunEdison calls them). SunPower uses a similar model for its SunPower Access program.

Solar installation financing is attracting major investors. Goldman Sachs, GE Capital and MMA Renewable Ventures (a subsidiary of Municipal Mortgage & Equity) are all investing in solar. In April 2008, for example, MAA Renewable Ventures announced that it would finance fourteen rooftop systems on Macy's California department stores, with SunPower providing panels and systems integration.

Redevelopment

Part of the vision for a new energy paradigm for Hawai`i must include dismantling the old facilities. For example, in 2006 LOL proposed replacing the Honolulu Power Plant[11], adjacent to Aloha Tower, with one level of parking and with a hilly park on top of the roof. This would provide greater access to Aloha Tower and provide a harbor park. Once the Hawai`i Free Trade Zone (located between Aloha Tower and Kewalo Park) is relocated to Sand Island and Kalaeloa Harbor, a Green Lei of parkland would then stretch from Aloha Tower to Ala Moana Beach Park.

Similarly, as OTEC and Distributed Generation displace fossil fuel generators, the Kahe Power Plant would need to be decommissioned. The facility could be replaced with a Telecommuting Park. A series of low rise (2-3 stories) buildings could be built, the lower floor would house agriculture (aquaculture, aquaponics, vegetables), while the upper floor could serve as a telecommuting center. Residents of Waianae and Kapolei, who want to avoid long commutes (by bus, car or train) could instead work in offices connected to their downtown workplace by high-speed internet.

---

[9] Sam's Club on Keeaumoku Street is the first of four Wal-Mart locations in Hawaii to receive a solar power system. January 28, 2008. http://solarcellsinfo.com/blog/archives/1299

[10] www.newcastleHawai`i.org/DocumentView.aspx?DID=1969

[11] Halekawila means "house of electricity." Halekawila Street runs adjacent to the Judiciary Building and once went to the Honolulu Power Plant adjacent to Aloha Tower. Building Nimitz Highway cut off Halekauila from the electric plant it was named after.

CHAPTER 2: ENERGY EFFICIENCY

Energy efficiency focuses on reducing the demand for grid-based electricity, and can be accomplished in many ways. The first step to becoming energy efficient is to simply use less: turn off lights when not in a room, open windows to take advantage of trade winds, and replace worn out appliances with ones that have an "Energy Star" rating; these are designed to operate using less electricity.

Meters

Unfortunately, devices can use almost as much electricity in the off position, a "consumer" convenience which allows quick starts. A "phantom" power load refers to the electricity used by a device even when it is off.

To address this problem many utilities are building smart meter networks to collect data from "smart" meters in a time frame that ranges from between every fifteen minutes to an hour. The collected data is then sent back to a collection point on the network. From that collection point, many utilities are bringing data back to the utility's back office where the numbers are processed and packaged for consumers once a day. This can significantly delay the time it takes the energy information to reach the customer, rendering the data outdated, often captured during a previous day of electric use.

Another approach is to measure these phantom loads in real time by installing small meters between an appliance cord and the wall socket. "The advantages of bypassing the smart meter aren't just the quick deployment times of these energy management devices. The set-up could also offer the customer more detailed and quicker energy data than data coming off of smart meters."[12]

The Plug-in Energy Meter and Electricity Cost Calculator[13] Small devices can be installed between a plug and a wall outlet that measure the flow to each device when the device is on.	The Energy Detective[14] (TED) runs about $200-300 (depending on desired features) and the cost for an electrician to install it. TED sends real-time data every 10 minutes to either a customer's iGoogle gadget or Google account.

[12] http://earth2tech.com/2009/10/05/googles-powermeter-bypasses-the-smart-meter-signs-up-first-gadget-partner/
[13] http://www.smarthome.com/11391/Plug-in-Energy-Meter-and-Electricity-Cost-Calculator/p.aspx
[14] http://www.devicedaily.com/wp-content/uploads/2009/02/energy-detective.jpg

Lighting

Consumers should replace incandescent light bulbs with compact fluorescent bulbs. Toy ovens are often powered by an incandescent light bulb, which readily cooks food because practically all of the energy emerging from an incandescent bulb is heat, not light. The practical effect of this truism is that in large buildings, the unwanted heat byproduct must be removed from rooms - using air conditioning. By switching to CFLs, heat is not created and the room does not need as much cooling.

A light-emitting diode (LED) is based on diode electronics. Currently they are more expensive and require specific heat management and current specifications. Their advantages include longer life, lower energy consumption and smaller size.

	
Compact Fluorescent Light Bulb (**CFL**)[15]	LED Traffic Light[16]

Daylighting

Rather than blocking off a building from its environment and then creating an artificial interior environment, daylighting allows an interaction between the two environments.

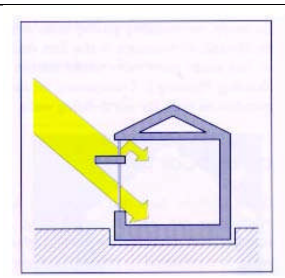
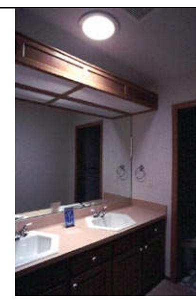
Skylights are horizontal windows or domes placed on the roof of buildings, often used for daylighting (using natural sunlight to provide lighting for buildings). The daylighting concept has been around for centuries but the name is recent. It goes against the traditional western “box architecture” with solid roofs.

Similarly, light “shelves” placed below windows can be used to reflect sunlight upward to illuminate the ceiling, creating general illumination without the use of electricity.

Rooftop Solar Tubes capture sunlight from a number of directions, and through reflective material and/or mirrors within the tube, transfer that light to where it is needed within buildings. Skylight windows or domes placed at the roof of buildings provide natural sunlight into buildings.

[15] http://akagreen.files.wordpress.com/2009/02/cfl.jpg
[16] http://www.fad.co.za/Diary/diary010/traffic-lights-led.jpg

	
Rooftop Windows[17]	Skylight[18]

		
Light shelves[19] placed below the windows can be used to reflect sunlight upward to illuminate the ceiling to create general illumination.	Solar Tubes capture sunlight from a number of directions, and through reflective material and/or mirrors within the tube, transfer that light to where it is needed within the house.[20]	Within the building the solar tube generates diffuse light.[21]

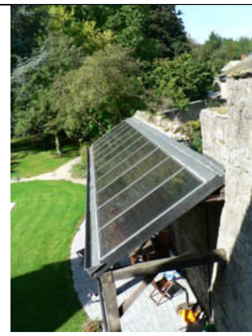
Solar Water Heaters

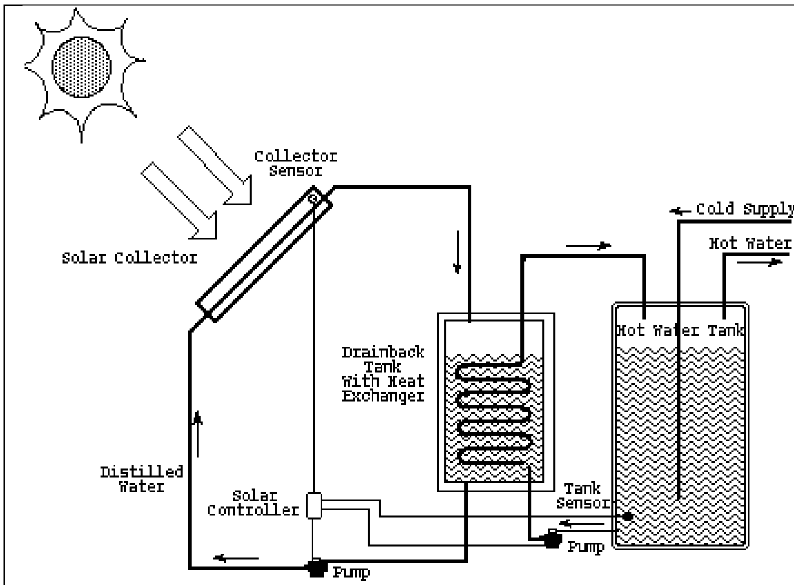
Solar water heating is water heated by the use of solar energy, lessening the need for electrical generation to heat water, often a household's biggest use of electricity. Solar heating systems are generally composed of solar thermal collectors and a fluid system to move the heat from the collector to its point of usage. The system may use

---

17 http://buildingcommissioning.files.wordpress.com/2008/01/daylighting1.jpg
18 http://farm1.static.flickr.com/83/216500844_7154d601a2_o.jpg
19www.robotecture.com/endofmechanics/CONTENT/Student%20Apps/EZ/Zambrano%20EOM%20final/template-img/light_shelves.jpg
20 http://www.inhabitat.com/2006/12/28/solar-tube/
21www.portlandonline.com/shared/cfm/image.cfm?id=114639

electricity for pumping the fluid, and typically has a reservoir or tank for heat storage and subsequent use.

	
Solar Water Heater[22]	Solar water heating panels for heating a swimming pool in the Netherlands[23]

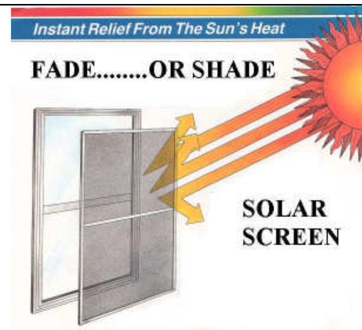
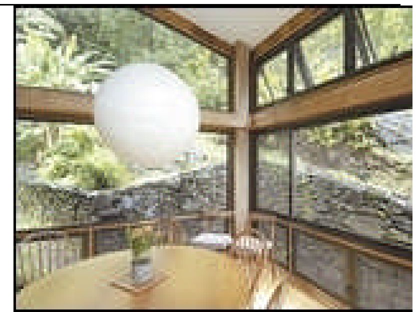


Solar water heating or a solar hot water system is water heated by the use of solar energy. Solar heating systems are generally composed of solar thermal collectors, a fluid system to move the heat from the collector to its point of usage. The system may use electricity for pumping the fluid, and have a reservoir or tank for heat storage and subsequent use.[24]

Architect Scott Wilson (American Institute of Architects–Honolulu Chapter Board of Directors; former President Malama O Manoa), lives in a historic house in the back of Manoa. Since the house is on the state's Historic Register, nothing could be modified that could be seen from the road. Undaunted, Wilson's house has solar panels to support a solar water heater, photovoltaic panels for other electrical use, and he makes use of daylighting, solar tubes, and a solar power screen which automatically descends when intense sunlight hits the back porch; the solar screen cuts down only slightly on the view while significantly reducing the heating of the house.[25]

---

[22] http://solar.calfinder.com/blog/wp-content/uploads/2009/10/solar-water-heater-rooftop.jpg
[23] http://en.wikipedia.org/wiki/Solar_water_heating
[24]www.energyeducation.tx.gov/renewables/section_3/topics/solar_water_heaters/img/fig20a_solar_water.gif
[25] www.hawaii.edu/malamalama/2009/07/scott-wilson/
Life of the Land's Youtube: http://www.youtube.com/watch?v=QKInmFMgyn4

		
Architect Scott Wilson[26]	Solar Screen[27]	Daylighting Dining Room[28]

Case Study: Saunders Hall at UH Manoa

The military is the largest energy user in the State, followed by the University of Hawai`i at Manoa (UHM). UHM has an average annual energy bill of $21,000,000.00, but until recently UHM did not know which buildings were using what amounts of energy because the campus had only one meter to measure its electricity use.

That changed when Shanah Faith Trevenna, a UH Graduate Student and former Canadian Mechanical Engineer, became the Sustainable Saunders Student Sustainability Coordinator about a decade ago. Additional meters were installed and energy "audits" conducted which led to startling data.

Saunders Hall is a seven story building which houses the Spark M. Matsunaga Institute for Peace and Conflict Resolution and the Department of Urban and Rural Planning (DURP). [29] Metering individual buildings on campus revealed that Saunders Hall alone had an annual electric bill of $760,000.

[26] http://the.honoluluadvertiser.com/dailypix/2007/Dec/10/hawaii712100304AR_b.jpg
[27] http://solarscreenusa.com/yahoo_site_admin/assets/images/sun_solar.26322434_std.jpg
[28] Ibid.
[29] http://www.publicpolicycenter.hawaii.edu/sustainablesaunders.html

When students surveyed Saunders Hall residents, they were told that classrooms were too bright, as well as too cold, for optimal studying. Light bulbs were removed, and windows opened, decreasing energy use by saving on lighting and air conditioning costs

In addition to the "delamping" program (removing light bulbs), the students known as HUB (Help Us Bridge) focused on a dozen other projects including going through the building's garbage on a regular basis to complete a comprehensive study of the waste stream; creating one of the most complete recycling programs on campus; developing a Sustainability Courtyard and holding annual Earth Day celebrations; xeriscaping; green roofing; green cleaning; and worm composting. HUB also installed a water catchment system, and installed water saving techniques in bathrooms.[30]

The now more sustainable Saunders Hall has saved 411,720 kWh (Air Conditioning Shutdown Project); 107,434 kWh (Delamping Project); 42,330 kWh (Incandescent Bulb Elimination); 108,761 gallons of water (Bathroom Retrofit Demonstration); and recycled 13,995 bottles/cans.[31] "In 2001, the last known accurate data for Saunders indicated that the building's electricity load was 3.1 million kWh annually. Based on new meter data available in 2007, the electrical load for Saunders is now only about 2.3 million kWh annually - a reduction of over 25%."[32]

---

30 http://sustainablesaunders.hawaii.edu/ See also www.hawaii.edu/offices/op/sustain.php?brief=2
31 www.publicpolicycenter.hawaii.edu/sustainablesaunders.html
32 www.publicpolicycenter.hawaii.edu/documents/delamp.pdf (3/21/2008)

Conclusion

Energy efficiency makes sense from an economic perspective. When using electricity it is wise to use what is needed, and no more. Energy efficiency has the best rate of return of any energy system. However, embracing energy efficiency will likely not reduce energy demand, hence the case for using more "renewable" energy.

As Lord Jevons pointed out in 1865, lowering the price of inputs ,lowers the price of the final product, which increases demand for that product, which raises the total energy that is needed to match the new demand level.

Put another way, businesses may switch to lower cost energy efficient air conditioners which will drive down their cost of business. This allows them to reduce the price at which they sell goods, which undercuts competition, which in turn may lead to an increase in sales. Thus, while the amount of electricity in each good they sell drops, they need more electricity because they are producing more goods.

Similarly, residents who replace an existing air conditioner with a new, more efficient air conditioner find that their energy bill drops, allowing them to spend more money on other things. Or residents who relied on opening windows may see all the advertisements for energy efficient air conditioners and decide that it is the smart move to buy one, even though it will increase their energy bill.

In the end, businesses and residents that save money by installing energy efficiency devices will invest the money, which will in turn be loaned out to others, resulting in increased economic activity, which ultimately raises the demand for electricity.

The net effect of these positive and negative impacts is unknown, due to the absence of peer reviewed studies to know which impact dominates.

The Hawaii Public Utilities Commission has removed energy efficiency from the HECO Companies and contracted with an independent Energy Efficiency Utility to oversee implementation of conservation measures.[33] This was thought necessary because of the implicit disincentive in a utility company overseeing less use of its product, which results in less profit for its shareholders.

[33] http://www.hawaiienergyefficiency.com/

CHAPTER 3: RENEWABLE ENERGY

(A) PHOTOVOLTAIC SOLAR ELECTRIC

Solar energy is the energy received by the earth from the sun. This energy is in the form of solar radiation which can be converted to electricity through the use of photovoltaic panels.

Hilo born energy expert Donald Aitkin notes that, "Solar energy is not an 'alternative energy'. It is the original and continuing primary energy source. All life and all civilizations have always been powered by solar energy. Expanding the technical applications of solar energy and its other renewable energy cousins to carry civilizations forward is simply a logical extension of its historic role, but also the inescapable key to achieving sustainability for human societies."[34]

According to the National Renewable Energy Laboratory, "The sun showers the Earth with an amazingly large supply of energy. Each day more solar energy falls to the Earth than the total amount of energy the planet's 6.1 billion inhabitants would consume in 27 years. While it's neither possible nor necessary to use but a small portion of this energy, we've hardly begun to tap the potential of solar energy. Only in the last few decades — when growing energy demands, increasing environmental problems and declining fossil fuel resources made us look to alternative energy options — have we focused our attention on truly exploiting this tremendous resource."[35]

At current levels of solar photovoltaic (PV) efficiency, and allowing for cloudier conditions in the north, the entire current electricity demand of the United States could be met from 10,000 square miles of PV, an area equivalent to 9 percent of Arizona. America's rooftops could generate at least a quarter of our electricity needs.

The use of only photovoltaic (solar) energy in conjunction with batteries (storage) could achieve energy self-sufficiency for all non-transportation needs: i.e., heat, light, electricity.

Markets

Globally there were 14,700 MW of solar powered energy in 2008, of which 5,500 MW were added in 2008 alone.[36]

---

[34] Transitioning to a Renewable Energy Future. Written by Donald W. Aitken, Ph.D., under contract to the International Solar Energy Society. www.donaldaitkenassociates.com/transitioning_daa.pdf Dr. Donald Aitken - physicist; solar architect; former Chief of Research at the Union of Concerned Scientists; Recipient of the World's Solar Industry Award; Affiliate Faculty Member at the Frank Lloyd Wright School of Architecture. Former staff research physicist and astrophysicist at Stanford University; Founder and Chairman of the Department of Environmental Studies at San Jose State University; Executive Director of the Western Regional Solar Energy Center for the U.S. Department of Energy; and Senior Staff Scientist for Renewable Energy Policy and Economics with the Union of Concerned Scientists.

[35] National Renewable Energy Laboratories. www.nrel.gov/documents/solar_energy.html

[36] Clean Energy Trends 2010, by Ron Pernick, Clint Wilder, Dexter Gauntlett, Trevor Winnie (March 2010) Clean Edge.

The solar energy field is very small in the U.S. but growing rapidly, at 40% per year. Solar currently provides less than 0.1% of the electricity in the U.S., [37] but growth went from 600 MW (2003) to almost 3,000 MW in five years (2008).[38] In 2007 large-scale solar projects attracted $17.7 billion, while total solar investment in the U.S. reached $26 billion (2008).[39] "More than 30,000 sites installed PV in 2008, with 62% of these sites and 86% of the installed capacity connected to the grid. Most of these installations are mounted on buildings, but some are ground-mounted installations."[40]

Photovoltaic prices are dependent upon the price of its major component: silicon. As demand surges, the price of silicon has dropped dramatically, although there was a temporary price spike in the middle of the past decade. "Component manufacturing was concentrated in a relatively few regional markets a few years ago, PV modules from around the world now trade freely on the open market."[41]

- "Historically, PV prices have dropped 20% for every doubling of installed power generating capacity."[42]
- "Because of rapidly declining solar PV prices, industry revenue between 2008 and 2009 was down about 20 percent – from a revised $38.5 billion in 2008 – as solar prices dropped from an average $7 peak watt installed in 2008 to $5.12 peak watt installed last year [2010]."[43]
- New capacity is coming on line that should reduce costs to $2.60 per peak watt.[44]

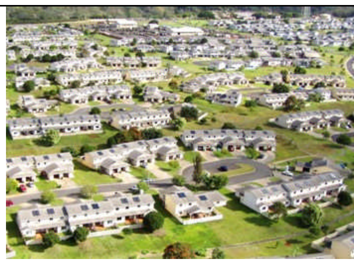
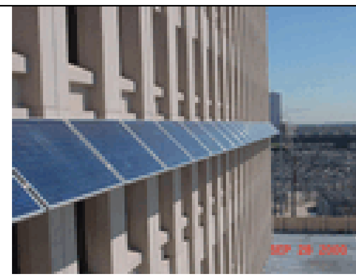
Similar to wind, the size of the average system is growing. This growth in size includes the residential market. "The average size of a grid-connected PV residential installation has grown steadily from 2.5 kW in 1999 to 4.8 kW in 2008. The average size of a non-residential system has also been growing in recent years, and was 106 kW DC in 2008."[45] While large systems are the fastest growing sector-- "those greater than 500 kW grew faster than any other sector,[46]" -- the number of residential installations continues to rise as well.

---

[37] Solar Energy: Market Trends and Dynamics by Robert M. Margolis (National Renewable Energy Laboratory), presented at the National Association of Regulatory Utility Commissioners (NARUC) 2009 Winter Committee Meeting: Energy Resources & Environment Committee. Washington, DC. February 16, 2009 p.4.
[38] Utility Solar Assessment (USA) Study: Reaching Ten Percent Solar by 2025 (June 2008) Clean Edge, Inc.; Co-op America Foundation.
[39] New Energy Matters: www.newenergymatters.com/UserFiles/File/WEF_NEF_2009_01_30_Davos_Green_Investing_Report.pdf
[40] Interstate Renewable Energy Council (IREC) 2009, Updates & Trends Report: Solar Installation Trends by Larry Sherwood, p.10.
[41] SEMI White paper: Advancing a Sustainable Solar Future, SEMI PV Group Policy Principles and Recommended Best Practices for Solar Feed-in Tariffs, p.3.
[42] SEMI White paper: Advancing a Sustainable Solar Future, p.2.
[43] Clean Energy Trends 2010, by Ron Pernick, Clint Wilder, Dexter Gauntlett, Trevor Winnie (March 2010) Clean Edge.
[44] Green Investing: Towards a Clean Energy Infrastructure www.weforum.org/pdf/climate/Green.pdf.
[45] Interstate Renewable Energy Council (IREC) 2009 Updates & Trends Report: Solar Installation Trends by Larry Sherwood p.13.
[46] U.S. Solar Market Trends 2008 (July 2009) by Larry Sherwood. Interstate Renewable Energy Council (IREC), p.5.

Throughout the country, "almost 19,000 grid-connected PV installations were completed in 2008, with 90% of these at residential locations. At the end of 2008, 69,000 PV installations were operating on the grid, including 61,000 residential installations."[47] "Residential installations were 27% of all new grid-connected PV systems installed in 2008 by capacity."[48]

Today solar installations are concentrated in a few states. Four states account for 82% of all grid connected PV (California, New Jersey, Colorado and Nevada); 95% is concentrated in the top 10 states (the next six being Arizona, New York, Hawaii, Connecticut, Oregon and Massachusetts). California launched a $3 billion, ten-year solar program in 2007,[49] Nevada built a 13 MW system in 2008, and Pennsylvania installed a 3MW system the same year."[50]

	
The U.S. army's Helemano Army Family Housing project near the city of Wahiawa boasts more than 400 solar water heaters[51]	Solar Ledge. PV Awnings at the University of Texas[52]

Hawai`i Energy Self-Reliance (MW)

Installation of grid-connected photovoltaic systems grew in Hawaii from 2.9 MW DC (direct current)[53] in 2007 to 8.6 MW DC in 2008, and the state ranked fifth in grid-connected photovoltaic systems, seventh in cumulative capacity, first in watts installed per person, and third in cumulative watts installed per person.[54]

---

[47] U.S. Solar Market Trends 2008. www.irecusa.org/fileadmin/user_upload/NationalOutreachDocs/SolarTrendsReports/IREC_Solar_Market_Trends_Report_2008.pdf.
[48] IREC's 2009 Updates & Trends Report, p.12.
[49] Id., p.8.
[50] U.S. Solar Market Trends 2008 (July 2009) by Larry Sherwood. Interstate Renewable Energy Council (IREC), p.4.
[51] http://www.solarthermalworld.org/node/500
[52] Completed in the fall of 2000, this 7-kilowatt photovoltaic awning is situated above the 8th floor windows of the 26-story University Center Tower on the Texas Medical Center campus in Houston, Texas. The awning serves a dual purpose: the SunSine® AC modules supply about 10,000 kilowatts of electricity annually, and the shading they provide offsets an air-conditioning load of an additional 2,600 kilowatts. By installing this system, the Houston Health Science Center is helping Texas to meet its aggressive mandate for 2,000 megawatts of new renewable power by 2009, which is part of the state's electric utility restructuring plan. The University of Texas Health Science Center partnered with Applied Power Corp. and Conservation Services Group on this project.
[53] Solar installations utilize Direct Current (DC) which is then converted to the electric grids Alternating Current (AC) using an inverter.
[54] IREC's 2009 Updates & Trends Report, p.15.

Rooftops in Hawai`i

There are a number of land-use zones in Hawai`i for which it is permissible to install photovoltaic panels. This includes land zoned conservation, agricultural, and urban.

There are also many rooftops available for residential and other small systems.

Oahu has 165,783 structures of which 67,000 were built after 1970,[55] and has 291,999 dwelling units (excluding structures on military bases): 153,609 single family and duplex units, 23,797 low-density multiple-family units, and 114,593 high-density multi-family units.[56] There are 437 buildings in Honolulu that are at least 12 stories tall, and of these, 57 are over 100 meters, the tallest being the First Hawaiian Bank Building at 131 meters.[57] Oahu has forty-four cemeteries, 827 churches, fifty-nine hospitals, and 119 schools.[58] The federal government holds a proprietary interest in 16,640 buildings in the state, of which 16,459 are owned outright, and 181 are subject to lease.[59] The City and County of Honolulu maintains records on real property.[60]

Schofield Barracks contains 3,733 housing units,[61] and the Marine Corps base in Hawaii includes 2,388 housing units.[62] The Pearl Harbor Naval complex has 6,615 family housing units in 28 "Navy" neighborhoods around Oahu.[63] Hickam Air Force Base has 2,659 family housing units on base. "All family housing units on Hickam AFB have been privatized and are managed and maintained by Hickam Community Housing (HCH)."[64] "Forest City Military Communities, LLC (FCMC) was established to [ ] participate in the privatization of the naval military family."[65]

PowerLight built a 0.3 MW photovoltaic (electricity) system on the roof of a naval structure on Ford Island. Completed in 2005, it occupies 3/4 of an acre. Since there are 640 acres in a square mile, a square mile of an equivalent area in Hawaii could produce 250 MW of photovoltaic renewable energy. Since O`ahu's peak electricity use is around 1,400 MW, Maui and the Big Island around 200 MW each, and Kauai around 100 MW, the state has a peak electrical demand of less than 2000 MW, which could be produced using less than eight square miles of solar panels; although in reality there would be roads, infrastructure, and shadows that would impact the overall amount of MW that could be produced within a given area.

---

[55] Table 6.02-- LAND USE AND STRUCTURAL CHARACTERISTICS OF OAHU: 1994 AND 1998. http://hawaii.gov/dbedt/info/economic/databook/db2008/section06.pdf
[56] Table 6.02-- LAND USE AND STRUCTURAL CHARACTERISTICS OF OAHU: June 1998 http://hawaii.gov/dbedt/info/economic/databook/db2008/section06.pdf
[57] Emporis.com - The World's Building Website. http://www.emporis.com/en/wm/ci/bu/sk/li/?id=102596&bt=2&ht=2&sro=0
[58] Table 6.06-- REAL PROPERTY TAX EXEMPTIONS FOR CEMETERIES, CHURCHES, HOSPITALS AND SCHOOLS, BY COUNTY: 2009. http://hawaii.gov/dbedt/info/economic/databook/db2008/section06.pdf
[59] Table 6.08-- REAL PROPERTY OWNED BY OR LEASED TO THE FEDERAL GOVERNMENT: 2003 http://hawaii.gov/dbedt/info/economic/databook/db2008/section06.pdf
[60] https://www.realpropertyhonolulu.com/portal/rpadcms/Reports?parent=REPORTS#2009
[61] http://en.wikipedia.org/wiki/Schofield_Barracks
[62] http://en.wikipedia.org/wiki/Marine_Corps_Base_Hawaii
[63] http://themilitaryzone.com/bases/pearl_harbor_naval_complex.html
[64] http://usmilitary.about.com/od/airforcebaseprofiles/ss/Hickam_6.htm
[65] http://www.fcnavyhawaii.com/

Mapunapuna Solar Assessment[66]

Mapunapuna is the one to two square mile industrial area just mauka of the Honolulu International Airport. A smaller portion is located makai of Nimitz Highway. The larger portion is located between the Nimitz Highway and H-1.

A research team led by University of Hawai`i's Steven Meder examined the potential of Mapunapuna to produce solar electric power. The research team examined the roof area, roof type, roof slopes (tilt angle or pitch), orientation or azimuth angle of rooftop surfaces, overhangs, shadow effects, clearness index (how much cloud cover should be considered), shading coefficient (produced by rooftop mechanical equipment, adjacent buildings, parapets, etc.), the Albedo factor (ground reflection), and the actual average monthly and yearly amount of solar radiation received.

The research team relied upon the City and County of Honolulu GIS website, aerial photographs, and DBEDT and the US Department of Energy's National Renewable Energy Laboratory (NREL) "sunshine maps", or solar calorie maps. The team also conducted walking and driving surveys, used Digital Elevation Models (DEM) and the Environmental System Research Institute's Image Analysis, a GIS-driven image recognition program. The results were that the Mapunapuna Area can create 60 to 64 million kWyr per year, or 60,000 to 64,000 MW per year. Thus, Mapunapuna rooftops alone could produce a peak load of 35 MW of solar electric.

A solar panel's output varies from zero at night to 100% during peak cloudless sunshine. On average its output is 20% of its maximum output. Thus 35 MW of peak solar energy is equivalent to 7 MW of continuous power (35 x 20% = 7).

The significance of this research is that it was the first detailed analysis of the ability of Hawai`i rooftops to provide significant amounts of renewable energy.

Case Study - Sarah and Duane Preble

The Preble's three-story house in Manoa is built on ten posts and is naturally cooled using passive cooling: air enters through low windows, circulates inside, and exits through high transom windows. This is known as a "chimney" design method. The Prebles also employ passive daylighting, and the roof is insulated to provide interior cooling and hosts photovoltaic panels for electricity and solar panels for the hot water heater.[67]

---

[66] Assessment of solar energy potential on existing buildings in a region (US Patent 7305983 granted in 2007) By Stephen E. Meder, Olivier A. Pennetier, David M. Ansberry, Meco Indriaja Marcus Brunner.www.freepatentsonline.com/7305983.html
[67] www.hawaiihomeandremodeling.com/green/dreamgreenhome.html

Sarah and Duane Preble[68]

"Manoa homeowners Sarah and Duane Preble may be in the vanguard when it comes to home-generated electricity. Photovoltaic cells on their roof have provided for part of their 2,400-square-foot home's electrical needs over the past two years. Now they're taking steps to get 24 more panels, so almost all of the wattage coming in to their home is from the sun."[69] The Preble's prove that photovoltaics are not restricted to flat sunny areas, as their house is in the back of Manoa Valley, on a steep hillside.

Conclusion

The overall use of solar is very popular but up to now it has been the most expensive renewable energy source. Solar panels are the easiest renewable energy systems to install, require the fewest permits, and there is a growing competitive market for both the panels and for their installation. Despite the price per kilowatt of energy created, the costs are falling sharply, and solar is now cheaper on Oahu than oil.

[68] Photo by Rebecca Breyer, http://the.honoluluadvertiser.com/dailypix/2006/Oct/01/FPI610120314AR_b.jpg
[69] Burst of sun power By Greg Wiles. Advertiser Staff Writer. http://the.honoluluadvertiser.com/article/2006/Oct/01/bz/FP610120314.html

(B) CONCENTRATED SOLAR POWER

There are four types of concentrated solar power systems (CSP): the “power tower”, the “parabolic trough”, the “Fresnel mirror”, and the “dish/engine” system. The low cost leader for utility scale facilities is the parabolic trough.[70] Nine parabolic trough CSP plants with a combined capacity of 400MW have been operating in the Mojave Desert since the 1980’s.[71] Nevada One, located about twenty miles south of Las Vegas, came on line in 2007. The facility consists of a solar grid containing forty-seven miles of parabolic mirrors.

	
Concentrated Solar Power (CSP) Luz Facility[72] located about 75 miles northeast of Los Angeles	Power Tower[73] located near Seville, Spain

Parabolic CSP systems are built using aluminum and glass, but not silicon, which is scarce and costly. A Hawai`i company, Sopogy, offers rooftop CSP. These systems use a parabolic mirror to capture the rays of the sun, and to focus it on a pipe, heating its liquid mineral oil contents into a gas to fire a gas turbine. Unlike the more traditional flat photovoltaic panel, CSP systems can store heat and produce electricity hours after the sun has set; this is significant as the maximum use of electricity in Hawaii typically occurs between 5-7 p.m. Using CSP allows a building to be powered by solar energy long after flat PV panels stop producing.

70 http://www.nrel.gov/csp/troughnet/
71 http://www.nrel.gov/csp/pdfs/43685.pdf
72 This line-concentrator power plant, with troughs built by Luz, is one of nine plants with combined output of 354 megawatts - the largest being 80 megawatts - operated by Kramer Junction Power. This solar power plant located in the Mojave Desert in Kramer Junction, California, is one of nine such plants built in the 1980's. During operation, oil in the receiver tubes collects the concentrated solar energy as heat and is pumped to a power block located at the power plant for generating electricity.
73 teeic.anl.gov/er/solar/restech/desc/index.cfm

Table 3: World Concentrated Solar Power (CSP) Installations. [74]

CSP Plant	Location	Technology Type	Year Installed	Capacity (MW)
Solar Electricity Generating Stations (SEGS)	California	Trough	1984-1991	354
Saguaro	Arizona	Trough	2005	1
Nevada Solar One	Nevada	Trough	2007	64
PS10	Spain	Tower	2007	11
GEF	Morocco	Trough		6

Markets

"Currently there are 679 MW of installed CSP capacity worldwide and more than 2,000 MW under construction. The USA is the market leader in terms of installed capacity with 63% market share, followed by Spain with 32% of operating capacity."[75]

"In 2007, there were 60 manufacturers and/or importers active in manufacturing, importing, and/or exporting solar thermal collectors, a significant increase from the forty-four companies operating in 2006. These companies shipped 15.2 million square feet of solar thermal collectors in 2007, compared with 20.7 million square feet in 2006."[76]

Kalaeloa Solar One and Two (2011)[77]

Keahole Solar Power, LLC is affiliated with Darren Kimura's firm Sopogy. Keahole Solar Power released a Draft Environmental Assessment (January 2011) for 10MW of solar in Kalaeloa: 5 MW of traditional photovoltaic and 5 MW of CSP.

"The project site is located within the ahupuaʻa of Honouliuli on the southwestern portion of the island of Oahu, in the district of Ewa. It is in the northwest area of the former Naval Air Station Barbers Point (NASBP) that was closed in 1999. NASBP is currently the Kalaeloa Community Development District managed by the HCDA [Hawai`i Community Development Authority]. The Navy has retained some NASBP

---

[74] Solar Energy: Market Trends and Dynamics by Robert M. Margolis (National Renewable Energy Laboratory) Presented at the National Association of Regulatory Utility Commissioners (NARUC) 2009 Winter Committee Meeting: Energy Resources & Environment Committee. Washington, DC. February 16, 2009, p.11.

[75] Global Concentrated Solar Power industry Report (2010-2011). http://www.csptoday.com/globalreport/index.shtml; See also http://en.wikipedia.org/wiki/Solar_thermal_energy; Solar Energy: Market Trends and Dynamics by Robert M. Margolis (National Renewable Energy Laboratory), Presented at the National Association of Regulatory Utility Commissioners (NARUC) 2009 Winter Committee Meeting: Energy Resources & Environment Committee. Washington, DC. February 16, 2009 at p.11.

[76] Energy Information Administration: Renewable Energy Annual, 2007 at p. 43.

[77] Draft Environmental Assessment (January 2011), Prepared for: Keahole Solar Power, LLC, Prepared by: TEC Inc. http://oeqc.doh.hawaii.gov/Shared%20Documents/EA_and_EIS_Online_Library/Oahu/2010s/2011-01-08-OA-DEA-Kalaeloa-Solar.pdf

lands, but most have been conveyed to others. The proposed project site is undeveloped, and has no known physical address. [ ] The site is void of structures, roads, or other obvious improvements. It consists of about 80 acres within Tax Map Key (TMK): (1) 9-1-13: parcel 028, which is 137 acres. DHHL owns the parcel."[78]

"There would be approximately 10,800 CSP collectors aligned north-south in 450 rows of 24 collectors per row. The collectors would be mounted to concrete anchors on grade and assembled in rows connected by carbon steel piping to a power block. The installation has a wind-resistant rating of 125 mph. Other operating equipment that would be installed includes a storage tank for the thermal fluid, pumps, flow meters, and temperature sensors. [ ] The heat source sub-system is a closed loop thermal system where the heat transfer fluid, in this case a Food and Drug Administration (FDA) approved organic mineral oil, is heated using solar collectors.

MicroCSP [Sopogy's trade mark] parabolic trough collectors concentrate the thermal energy from the sun. Due to the curved shape of the CSP collectors the sun's rays are concentrated onto the central absorber pipe (concentration ratio of 60:1), located at approximately one foot above the bottom of the panel [ ] The curved shape also collects the sun's rays to the point where there is minimal external reflection or thermal currents created."[79]

"The heat transfer fluid is heated in the absorber pipe located inside the parabolic trough. [ ] The pipe conveys the heat transfer fluid through the CSP collectors. A pump is used to circulate the heat transfer fluid from the CSP collectors to the Power Generating Building where the 300-500º F thermal fluid 1) generates steam to drive a steam turbine generator and generate alternating current (AC) electricity, or 2) is temporarily retained in a storage tank before being conveyed to the engine block. The thermal fluid is cooled and recycled through the CSP collectors. The cooling process would rely on water. Benefits to having a storage tank for the thermal fluid include an uninterrupted electricity supply in the eventuality of clouds or rain where there could be very little or no solar energy."[80]

Conclusion

CSP is an intermittent source in that it produces power during only part of the day. Its significance lies in the fact that it can store some daytime solar energy and transfer its use to the evening peak which occurs after dark.

[78] Ibid. 2-1.
[79] Ibid. 2-4.
[80] Ibid. 2-6.

(C) CENTRAL STATION WIND POWER

A wind turbine is a device for converting wind energy into electricity. Wind power is currently the cheapest renewable energy power source available throughout the world.[81] Turbines are more effective in windy areas, but as the towers grow in height to take advantage of stronger winds aloft, they engender greater aesthetic objections. Another major environmental impact is bird and bat-tower interactions or fatalities.

The sun heats different parts of the earth (water, land, forests, glaciers, and pavement) at different times (day, night, and summer, winter) and at different rates. Warm air rises and colder air moves in. A wind energy system that transforms the kinetic energy of the wind into mechanical power (raising water, grinding grain, pushing a sail) or electrical power has been used for hundreds of years. There are two basic designs of wind electric turbines: vertical-axis ("egg-beater") style, and the horizontal-axis (propeller-style) machines.

Utility-scale wind power plants are a more recent development, and require a minimum average wind speed of 13 mph. The power available in the wind is proportional to the cube of its speed, which means that doubling the wind speed increases the available power by a factor of eight.

Hawai`i Wind Systems (existing, planned and proposed)

O`ahu	Kahuku I	30	Under construction
	Kahuku II	50	Proposed
	Kawailoa (Hale`iwa)	70	Proposed by Bishop Estate
	Kalaeloa (0ffshore)	300	Proposed
Maui	Kaheawa I	30	On line 2006
	Kaheawa II		Permitting Stage
	Ulupalakua Ranch	40	Proposed Auwahi wind farm
Hawai`i	Lalamilo	1.2	Originally built 1985. Needs overhaul
	Kahua Ranch		Former wind site
	Parker Ranch		Private solar-wind system
	Upolu Point, Hawi	10.5	Operational
	Ka Lae (South Point)	20.5	Renovated. On line 2007

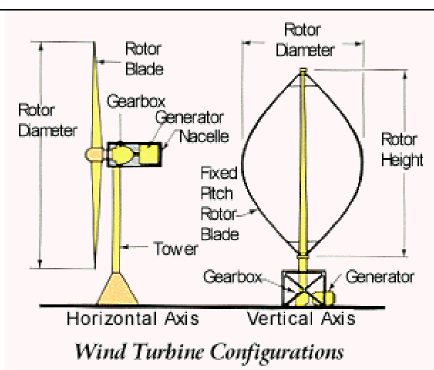
[81] Damming giant rivers to produce electricity can be cheaper per kilowatt-hour of electricity produced, but the opportunity exists in only a few areas, and damming large rivers is not considered to be either renewable or sustainable.

Turbine subsystems include a tower (to support the rotor and drive train), a rotor (blades which convert the wind's energy into rotational shaft energy), a nacelle (an enclosure containing a drive train, a generator and usually including a gearbox), and electronic equipment (controls, electrical cables, ground support equipment, and interconnection equipment). The towers are mostly tubular and made of steel. The blades are made of fiberglass-reinforced polyester or wood epoxy.

Wind turbines have been getting larger over time. Large-scale commercial blades have increased in size from 30 feet (1981), 80 feet (1990), to 210 feet (2000). The rating increased from 0.025 MW (1981), 0.55 MW (1990), to 1.65 MW (2000). Land-based wind farms can have 270 foot towers and 270 foot rotors for a total height exceeding 440 feet.

Capacity factor is one element in measuring the productivity of a wind turbine or any other power production facility, and is derived by comparing the plant's actual production over a given period of time with the amount of power the plant would have produced if it had run at full capacity for the same amount of time. Although modern utility-scale wind turbines typically operate 65% to 90% of the time, they often run at less than full capacity. So while a turbine may achieve a higher capacity factor during windy weeks or months, a typical capacity factor of 25% to 40% is common. For example, a wind turbine at a typical location in the Midwestern U.S. might run about 65-90% of the time, but much of the time it will be generating at less than full capacity.

Availability factor (or just "availability") is a measurement of the reliability of a wind turbine or other power plant. It refers to the percentage of time that a plant is ready to generate (that is, not out of service for maintenance or repairs). Modern wind turbines have an availability of more than 98%--higher than most other types of power plants. After more than two decades of constant engineering refinement, today's wind machines are highly reliable.

<table>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>Horizontal and Vertical Wind Systems[82]</td>
<td>The Kaheawa Pasture Wind Farm on Maui mauka of Ma`alaea.[83]</td>
</tr>
</table>

[82] www.awea.org/faq/wwt_basics.html

The potential wind power resource of the US, that is, what could be developed without incurring undue impacts to birds, noise, or visibility, is estimated to be between two to ten times the entire electricity consumption of the US.[19]

Markets

Wind is the number one leader in the worldwide renewable energy surge.[84]
"Global wind power capacity grew by 28 GW in 2008 to 122 GW. This was the fifth consecutive year of accelerating growth at just over 28 percent per annum. The US led the growth with 8.4 GW, a 49.5 percent increase on 2007; while China came second with the fastest growth rate and the second highest capacity increment at 6.2 GW."[85]

"Wind power (new installation capital costs) is projected to expand from $63.5 billion in 2009 to $114.5 billion by 2019. Last year's global wind power installations reached a record 37,500 MW. China, the global leader in new installations for the first time, accounted for more than a third of new installations, or 13,000 MW."[86]

Hawai`i Wind Potential

The Kohala – Waikoloa area of Hawai`i Island is a large area with Class 7 winds. If the entire area were covered with wind towers, and supplemented with batteries, it could probably produce all of the electricity needed within the State.

The second best Class 7 land area in the State is an area of Maui extending from the Kaheawa Wind Farm site down to the coast near Ma`alaea. With batteries, this area could produce 1/3 of the State's electricity demand.

Both of these options are environmentally and culturally sensitive areas.

Conclusion

Wind farms will multiply across Hawaii and in the mainland United States. Several new wind farms are in the planning phase, including Kahuku, Kaheawa II, and Ulupalakua Ranch. The most difficult issue in planning a wind project is identifying sufficient land with great wind potential that does not raise objections from governmental entities or neighbors. Investors who are able to find such sites will be rewarded with profits.

---

83 Photo: UPC Wind, After Oil. By Jan TenBruggencate, Photo courtesy of UPC Hawaii Wind Partners Farming the wind on Maui. www.honolulumagazine.com/Honolulu-Magazine/March-2008/After-Oil/index.phpcparticle=2&siarticle=1
84 Global Trends in Sustainable Energy Investment 2009 p.17.
85 Green Energies: 100% Renewables by 2050 By Mae-Wan Ho, Brett Cherry, Sam Burcher & Peter Saunders. Institute of Science in Society (UK), Third World Network.
86 Clean Energy Trends 2010 by Ron Pernick, Clint Wilder, Dexter Gauntlett, Trevor Winnie (March 2010) Clean Edge.

(D) ROOFTOP MICRO WIND ENERGY

Just as wind gains speed as it rises over mountains, it gains speed as it rises over buildings. Small wind systems could be installed on thousands of rooftops in Hawai`i. The advantage of wind is that it is the cheapest renewable energy source of electricity in Hawai`i and in much of the world. Rooftops could be used for multiple systems: solar water heaters, photovoltaic panels or concentrated solar power, and micro-wind; small stand-alone wind minds and rooftop systems are easy to install.

In Hawai`i, people stop to take pictures of the wind mills at South Point, wonder why the wind towers at Kahuku are not spinning, and support proposed future wind farms at Kaheawa and at Maui Community College. On the other hand, there is wide-spread protest against proposed fossil fuel generators at Keahole, Waena and elsewhere.

			
Small wind turbines on the roof of an office in London [87]	A Windsave micro turbine in Scotland.[88]	Veneko / Bergey Windpower in Bosnia[89]	University of Hawai`i's Shanah Trevenna[90] at Saunders Hall[91]

Wind Speed and Data

Rooftop systems tend to operate at lower wind speeds than large centralized wind facilities which are built on towers to capture wind currents.

---

[87] Renewable Energy World. January / February 2007. http://www.thailand-energy.info/News/34001132.htm
[88] Renewable Energy World. January / February 2007. http://www.thailand-energy.info/News/34001132.htm
[89] Renewable Energy World. January / February 2007. http://www.thailand-energy.info/News/34001132.htm
[90] http://media.collegepublisher.com/media/paper872/stills/8518azzp.jpg; PacWind SeaHawk vertical axis wind turbine: http://www.pacwind.net/gallery/seahawk-1-lg.jpg
[91] Ibid. The 1.1kW pole-mounted vertical axis wind turbine was donated by Energy Management Group, Inc. (EMG). The system is wall mounted near the northeast corner of Saunders. The dimensions of the wind device are three feet wide and five feet tall. The top of the wind tower will be 3-6 feet above the roofline.

The power available in the wind is proportional to the cube of its speed, which means that doubling the wind speed increases the available power by a factor of eight. Thus rooftop systems are far less efficient than industrial-scale wind facilities.

Wind farm investors often gather wind data over a period of a year or more, and use computers to map out where wind towers should be placed. Individuals and businesses that place wind systems on their roofs often do not have much knowledge about wind patterns on their roofs.

The micro-wind market is just emerging. While wind turbines do not operate below certain wind speeds, wind turbines have varying maximum wind speeds at which they shut down. Some systems are able to handle directional shifts in wind, others can handle swirling wind and some can't do either.

Rooftop and ground wind characteristics are often very different and can significantly affect performance.

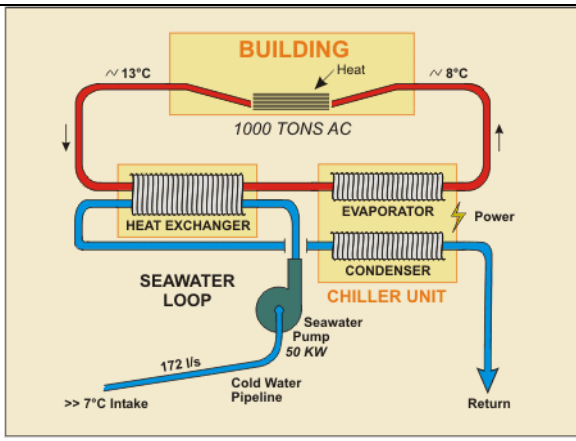
Conclusion

Micro-wind has a great potential in Hawai`i in the mid-term, and its future is bright. Among the issues that need to be resolved are county ordinances and community acceptance.

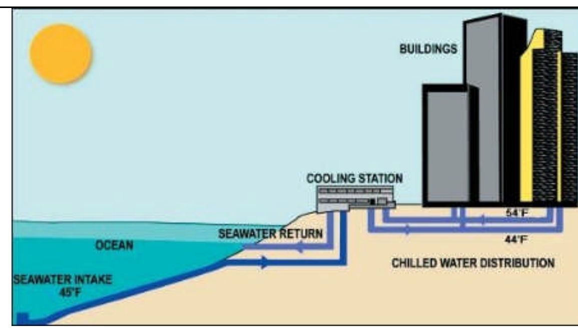
(E) SEA WATER AIR CONDITIONING

Rather than importing electricity into large buildings to power chillers to cool the building, a system involving three sets of pipes are used in sea water air conditioning systems (SWAC), with heat transfer units located where the pipes meet. These pipes consist of the building's internal pipes, an inter-building loop, and an ocean loop. In essence, cold salt water is brought up from the ocean's depths, meets the inter-building pipe loop and pulls heat from it, and then returns the ocean water to a warmer section of the ocean. The cold water in the inter-building loop travels from building to building, where it absorbs heat from each building's internal loop.

Cornell University built a six-mile intake pipe from a cold Finger Lank in upstate New York. The total heat added to the lake, over the course of a year, is equivalent to the heat that the lake absorbs from one hour of summer sunshine. Cornell did a thorough multi-year environmental analysis of the impacts and found them to be minimal. Makai Ocean Engineering, a Hawaii company, built the Cornell SWAC system as well as one in Toronto.



SWAC Diagram[92]



SWAC System[93]

Conclusion

Oahu could handle six to seven systems, including two for Waikiki; this would displace 40% of Waikiki's energy load, reducing Waikiki's energy bill by 40% using cold ocean water.[94]

---

92 www.zulenet.com

93 www.renewableenergyworld.com/assets/images/story/2008/7/9/1332-investors-fund-us-10-75-m-for-honolulu-seawater-air-conditioning.jpg

94 Uncontested testimony by Life of the Land witness Dr. John Harrison during the Board of Land and Natural Resources (BLNR) contested case hearing re: Conservation District Use Application (CDUA) OA-2801. Dr. Harrison worked as a post-doctoral marine scientist for the University of California at Berkeley where he administered the U.S. Department of Energy-funded ocean thermal energy conversion (OTEC) environmental research program in Hawaii. Dr. Harrison wrote the Ocean Thermal Energy Conversion (OTEC) handbook for the U.S. Department of Energy's solar energy research institute. The U.S. Department of Commerce, National Marine Fishery Services hired Dr. Harrison to write the environmental

(F) WAVE ENERGY CONVERSION SYSTEMS

Wave Energy Systems should not be confused with waves crashing down along reefs or along a coastline. Rather, they get their energy from the wave action of water rising and falling in the open ocean. The waves are generally far more predictable than wind, which does not always blow, or even the sun which can be blocked by clouds and eventually sets each day.

Responding to House Resolution 8-2001, and building on previous studies on wave power (among them DBEDT's "Feasibility of Developing Wave Power as a Renewable Energy Resource for Hawaii (1992)"), the Department of Business Economic Development and Tourism released a study acknowledging that wave power (buoys) could generate all (100%) of the state's electrical needs.[95] In fact, the cheapest wave energy system would cost 9.8 cents/kWh. The DBEDT study was based on a buoy system which is inferior to the oscillating water column (OSC) also known as the "blowhole," which has a much higher efficiency factor.

In 2004 the Electric Power Research Institute (EPRI), a national utility think tank whose members represent over 90% of the electricity generated by shareholder-owned utilities in the United States, examined wave power, and more specifically, looked in detail at Hawai`i's potential wave power. EPRI found that each island in Hawai`i could meet all of its electricity needs through wave energy.

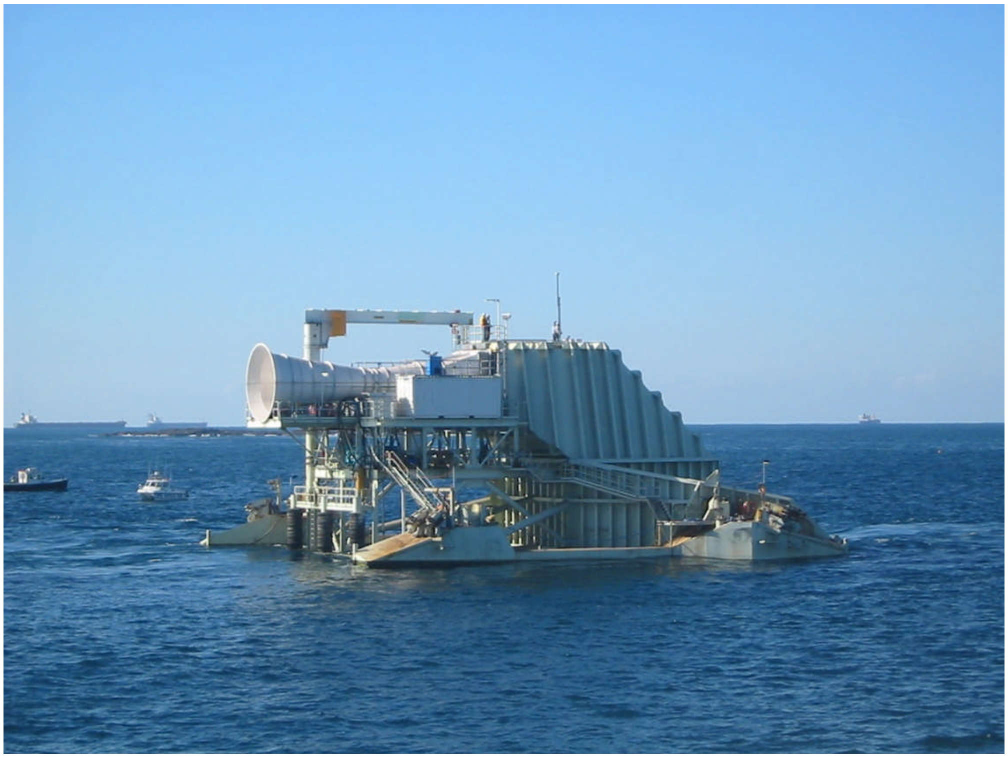
According to EPRI's study "Offshore Wave Power in the US: Environmental Issues (2004)": "Like any electrical generating facility, a wave power plant will affect the environment in which it is installed and operates. We conclude that, given proper care in site planning and early dialogue with local stakeholders, offshore wave power promises to be one of the most environmentally benign electrical generation technologies. We recommend that early demonstration and commercial offshore wave power plants include rigorous monitoring of the environmental effects of the plant and similarly rigorous monitoring of a nearby undeveloped site in its natural state (before and after controlled impact studies)."[96]

---

analysis section of the federal environmental impact statement for the 40-megawatt ocean thermal energy conversion (OTEC) pilot plant that was intended to be installed at Kahe Point, adjacent to and in concert with the Hawaiian Electric Kahe Point generating facility.

[95] Feasibility of Developing Wave Power as a Renewable Energy Resource for Hawaii. This report is the DBEDT's response to House Resolution No. 8 (HR 8) - "Requesting the Department of Business, Economic Development, and Tourism (DBEDT) to Study the Feasibility of Developing Wave Power as a Renewable Energy Resource for Hawaii," was adopted by the House of Representatives of the Twenty-First Legislature of the State of Hawaii, Regular Session of 2001.

[96] "Wave Energy Resource Assesmment for the State of Hawaii,"Principal Investigator: George Hagerman of SEASUN Power Systems. Contributors: Roger Bedard (EPRI) December 21, 2004. www.epri.com/oceanenergy/attachments/wave/reports/007_Wave_Envr_Issues_Rpt



Oceanlinx Wave Energy Systems[97]

Another EPRI study[98] found that Oahu had excellent wave energy resources along its northeast coast from Kahuku to Makapuu Points, and that Honolulu has the best port harbor and port infrastructure in the Islands [to] support “device fabrication and assembly. [There is a] unique opportunity for a wave energy pilot facility off the northeast coast of Oahu, just west of the humpback whale marine sanctuary boundary. The unique opportunity is the existence of Makai Ocean Engineering's fully instrumented pier and offices.''[99]

Blow-Hole Wave Energy System

The Blow-Hole (oscillating water column) Wave Energy System can produce net power (after accounting for the power to run the system) with an eight inch ocean swell. The system consists of a compartment with water at the bottom and air on top. When a wave arrives, the water level rises and air is forced out of the blowhole. When the wave recedes, the air is sucked back in to the blowhole. A two-way air turbine spins in the same direction as the air goes in and out, generating electricity. Having the spinning device rotating in the same direction - regardless of which way the wind is moving - significantly increases the efficiency of the generator. There is only one moving part in Oscillating Water Column systems, and unlike most other wave energy systems, it is

---

[97] Picture from Oceanlinx. http://sydney.edu.au/warrencentre/bulletin/NO57/ed57art5.htm
[98] E2I/EPRI Offshore Wave Energy Plant Site Assessment - State of Hawaii (2004); see also EPRI, Survey and Characterization of Potential Offshore Wave Energy Sites in Hawaii. Principal Investigator: George Hagerman. Contributors: Roger Bedard and Mirko Previsic. June 15, 2004. http://www.epri.com/oceanenergy/attachments/wave/reports/003_Hawaii_Site_Repo
[99] Ibid.

above the water level. The physical structure rises about thirty feet above sea level, and was developed by Oceanlinx (formerly Energetech), an Australian firm. The International Academy of Sciences named Oceanlinx a Top Ten Finalist for Scientific Innovations of 2006; they are currently going through the planning stages to build a small system off Maui[100] and the company is looking to expand throughout Hawai`i.

[100] The specific timing will depend on final approval by Maui Electric and the PUC.

(G) OCEAN THERMAL ENERGY CONVERSION

Ocean Thermal Energy Conversion (OTEC) systems create usable energy through the differential in temperature between two different ocean layers. OTEC can only work in the tropics, in areas without continental shelves. Only a few hundred sites exist around the world, mostly islands, where there are sharp differences in temperature layers close to the coastline and electric transmission grids are nearby.

OTEC resembles sea water air conditioning (SWAC) in that there are three distinct piping systems. There is a pipe loop above water filled with ammonia. A second pipe with warm surface water brings sufficient heat to vaporize the ammonia and send it through a turbine. A third pipe containing deep - and cold - ocean water turns the ammonia back into a liquid.

This approach is being advocated in Hawai`i by a number of academic and industry people.[101]

The pipes are constructed to minimize harming sea life which can be trapped on the intake valve, sucked through the system, or affected by the water discharge. These three impacts are called "entrainment" (the traveling of biota through the system), "impingement" (the hitting and trapping of biota against the screen on the intake pipes), and "secondary entrainment" (caused by biota interacting with the turbulent discharge water).

Chapter 4 presents our OTEC-based plan.

ALTERNATIVE TECHNICAL APPROACHES

An alternative approach is being promoted by MELE Associates, OTEC International, and the Abell Foundation.[102] Their working fluid is propylene instead of ammonia, and they propose that an OTEC system (for both on-shore and off-shore) that will have four byproducts: electricity, hydrogen, jet fuel and drinking water.

They contend that the heat exchange will be far more efficient, allowing much smaller, lighter, more efficient hot water and cold water intake pipes, made of fiberglass.

The consortium alleges that "the D.O.E. [Department of Energy] Hawaii OTEC program used standard heat exchange practices common to the power industry with smooth tubes and a U value[103] of about 600. For 75 years the refrigeration industry has been using enhanced surfaces on their HX tubes to increase heat transfer with U values around 1,300. [They have] designed new high performing enhancements for both the

---

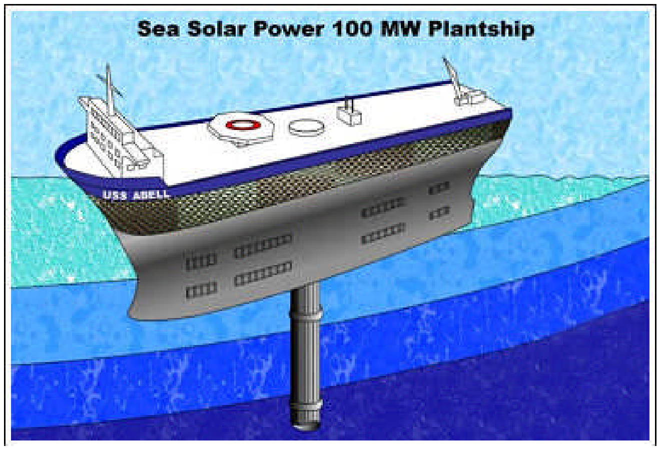
101 See Chapter 10: Economic Analysis

102 Mel Chiogioji, President , CEO MELE Associates, Inc.; http://www.meleassociates.com/c/517/ocean-energy-thermal-conversion-otec; http://www.meleenergygroup.com/c/268/about-us; http://www.meleenergygroup.com/c/8/contact; http://www.abell.org/abellinvestments/index.html

103 "The overall heat transfer coefficient ***U*** is a measure of the overall ability of a series of conductive and convective barriers to transfer heat. It is commonly applied to the calculation of heat transfer in heat exchangers." http://en.wikipedia.org/wiki/Heat_transfer_coefficient#Overall_heat_transfer_coefficient

internal and external surfaces of the HX tubes for the evaporators and condensers with an optimized pressure drop exceeding a U value of 2000."[104]

100 Megawatt (Power) Plant Ship[105]



Conclusion

OTEC can provide the baseload power needed within Hawai`i.

The approach used by Sea Solar Power MELE Associates, OTEC International, and the Abell Foundation offers a different and less researched alternative. For the time being we continue to advocate for the traditional ammonia approach. However, it is important in any comprehensive document to detail alternative approaches such as this one.

[104] Statement to Support Public Comment by Robert J. Nicholson, III, Sea Solar Power International, LLC., U.S. Commission on Ocean Policy Meeting. Washington, D.C., January 24, 2003. http://www.oceancommission.gov/publiccomment/janmtg/nicholson_comment.pdf
[105] http://www.meleassociates.com/c/517/ocean-energy-thermal-conversion-otec

(H) WASTE OIL BIOFUELS

“Biomass” is any organic matter such as agricultural crops and residue, wood and wood waste, animal waste, aquatic plants, and organic components of municipal and industrial wastes. “Biomass fuel” is any liquid, solid or gaseous fuel produced by the conversion of biomass to fuel. The two most common types of biofuel are ethanol and biodiesel.

Biodiesel is a biofuel produced from animal or vegetable oil, including soybean oil, rapeseed oil, animal fats, waste vegetable oil or microalgae oil.

The only successful biodiesel refineries in Hawaii are run by Pacific Biodiesel,[106] which processes waste oil into biodiesel; one plant exists on Maui and one is planned for the Big Island.

Pacific Biodiesel founder Robert King said in 2008, "Note that when the environmental, economic and social impacts of producing one gallon of biodiesel versus another are calculated, it is clear that not all biofuels are equal. Not all biofuels are ‘green’ or sustainable."[107]

Co-founder Kelly King stated, "Many of us who had been involved in the industry for several years or more were very worried about the boom in biofuels investment leading to massive greenwash[108] efforts and a negative impact from biodiesel companies who are only focused on greening their own wallets."[109]

Conclusion

Biofuel is currently being used for transportation. In the future it should be used for jet fuel. It is not the best solution for producing electricity, in light of the many other solutions available.

---

[106] Pacific Biodiesel was founded by Robert and Kelly King. See http://www.biodiesel.com/

[107] Robert King, President Pacific Biodiesel, Docket 2007-0346, EH1 LOL T-2 55:5-7

[108] "Greenwashing (a portmanteau of 'green' and 'whitewash') is a term describing the deceptive use of green PR or green marketing in order to promote a misleading perception that a company's policies or products (such as goods or services) are environmentally friendly. The term green sheen has similarly been used to describe organizations that attempt to show that they are adopting practices beneficial to the environment. Greenwashing may be described as 'spin'." http://en.wikipedia.org/wiki/Greenwash

[109] Kelly King, Co-founder, Board member, Sustainable Biodiesel Alliance. Docket 2007-0346, EH1 LOL T-3 58:2-5)

(I) GEOTHERMAL

The geothermal resource cannot be separated from the history of using geothermal in Hawai`i. It is one of a few baseload renewable energy resources available for Hawai`i, it is a low climate impact option, and its use has enormous cultural significance.

Geothermal[110] (earth heat) has been known and used by people around the world for at least 10,000 years in many places including areas currently called Russia, Iceland, Hungary, New Zealand, the United States, and Italy. In many areas reservoirs of steam and hot water are trapped near the surface in areas of past volcanic activity and are brought to the surface by geysers, steam vents and hot springs. National Parks such as Yellowstone have sprung up around geysers which draw millions of visitors. Hot Springs, Arkansas is named for the spring-fed geothermal baths.

The Earth's core has a temperature upwards of 9,000°F. Heat radiating upwards has continued for 4.5 billion years, and will continue to do so for billions of years to come. Thus, geothermal energy is renewable energy.

The first use of geothermal power for electricity occurred in Italy in the very early years of the 20th century. Iceland receives most of its power from geothermal heat and electricity plants. There are about 50 geothermal plants in the U.S., most of which are in California and Nevada.

The Massachusetts Institute of Technology conducted an extensive study released in 2006, named, "The Future of Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century."[111] The study concluded that "[t]he total resource base to a depth of 10 km can also be estimated. [ ] By almost any criteria, the accessible U.S. EGS resource base is enormous – greater than 13 million quads or 130,000 times the current annual consumption of primary energy in the United States. Of course, the economically recoverable reserve for EGS will be much lower, subject to many technical and economic constraints that are evaluated throughout this report."[112] At the time, the study focused on what exists within the top 10 km; drill bits today can dig down 30 km.

Geothermal wells are similar oil wells in that long pipes are stuck into the ground, in the case of geothermal to tap into hot steam rising from geothermal heat sources, in the case of oil to tap into oil fields. The steam can be harnessed to power an electric turbine.

The chief byproducts of geothermal wells are carbon dioxide (CO_2) and hydrogen sulfide (H_2S), with the latter distinguished by its "rotten egg" smell and detectable by

---

110 For additional information, See: Melody Kapilialoha MacKenzie, www2.hawaii.edu/~nhlawctr/article4-1.htm; http://thefraserdomain.typepad.com/energy/geothermal; http://www.punageothermalventure.com/PGV; http://www.msnbc.msn.com/id/24471365/

111 http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

112 MIT Report page 1-15

people at levels as low as 30 parts per billion (ppb). These levels are below those associated with coal and oil power plants.

Geothermal facilities, like OTEC facilities, can use Rankine engines to generate electricity. The organic Rankine cycle-based power system is an advanced binary cycle system that is driven by a simple evaporation process and is entirely enclosed, which means it produces no emissions. The only byproduct is electricity, and the system's "fuel" -- geothermal hot water -- is a renewable resource.[113]

The Hawai`i Experience

Geothermal research started on the Big Island in 1961 when the Hawaii Thermal Power Company drilled four privately owned wells in Kilauea's east rift zone, and the State and the National Science Foundation have continued to research geothermal possibilities for Hawaii. In 1975-76 the Hawaii Geothermal Project Well-A (HGP-A) was constructed, and a 3 MW geothermal generator was in operation from 1981-89. The generator was eventually shut down due to leaks, fear of well blowouts and other environmental and community concerns.

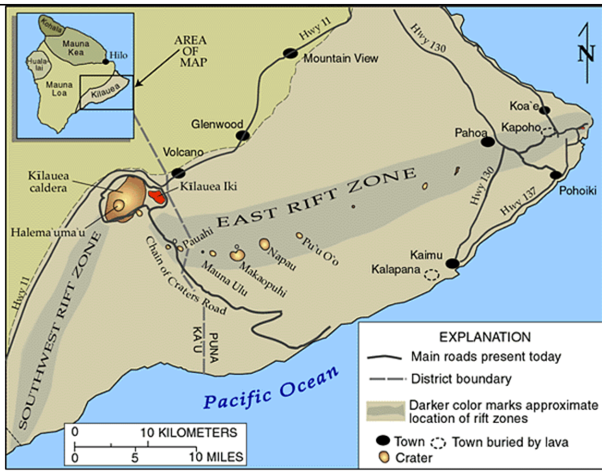
The eruption of Kilauea in 1983 forced the State to change the location of planned geothermal well drilling.

In 1983 the State Legislature passed Act 296: "Beginning in 1983, the Board of Land and Natural Resources shall conduct a county-by-county assessment of areas with geothermal potential for the purpose of designating geothermal resource subzones. This assessment shall be revised or updated at the discretion of the board, but at least once each five years beginning in 1988."[115] Shortly thereafter, the State designated a portion of the Kilauea Middle East Rift Zone, located primarily within Wao Kele 'O Puna, as a geothermal resource subzone.

---

[113] http://thefraserdomain.typepad.com/.shared/image.html?/photos/uncategorized/2008/01/18/utc_geothermal_power.gif

[115] HRS §205-5.2 (a) Designation of areas as geothermal resource subzones. www.capitol.hawaii.gov/hrscurrent/Vol04_Ch0201-0257/HRS0205/HRS_0205-0005_0002.htm



Kilauea's East Rift Zone[116]

Wao Kele 'O Puna Forest Reserve[117]

Wao Kele O Puna and the Legacy of the Pele Defense Fund

Beginning in 1982 and for the next eight years, the state considered building a 500 MW generator and constructing a deepwater cable to bring power across the Alenuihaha Channel between Hawaii Island and Maui, then onward to Oahu (the federally funded Hawaii Deep Water Cable Project). At about the same time, Campbell Estate negotiated with the state to trade conservation land it owned that was buried in lava flow, with land owned by the state, to pursue building geothermal plants. In 1985 the swap was completed: about forty square miles of lava for about forty-two square miles of pristine land, including land in the Wao Kele 'o Puna, an area favored as a potential 500-MW geothermal field.

In addition to its geothermal potential, Wao Kele O Puna was also habitat to over two hundred threatened and endangered species, including many native species such as the ʻohiʻa, häpuʻu fern, ʻieʻie vine, hala, köpiko, ʻio (Hawaiian hawk), opeʻapeʻa (Hawaiian bat), ʻapapane and ʻamakihi honeycreepers. The area has been used for cultural access and gathering for hundreds of years,[119] and has many burial sites, underground lava tubes and hosts native religious, hunting and gathering (la'au lapa'au (herbal medicine practitioners). Indeed, the area was so signficant that it was included in the State Natural Area Reserve (NAR) system.

The 1986 State Legislature had the power to stop the transfer, but chose not to do so.

Enthusiasm over geothermal energy's potential led supporters to misunderstand, or simply disregard, native Hawaiian cultural and religious sensitivities surrounding geothermal energy, and many Hawaiians came forward to say exploitation of this

[116] http://keith.martin.home.att.net/KilaueaRifts.gif
[117] http://www.oha.org/library/images/Wao_Kele_O_Puna-map1.jpg
[119] www.oha.org/index.php?option=com_content&task=view&id=398&Itemid=293

potential energy source would be an affront to Pele, goddess of fire and protector of the Big Island's volcanoes. Such miscalculations included a Hawaiian Electric Company TV spot in the early '80s, shot near the rim of Halemaumau Crater, which closed with a visual of a giant electric plug being jammed into a giant receptacle planted on the ground. A leader in the Pele Defense Fund movement later offered the opinion that the TV ad's symbolic "plunging of a dagger into Pele's breast" was the trigger that fueled opposition to geothermal energy on the island.[120]

"Native Hawaiian concerns about the industry's potential to respect their culture, as well as damage the Wao Kele O Puna rainforest, was instrumental in blocking plans to expand the geothermal field. The Pele Defense Fund, backed by the Rainforest Action Network, was the most visible defender of cultural practices and an environment cherished by Hawaiians, including the rainforest, described by the Network as the last large lowland expanse of tropical rainforest in Hawaii,

The result of the growing opposition was the Pele Defense Fund (PDF, incorporated in 1987) by followers of traditional Hawaiian religious practices, particularly worship of Pele, the volcano goddess. Protests numbering upwards of 1,000 people proliferated, and lawsuits were filed by the Sierra Club Legal Defense Fund (now known as EarthJustice), representing the Wao Kele O Puna Rainforest, Greenpeace USA, Big Island Rainforest Action Group, Blue Ocean Preservation Society, Citizens for Responsible Energy Development with Aloha Aina, Friends of the Earth, Greenpeace Hawaii, Kapoho Community Association, O'ahu Rainforest Action Group, Pahoa Business Association, Pele Defense Fund, Rainforest Action Network, to block the project. Hawaiians associated with opposing the proposal included Palikapu Dedman, Dr. Noa Emmett Aluli, Pua Kanahele, Henry Auwae, Davianna McGregor, Paul Takehiro, Tom Luebben, Alapa'i Hanapi, and Ka'olelo 'Ulaleo.

In 1992 the Hawaii Supreme Court ruled that although the Pele Defense Fund could not contest the transfer of public ceded lands, it could litigate the extent to which Hawaiians retained rights customarily and traditionally exercised for subsistence, cultural and religious purposes in Wao Kele 'o Puna. The high court's landmark decision acknowledged that the State Constitution protected Hawaiian cultural rights, including traditional access, gathering and hunting.

After years of litigation, the Cambell estate put the property up for sale in 2001. Led by the Pele Defense Fund the land was acquired by the Trust for Public Land in 2006 with support from the Office of Hawaiian Affairs, the Hawai`i Department of Land and Natural Resources, and the U.S. Department of Agriculture Forest Legacy Program. OHA subsequently acquired Wao Kele o Puna rainforest in 2006, and agreed to manage the forest in partnership with the surrounding communities, ensuring that the land will be permanently preserved from development.

---

[120] Big Island Geothermal Venture Marks 15th Year. By Doug Carlson. December 11, 2008. http://hawaiienergyoptions.blogspot.com/2008/12/big-island-geothermal-venture.html

Other Efforts

Puna Geothermal Venture entrance sign[121]

Aquaculture: Puna Geothermal Venture [122]

In 1990, Puna Geothermal Venture (PGV), located twenty-one miles from Hilo Town, replaced the HPG-A facility. The PGV facility is located on twenty-five acres as part of a larger 500 acre plot located in the Lower East Rift Zone. In 1991 PGV had a well blowout that lasted 31 hours; nonetheless new wells were dug in 1992 and 1993. According to a U.S. Environmental Protection Agency report, PGV had 19 gas releases between 1991 and 1996 and the plant was a significant source of hydrogen sulfide released into the environment. [123]

Ormat Technologies, Inc. acquired Puna Geothermal Venture (PGV) in 2004. The power plant comprises ten combined cycle ORMAT Energy Convertors (OECs) installed in parallel. Each OEC consists of a Level I topping steam turbine and a Level II organic turbine connected to a common generator.

Geothermal Geography

The Big Island can be thought of as having an east side (Hilo) and a west side (Kailua Kona). The Hilo side has far more electrical generation than it needs (the area has 60% of the electricity supply, while having only 40% of the electricity demand), while the Kailua Kona side has a shortage (40% supply, 60% demand). Increasing power to the west side can be done in two ways: relying on the overly abundant wind and solar

---

[121] A history of contention: What role does geothermal play on the Big Island? by Daniel Brock. West Hawaii Today. June 22, 2008. www.westhawaiitoday.com/articles/2008/06/22/local/local01.txt Photo By Baron Sekiya | West Hawaii Today

[122] Ibid. Eddie Marshall, left, and Tom DeKok, of Tropical Ponds Hawaii, harvest aquarium fish in ponds using water from Puna Geothermal Venture. The business is a neighbor to the geothermal power plant. - Baron Sekiya | West Hawaii Today

[123] In 2004, the Hawaii Supreme Court dismissed a health-based lawsuit, citing the plaintiff's failure to produce enough evidence linking PGV to physical ailments.

resources of the west side, or building new geothermal plants in sensitive environments and building additional large transmission lines across the island. While would seem self-evident that reliance on local abundant resources is prefereable, there have been and still are a group of west side politicians and business leaders who are working with DBEDT on finding ways to revive the geothermal-powered inter-island cable.

Geothermal Resources

The following *italicized paragraphs* are from Geothermal Energy in Hawaii By Donald M. Thomas (1986)[127]

Geothermal Resource Potential (PGRAs) in Hawai`i:

On the island of Hawaii:

- *Puna*
- *Ka'u*
- *South Point*
- *Hualalai-North Kona*
- *Kawaihae*
- *Keaau*
- *Kohala*

On the island of Maui:

- *Haleakala Southwest Rift*
- *Haleakala East Rift*
- *Pauwela*
- *Lahaina*
- *Olowalu-Ukumehame*
- *Honokowai*

On the island of Oahu:

- *Kaneohe-Waimanalo*
- *Lualualei*
- *Honolulu Volcanic Series*
- *Haleiwa*
- *Laie*
- *Pearl Harbor*

O`ahu

Lualualei Valley: Geologic mapping located the focus of the late-stage eruptive activity near the back of Lualualei Valley and tentatively identified the Waianae caldera

[127] Special Issue: Geothermal Energy in Hawaii By Donald M. Thomas, Hawaii Institute of Geophysics, University of Hawaii, Geothermics, Volume 15, Issue 4, 1986, Pages 435-514. http://linkinghub.elsevier.com/retrieve/pii/0375650586900143

boundaries within the valley. Soil geochemistry studies defined anomalous zones of mercury concentrations and radon emanation that appeared to be coincident with the caldera boundary faults. Groundwater chemistry and temperature measurements identified a distinctly anomalous well near the back of the valley and several others with slightly anomalous conditions on the caldera boundary faults. Geophysical soundings indicated low subsurface resistivities within the valley that were interpreted to correspond to warm fresh to saline water-saturated basalt. On the basis of the available data, the probability for a low- to moderate-temperature resource (50–125°C) within 3 km of the surface is assessed at 10–20%. The probability for a higher temperature resource is less than 5%.

Mokapu Peninsula and Koolau Caldera: Geologic mapping identified three post-erosional volcanic vents on Mokapu Peninsula; the inferred ages were on the order of 300,000 years. Geochemical studies on Mokapu were unable to identify a self-consistent pattern of soil geochemical anomalies or significant groundwater chemical anomalies that would suggest a geothermal resource. Resistivity soundings determined subsurface resistivities that were consistent with cold seawater-saturated sediment. The probability for even a low-temperature geothermal source at depths of 3 km or less beneath Mokapu is considered to be less than 5%.

Results of preliminary soil geochemical studies and interpretation of available groundwater data to the south of Mokapu, within the Koolau caldera, suggest that some thermally induced alterations may be present. Interpretation of geophysical data indicates that the temperatures within the ancient Koolau magma chamber are less than 540°C and that the shallow subsurface resistivities show no evidence of thermal effects.

On the basis of the rather sparse data currently available, the probability for a low- to moderate-temperature resource associated with the Koolau magma chamber is considered to be 10% or less.

Maui

Geothermal assessment activities on Maui included an evaluation of the major rift zones and post-erosional volcanic vents on both West Maui volcano and Haleakala volcano. Field surveys conducted on West Maui yielded the following results.

Olowalu and Ukumehame Canyons: extensive geologic mapping characterized the southwest and southeast rift zones of West Maui volcano and interpreted these structures to suggest a migration of the rift zone activity late in the formation of West Maui. Numerous late-stage alkalic and trachitic dikes and plugs were also identified in the survey area. Ground-water geochemical and temperature measurements identified distinctly anomalous water chemistry and temperatures. Resistivity sounding data for the area was interpreted to indicate a thick layer of warm, fresh to saline water beneath the Olowalu and Ukumehame Canyons. The probability of a thermal resource having a temperature greater than or equal to 50°C is estimated to be 50–60%, whereas a temperature greater than or equal to 125°C has an estimated probability of 10% or less.

Lahaina-Kaanapali: soil geochemical surveys were unable to identify a self-consistent pattern of soil mercury concentrations or radon emanation rates that would suggest a thermal resource. Groundwater temperature measurements and chemical analyses were *similarly unable to detect significant thermal alterations. Geophysical soundings detected subsurface resistivities consistent with cold water-saturated alluvium and basalt. The probability of a thermal resource existing in this area is less than 5%.*

Honokowai: groundwater chemistry and temperature data for this area were unable to confirm the existence of any thermal impacts and geophysical soundings indicated normal subsurface resistivities. Hence the probability for a resource in this location is believed to be less than 5%.Field surveys on Haleakala were confined to the lower portions of the three major rift zones and yielded the following analyses:

Haleakala Northwest Rift: soil geochemical and groundwater chemical studies in this area both indicate potential anomalies. The interpretation of the anomalies with regard to thermal alterations was not, however, unequivocal. Geophysical soundings were unable to identify significantly anomalous subsurface resistivities or self-potential variations. The probability of a low- to moderate-temperature resource is placed at 10–20%, whereas that for a high-temperature resource is less than 5%.

Haleakala Southwest Rift: geologic mapping has determined that several flows on this rift are less than 10,000 years of age and that a few are less than 1000 years old. Preliminary geochemical studies were unable to identify unequivocal evidence of thermal effects on the lower rift zone area, whereas geophysical soundings indicated that thermal groundwaters may be present at depths of less than 3 km. The probability for a low- to moderate-temperature resource is estimated to be 30–40%, whereas that for a high-temperature resource is placed at 15–25%.

Haleakala East Rift Zone: preliminary geochemical and geophysical surveys were performed in this area. The results of these efforts did not identify significant anomalies; however, difficulties in interpretation and the small amount of data available do not allow an assessment of geothermal potential to be made.

Conclusion

Geothermal is a low climate impact baseload energy source. Hawai`i has a great amount of geothermal energy, but if it is to be accessed it must be done in a culturally appropriate way: "[a]mong the issues which have concerned geothermal opponents are: Interference with worship of the Goddess Pele; Interference with certain Native Hawaiian practices; Possible health and safety impacts; Disruption of the way of life for nearby residents; Hydrogen sulfide and other air quality issues; Noise; Increased strain on an inadequate infrastructure; and Impact on native fauna and flora."[128]

[128] Hawaii and Geothermal: What has been happening? Compiled by Tonya L. Boyd, Geo-Heat Center; Donald Thomas, SOEST, University of Hawaii, Hawaii; Andrea T. Gill, DBEDT Energy, Resources and Technology Division, Hawaii. GHC Bulletin, September 2002. http://geoheat.oit.edu/bulletin/bull23-3/art4.pdf

(J) SMALL GEOTHERMAL

Small geothermal units are 1-10 MW in size and can be distributed around an island. They can operate at lower heat levels than traditional central station generators.

Doyle Brewington has spent the past eighteen years developing and patenting a small geothermal power plant, and his company, Power Tube Inc. became one of the first to join the Clean Energy Incubator (CEI) launched by the Austin Technology Incubator ten years ago.

The Power Tube is "a double-walled tube [that] consists of four modules stacked sequentially. Geothermal rock heats the lowest module, essentially the boiler module containing a fluid. The second-lowest module is a turbine that turns the generator at the top of the Power Tube. Between the turbine and generator is a condenser that cools the fluid. The cooled fluid then flows down the outside layer to begin the cycle again. The 25-meter-long prototype is being designed to generate 1 MW of electricity."[129]

An Open Access article published in 2001 quoted Brewington: "Much of the technology integrated into the Power Tube is new to the industry. It took quite a while because Power Tube itself has four new technologies and ten different disciplines. Because of that, it took us pretty close to six years to get the patent. We don't need to estimate steam or pressure or anything like that. All we need to know is where the heat is. The other difference is the only thing you see on the surface at one of our installations is a ten meter by ten meter building with about a 3 meter roof."[130]

The first prototype Power Tube measured eighty-five feet in length and was twenty-nine inches in diameter. The working fluid was a mixture of iso-pentane and iso-butane. The unique super-cooling condenser was powered by sound. The input heat must be at least 220 degrees Fahrenheit (104 C). It uses low to medium temperature heat, from 110-200 C.

In a traditional geothermal power plant water plays the vital role of a heat conductor. The Power Tube "Argus" is a geomagnetic device that does not need water, steam or steam pressure to operate. The Argus units are designed for the 1, 5 and 10 Megawatt market.

The Power Tube uses a monocoque turbo-generator device. Monocoque is a construction technique that supports structural load by using an object's exterior, as opposed to using an internal frame or truss that is then covered with a non-load-bearing skin or coachwork. The word monocoque comes from the Greek for single (mono) and French for shell (coque).

---

129 Diversifying renewables by Emily Sopensky http://www.iriscompany.com/articles/Feb2003_Spectrum.pdf

130 Power Tube Taps Earth's Geothermal Heat: An interview with Power Tube inventor, Doyle Brewington By Bill Moore. Open Access Article Originally Published: October 07, 2001/ http://evworld.com/article.cfm?storyid=244, p.2: http://evworld.com/article.cfm?storyid=244&first=4241&end=4240

The Power Tube has seventy-six sensors that monitor temperature, speed, pressure, flow and seismic activity and then sends the data to a satellite so it can be tracked anywhere in the world.

Even with small geothermal projects, however, not everyone agrees that its use is "pono."

According to Hawaii Business in 1991, "Puna resident Kristine Kubat, an artist who is a member of the Big Island Rainforest Action Group, [asked] 'Is geothermal good business? I think not. It's risky, it's unreliable, and there are no guarantees. When you look at alternatives which are good business, like developing energy-efficiency programs, you can't imagine why the state is having anything to do with it.' "[131] The same year Kubat told Home Power, "Our group has taken an unconditional stand against geothermal here in the islands. [] That puts us in a difficult position because the State is promoting the use of geothermal as a means for achieving energy self-sufficiency. We're in favor of self-sufficiency in the broader sense, the extent to which we as individuals can reach out there and grab our own power. Geothermal development not only endangers our forests and jeopardizes the health of those living near proposed developments, it undermines the efforts of those working towards true energy independence. I guess it's up to us to validate the options.'"[132]

Kubat, a former editor of Big Island Weekly, and Weekly writer Shawn James-Leavey have formed a company (Moku Power[133]) that owns the rights to the Power Tube Technology in Hawai`I, and had this to offer: "As for the fluids, a 10MW unit uses only 50 gallons of working fluid (isopentane, isobutane mix), circulating through 1" channels in numerous ropes of stainless steel tubing. Even if the doubled-hulled casing of the heat exchanger breaks open, the fluid is not lost to the environment but remains in the thick-walled tubing. But even if both walls of the exchanger are damaged and somehow each and every tube in the device cracks open and the fluid leaks out, being highly volatile, it will evaporate as soon as it contacts the hot rock surrounding it. The only other fluid is a biodegradable thermal transfer oil (approved by EPA-approved for use in kitchens) that runs through the thermal riser."

---

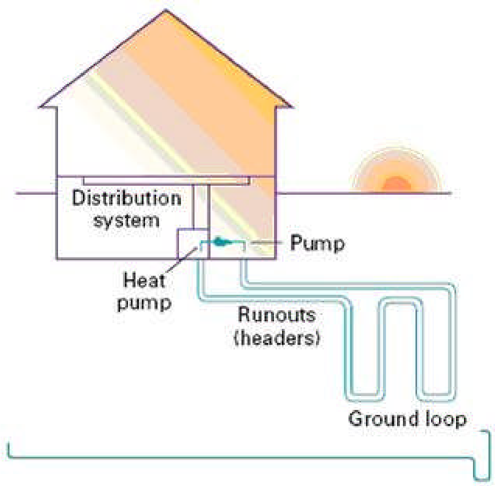
[131] Turning up the heat By Susan Hooper, Hawaii Business, November 1 1990 http://www.allbusiness.com/north-america/united-states-hawaii/126777-1.html

[132] Home Power": The Hand-on Journal of Home-Made Power. Volume #21 Feb/March 1991. http://www.magergy.com/documents/Energy%20Ebooks/Home%20Power%20Magazine%20-%20Issue%20021%20-%20Feb%20-%20Mar%201991%20-%20Renewable%20Solar%20Wind%20Energy.pdf

[133] www.mokupower.com

(K) MICRO-GEOTHERMAL

Micro-geothermal units operate in the kW range.



A Residential Geothermal Heat Pump System:[134]

While parts of the U.S. range from 134 degrees Fahrenheit (Death Valley) to below 70 degrees (Montana), the temperature six feet below the ground varies only from about 45 to 75 degrees. Without the impact of external forces, hot substances will give off heat to cool substances, so if the ground is warmer than the house, then the ground heat goes into a house. Conversely, if a house is warmer than the ground, then heat goes from the house to the ground. Thus, in the winter caves and igloos are warmer than the land around them, while in summer they are cooler, demonstrating the practical effect of natural geothermal principles.

A micro-geothermal system uses a heat pump to move heat from one place to another, usually using air as the medium. A working fluid ("refrigerant") transfers the heat from one area to another. The working fluid is a substance which is a high temperature liquid when compressed and a low temperature gas when it expands.

"Geothermal heat pumps are similar to ordinary heat pumps, but use the ground instead of outside air to provide heating, air conditioning and, in most cases, hot water. Because they use the earth's natural heat, they are among the most efficient and comfortable heating and cooling technologies currently available."[135] Geothermal heat pumps qualify as EnergyStar devices and qualify for federal tax credits.

134 http://www.swansea.gov.uk/index.cfm?articleid=25448
135 http://www.energystar.gov/index.cfm?c=tax_credits.tx_index

(L) HYDROELECTRIC

Hydroelectric Resources[136]

Island	Stream or Ditch	Hydro Name	Operator	Capacity (MW)	Million kwh/year
Kauai	Kekaha Ditch	Waiawa	Kekaha Sugar	0.48	1.8
	N. Wailua Ditch	LowerWaiahi	LihuePlantation	0.76	4.3
	N. Wailua Ditch	Upper Waiahi	LiliuePlantation	0.46	3.1
	Wainiha	Wainiha Hydro	McBryde Sugar	3.6	30.0
	Alexander Resevoir	Kalaheo Powerhouse	McBryde Sugar	1.0	5.0
	Waimea	Mauka Powerhouse	Kekaha Sugar	1.0	5.6
	Makaweli	Olokele	Olokele Sugar	1.25	6.0
Maui	Wailoa Ditch	Paia	Hydro HC&S	1.0	3.0
	Wailoa Ditch	Hamakua	HC&S	0.5	2.2
	Wailoa Ditch	Kaheka	HC&S	4.5	19.0
	Kauaula	Kauaula Hydro	Pioneer Mill	0.3	0.9
Hawai`i	Kohala Ditch	Hawi	Ha Ag. Engineer	0.2	1.5

136 Hawaii Stream Assessment: A Preliminary Appraisal of Hawaii's Stream Resources. A Cooperative Project. Prepared for COMMISSION ON WATER RESOURCE MANAGEMENT. By HAWAII COOPERATIVE PARK SERVICE UNIT, Western Region Natural Resources and Research Division, National Park Service. Honolulu, Hawaii. December 1990. Pp. 96-97
http://hawaii.gov/dlnr/cwrm/publishedreports/R84_HSA.pdf

	Hamakua Ditch	Haina	Hamakua Sugar	0.5	2.5
	Ainako	Wenco Energy	Wenco Energy	0.01	0.1
	Kaieie		Hoowaiwai	0.05	0.2
	Wailuku	Waiau	HELCO	1.0	6.3
	Wainaku	Pueo	HELCO	2.25	12.8
	Waikaloa	Waimea	Hawaii County	0.02	0.1
Total				19+	100+

The use of hydropower dates to the ancient world. Most hydropower plants operate in one direction: when water flows downhill, it creates power. Those with a dam and storage facility in the upper region of the water flow are called “storage plant” hydropower facilities, and those without storage are called “run-of-river” plants. These generate electricity when the river runs, but do not produce electricity during periods of low flow.

Other hydropower plants operate in two directions. For example, when renewable energy production exceeds demand, water can be pumped uphill from a lower reservoir to an upper reservoir. When demand exceeds supply, the water is "dropped" down, generating additional supply. There were over 200 hydropower plants operating in the US in 1900, and by 1920 hydropower accounted for 40% of all power generated in the U.S. What has changed in the modern world is the size of the largest hydroelectric generator. In the 1800’s they were measured in kilowatts (1/1000 MW), but by the 20th century, the sizes shot up:

Hoover Dam (1936) 1345 MW
Grand Coulee Dam (1942) 6809 MW
Brazil's and Paraguay's Itaipu Dam (1984) 14,000 MW
China's Three Gorges Dam (2008) 22,500 MW

Hydropower Facilities are distinguished by their size. The specific sizes are generally as follows: Large = 50+ MW; medium =10 - 50 MW; small=1.0 - 10 MW; mini= 0.1 - 1.0 MW; and micro = 0.0 - 0.1 MW.

Below are the potential hydroelectric resources in M kwh/year for Hawai`i streams:

<u>Kau`ai</u>: Wainiha (17.4); Lumahai (14.1); Hanalei (11.46); Wailua (25.2)
<u>Molok`ai</u>: Halawa (9.9)
Maui: E&W Wailuaiki (15.08)
Hawai`i: Honolii (17.57), Wailuku (11.07), Wailoa (10.29)

(M) PUMPED STORAGE HYDROELECTRIC

Pumped Storage Hydro (PSH) can be used for long-term power firming, shifting intermittent electrical supply from off-peak to on-peak periods.

PSH can also be used for short-term power firming, off-setting second-to-second and minute-to-minute variability in changes in wind speed and solar energy output associated with passing clouds.

Shell Wind Proposed a wind facility at Ulupalakua Ranch that may be accompanied by a 30 MW pumped storage hydro system.

"HELCO has examined potential pumped storage hydro systems at two sites:

• Puu Anahulu: 30 MW and 5 hours of storage (150 MWh total) operating at a 21% capacity factor with 850 feet of gross head, and 510 cubic feet per second flow. For this system, the upper reservoir would be 17 acres, and the lower would be 16 acres.

• Puu Enuhe: 30 MW and 5 hours of storage (150 MWh total) operating at a 11% capacity factor with 1,230 feet of gross head and 350 cubic feet per second flow. The upper reservoir would be 9 acres and the lower 16 acres.

A study contracted by MWH Americas, Inc. to determine the potential for developing two separate 25 MW pumped storage hydro systems on the island of Hawaiʻi estimated total construction costs to be around $239 million."[137]

A U.S. Mainland Pumped Storage Hydro company proposed a PSH facility on O`ahu, in the Kahe area. After meeting with the utility, the company produced preliminary plans for a PSH in West O`ahu. The utility subsequently changed its mind, and said the power was really needed in East O`ahu, not West O`ahu. The developer examined craters in East O`ahu to explore the potential for storage of either fresh or salt water. The utility subsequently changed course a second time, and said it was really needed in the Kahe area. Ultimately the PSH developer abandoned plans to proceed.

In 2010 a 300 MW seawater-based PSH project was proposed for the island of Lana`i, and in 2011 two preliminary permit applications were filed with the Federal Energy Regulatory Commission for projects on Kaua`i.

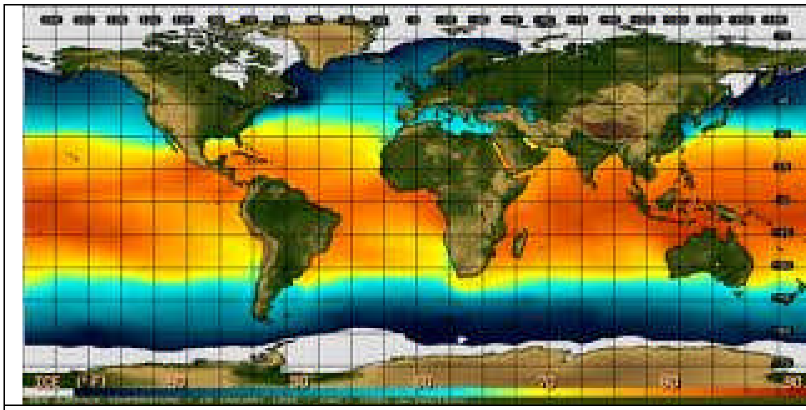
---

[137] ANALYSIS AND RECOMMENDATIONS FOR THE HAWAIʻI COUNTY ENERGY SUSTAINABILITY PLAN (OCTOBER 3, 2007) By Michael Davies, Claire Gagne, Zeke Hausfather, & Dawn Lippert. Project Manager: Jeremiah Johnson, Ph.D. Faculty Advisor: Marian Chertow, Ph.D. Yale School of Forestry and Environmental Studies. Research conducted for The Kohala Center, Kamuela, Hawaiʻi and the Hawaiʻi County Department of Research and Development. Prepared for and Funded by the Hawaiʻi County Council. http://www.kohalacenter.org/pdf/analysis_and_recommendations.pdf

CHAPTER 4: INTRODUCTION TO THE VISION- OCEAN THERMAL ENERGY CONVERSION

Thermal Resources

According to the U.S. Department of Energy, National Renewable Energy Laboratory (NREL): "On an average day, 60 million square kilometers (23 million square miles) of tropical seas absorb an amount of solar radiation equal in heat content to about 250 billion barrels of oil. If less than one-tenth of one percent of this stored solar energy could be converted into electric power, it would supply more than 20 times the total amount of electricity consumed in the United States on any given day."[138]



Ocean Thermal Resources[139]

Kahe Marine Research Park (KMRP) Draft Plan

This document advocates the building of an off-shore Marine Research Park to include a 125 MW Ocean Thermal Energy Conversion (OTEC) facility, off Kahe Point on O`ahu. Although some have advocated a 1-10MW pilot project, Life of the Land believes that the immediate and increasing threat of climate change dictates that the comparative capital expense for a 10MW+ commercial prototype system is far more cost-effective.[140]

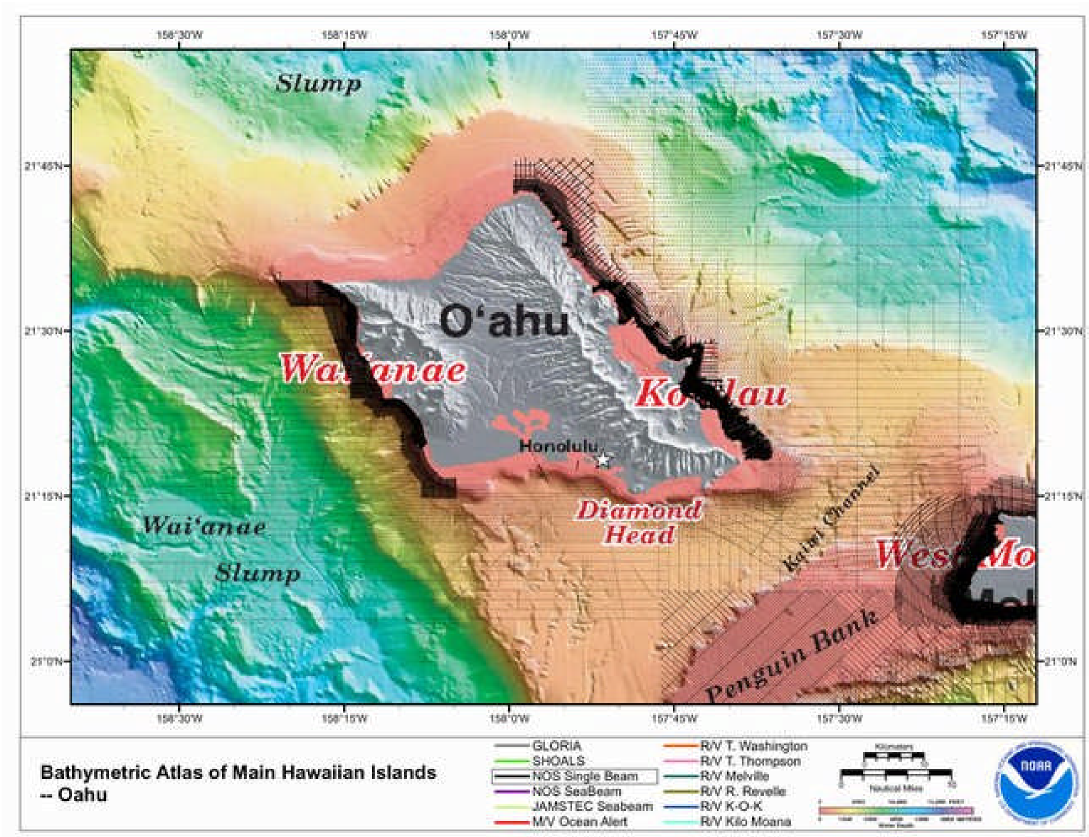
At the National Oceanic and Atmospheric Administration (NOAA) OTEC Open House at University of Hawai`i (June 17, 2010) Dr. Luis Vega noted the following economies of scale: a 100MW system would produce electricity for less than $0.20 kWh while a 1MW system would produce electricity for more than $0.90 kWh.[141]

---

138 http://www.nrel.gov/otec/what.html
139 http://zebu.uoregon.edu/1996/ph162/images/oceant.gif
140 Technical Readiness of OTEC. NOAA, UNH CRRC
141 http://coastalmanagement.noaa.gov/otec/docs/otechistoryhi061710.pdf, p.129

THE KAHE LOCATION

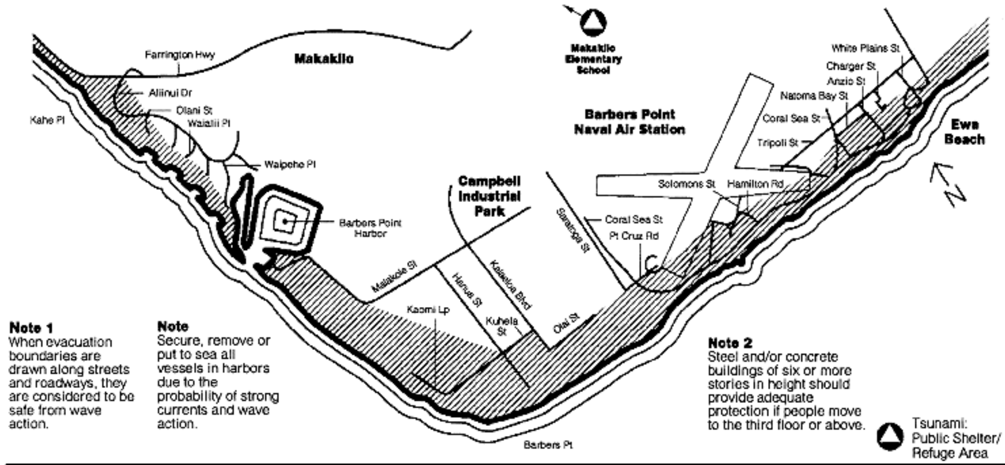
Kahe Point is the southwest corner of O`ahu where deep water is close to the coast. The facility would be located 3-4 miles SW of this point.[142]



---

[142] An existing Kahe Power Plant is located across the road from Kahe Point Beach Park, also known as Electric Beach. Just north of this beach, next to railroad tracks, is a park called Tracks Beach.

Map 17: Kahe Point to Ewa Beach



The topography of the ocean off O`ahu is a series of terraces (plateaus, shelves) connected by escarpments (long steep slope or cliff that separates two relatively level areas of differing elevations). The coastal topography is varied and the depth is usually measured in meters. Converted to feet, the coastal terrace at Kahe reaches 20-30 feet deep at distances of 300-750 feet from shore.[143]

There is a 33 foot escarpment between depths of 165 and 195 feet. At the bottom end of the escarpment is the Mamala Terrace which ranges from 230-407 feet deep off the Waianae Coast.

Another escarpment occurs at 360 feet and drops about 328 feet to a depth of 705 feet with slopes of 60°-80°. At the bottom end of the escarpment is the Lualualei Terrace which is below 590 feet and runs 810-3,058 feet deep off the Waianae Coast.

At 2.5 miles from the coast the water is 2,200 feet deep.[144]

Located off Kahe Point in water 3,000 feet deep is Station Kahe.[145]

The KMRP would be located in 4,000 feet of water.

A contour map shows that the area southwest of Kahe and also an area south and west of Campbell Industrial Park is not as steep as the area just west of Kahe.[146]

---

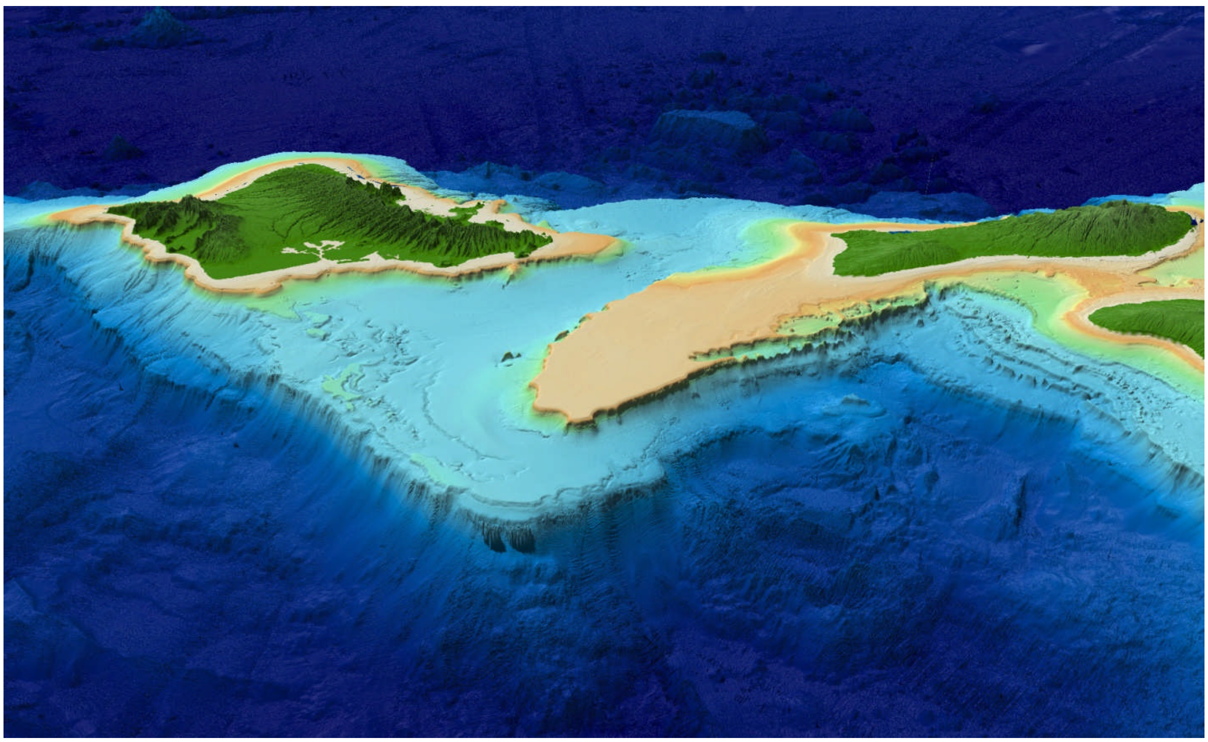
[143] http://en.wikipedia.org/wiki/List_of_fatal,_unprovoked_shark_attacks_in_the_United_States
[144] http://docs.lib.noaa.gov/noaa_documents/NMFS/SWFSC/TM_NMFS_SWFSC/NOAA-TM-NMFS-SWFC-68.pdf
[145] The facility was established in 1988 as part of a federal and state, government and academia, interdisciplinary research facility used for the purpose of observing and interpreting oceanic variability.
[146] Cable Failures off Oahu, Hawaii Caused by Hurricane Iwa by Charles D. Hollister. August 1984. Technical Report. Woods Hole Oceanographic Institution, WHOI-84-31
https://darchive.mblwhoilibrary.org/bitstream/handle/1912/2933/WHOI-84-31.pdf?sequence=1

BATHYMETRY MAPS

The following three maps (jpegs) can be blown up to show the characteristics offshore from Kahe Point.

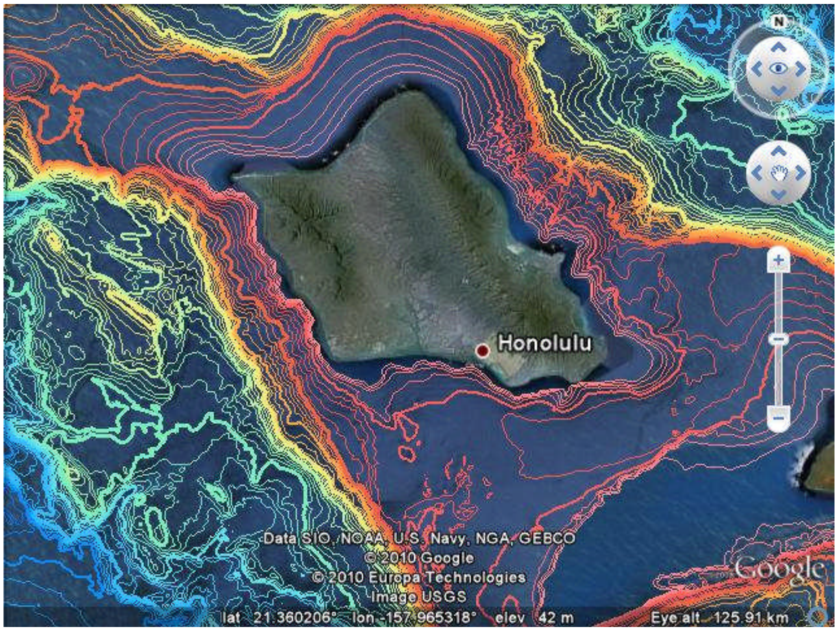
O`ahu and Moloka`i[147]

The first jpeg shows both the drop off at Kahe and the extensive area off southwest Moloka`i known as Penguin Banks, which has depths between 50-200 meters with an average depth of 60 meters. The surrounding water has an average depth of 600 meters. Penguin Bank was formerly part of Maui Nui which was composed of seven major volcanoes: Penguin Bank, West Molokaʻi, East Molokaʻi, Lānaʻi, West Maui, East Maui and Kahoʻolawe. Penguin Bank is now a submerged volcano which plays an important role in marine ecology, for whales, sharks and fish. It is one of the premier fishing grounds in Hawai`i.

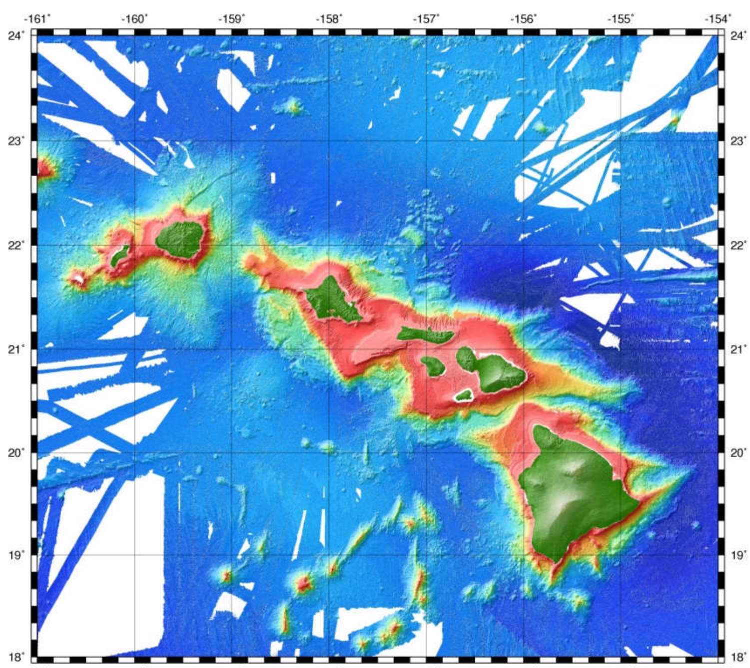


[147] http://www.soest.hawaii.edu/HMRG/Multibeam/images/Oahu_to_Molokai.jpg

O`ahu Bathymetry[148]



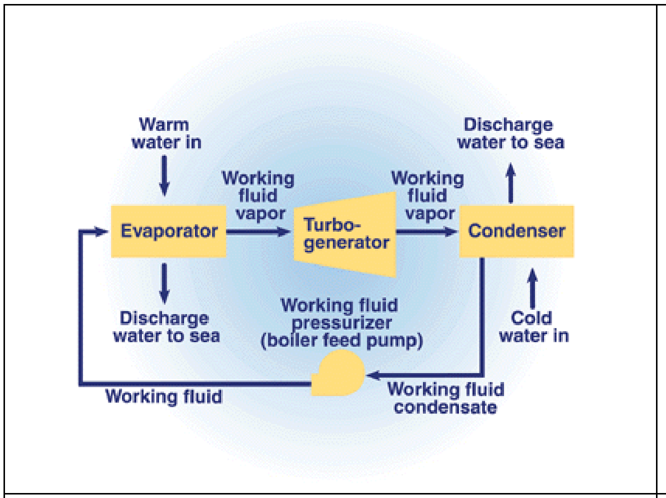
O`ahu Bathymetry[149]



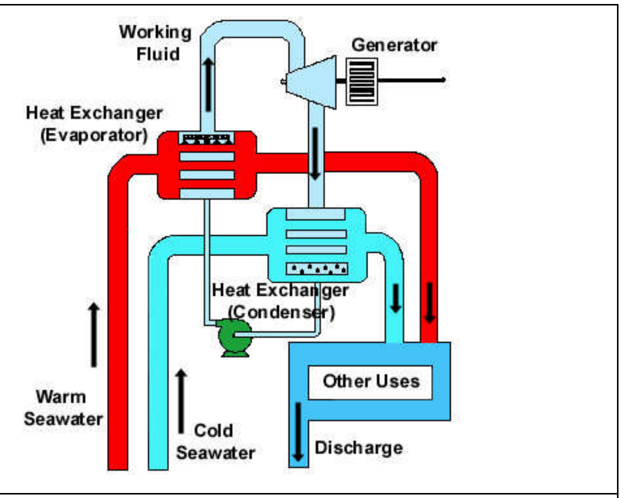
148 http://bbs.keyhole.com/ubb/ubbthreads.php?ubb=showflat&Number=1353559
149 http://www.soest.hawaii.edu/HMRG/Multibeam/grids.php#50mBathy

Ocean Thermal Energy Conversion

OTEC uses the surface water of the ocean to boil anhydrous ammonia[150] and send it under pressure through a turbine, generating electricity. Then cold water is pulled up from the ocean depths and used to condense the ammonia. The ammonia is in a self-contained tube, and turns from liquid, to gas, to liquid. The gross power of an OTEC unit refers to the amount of electricity generated, and the net power refers to the gross power minus the power needed to operate the warm water and cold water pumps.



Closed Cycle OTEC[151]



Closed Cycle OTEC[152]

Historical Use of Ammonia

Mechanical refrigeration was developed in the mid 1800s using a variety of refrigerants, including carbon dioxide (CO2), methyl chloride, sulfur dioxide, sulfuric ether, some hydrocarbons, and ammonia (NH3). Halocarbons (CFCs, HCFCs and HFCs, Freon) were developed as refrigerants in the 1930s before their negative environmental impacts were known. Today only ammonia continues to be used as a refrigerant, and can be used from local ice skating rinks to air conditioning applications in colleges and hospitals, museums, airports, government office buildings, power plants, and even in Biosphere II, the International Space Station.

Advantages of Ammonia

Since ammonia vapor is lighter than air, leaks will evaporate. It is difficult to ignite, has a narrow range of flammability and will not sustain a flame on its own. It will not explode.

---

150 Anhydrous is a Greek word meaning "without water." Anhydrous ammonia is essentially pure (>99%) ammonia (NH3). Most ammonia in the U.S. is used in agriculture, some is used for refrigeration, and some is used as a household cleaning solvent.
151 http://www.nrel.gov/otec/images/illust_closed_cycle.gif
152 http://www.celsias.com/media/uploads/admin/closedcycel.jpg

Ammonia has superior thermodynamic properties to other refrigerants, and has an ozone depletion potential (ODP) and a global warming potential (GWP) of zero.

And ammonia costs less. “Not only is ammonia significantly cheaper than the least expensive halocarbons, but because the density of ammonia is half that of halocarbons, only half as much material needs to be purchased to charge a system. Ammonia is more efficient. Its mass flow rate for a given refrigerating capacity is 1/7 that of HCFC-22, meaning only 1/7 the liquid needs to be pumped for a given refrigerating capacity. [ ] Ammonia systems are more tolerant of water contamination than freon systems. Water concentrations of less than 100 parts per million causes no penalty to ammonia system operation. Ammonia has more favorable heat-transfer coefficients than halocarbons.”[153]

“As a refrigerant, ammonia offers three distinct advantages over other commonly used refrigerants. First, ammonia is an environmentally compatible refrigerant because it has an ozone depletion potential (ODP) of zero and a global warming potential (GWP) of zero. Second, because of its superior thermodynamic properties, ammonia as a refrigerant requires less energy than other refrigerants when used in large industrial systems. Third, ammonia refrigeration has a proven safety record, in part because of the physical properties of ammonia, not the least of which is ammonia’s well-recognizable and easily-detectable odor.”[154]

<u>The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) issued this position statement:</u>

“Globally, there is growing interest in ammonia as a refrigerant. Restrictions on chlorine and fluorine containing refrigerants have focused attention on ammonia to emerge as one of the widely used refrigerants that, when released to the atmosphere, do not contribute to ozone depletion and global warming. Ammonia is an efficient refrigerant used in food processing and preservation, as well as many other refrigeration and air conditioning processes. Ammonia has desirable characteristics as a refrigerant, which have been well known for over a century. It is corrosive and hazardous when released in large quantities. Because of its irritating odor, persons will not voluntarily stay near concentrations that are health threatening. Although ammonia will burn in a narrow range of high concentrations, it is difficult to ignite and will not support combustion after the ignition source is withdrawn. ASHRAE considers that the continued use of ammonia is necessary for food preservation and air conditioning. ASHRAE promotes a variety of programs to preserve the economic benefits of ammonia refrigeration while providing for the management of risks.”[155]

“Ammonia is the preferred working fluid, due to its superior thermodynamic and thermal characteristics over other substances. An OTEC closed cycle system is

---

[153] Phillips Refrigeration. www.haphillips.com/ammonia.html
[154] International Institute of Ammonia Refrigeration Greenpaper. http://www.iiar.org/aar/aar_greenpaper.pdf
[155] Approved by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Board of Directors (January 17, 2002); Reaffirmed by ASHRAE Board of Directors (January 26, 2006) http://www.ammonia21.com/files/papers/ashre-position-ammonia-refrierant-2002.jpg.pdf

essentially a reversed refrigeration cycle, and there is substantial operational experience with ammonia refrigeration in commercial and industrial applications."[156]

Ammonia Risks and Toxicity

National Oceanic and Atmospheric Administration (2009): "The most appropriate working fluids for OTEC are propylene and ammonia, with an emphasis on the latter due to its thermodynamic properties and extensive experience with similar applications."[157] "Ammonia turbines are reliable, but there is little data in their use at this scale."[158]

According to the National Oceanic and Atmospheric Administration (2010), the regulatory driver for ammonia discharges into the ocean is the Clean Water Act. Is it Likely? Yes. Is it Significant: No. Its regulatory priority is Low.[159]

Although ammonia has a well-recognizable and easily-detectable odor, the EPA (2001) stated: "More than 80% of ammonia produced is used for agricultural purposes; less than two percent is used for refrigeration. Ammonia can safely be used as a refrigerant provided the system is properly designed, constructed, operated, and maintained. It is important to recognize, however, that ammonia is toxic and can be a hazard to human health."[160]

According to the Occupational Safety & Health Administration: "Ammonia is not, strictly speaking, a poison and repeated exposure to it produces no additive (chronic) effects on the human body. However, even in small concentrations in the air it can be extremely irritating to the eyes, throat, and breathing passages."[161]

KMRP HOUSING MODELS

KMRP could be built on a semi-submersible vessel, which is a cross between a submarine (which can go below the water) and a ship (which rides on the water). Part of the lower part of the semi-submersible vessel is filled with water to prevent its movement. The contained water can be removed, allowing the facility to move under either its own power, or to be towed. The operating deck is either sealed or located on a platform above the wave height. The four components of a platform facility are the pontoons, structural columns, the operating deck, and the working area (offices, dorms, etc.)

---

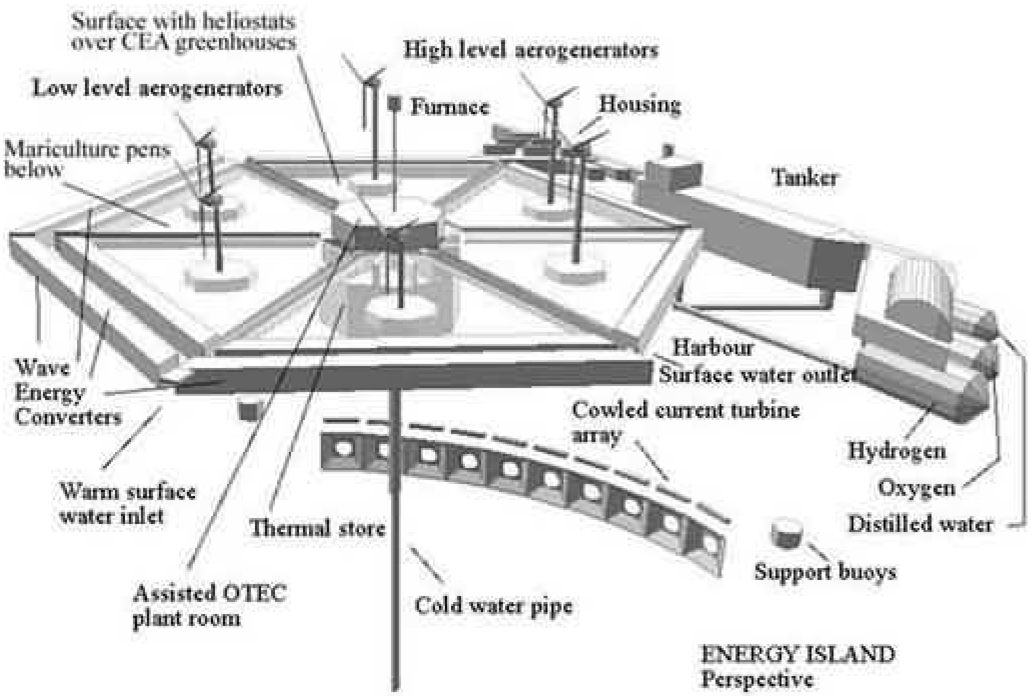
[156] Ocean Thermal Energy Conversion (OTEC): Technical Viability, Cost Projections and Development Strategies. T.J. Plocek and M. Laboy, Offshore Infrastructure Associates; J.A. Martí, Technical Consulting Group. 2009 http://www.offinf.com/OIA_at_OTC.pdf
[157] Technical Readiness of OTEC. (National Oceanic and Atmospheric Administration (NOAA) & Coastal Response Research Center at the University of New Hampshire, 2009), p.15.
[158] Ibid. p.19
[159] Table 8, page 25, Ocean Thermal Energy Conversion: Assessing Physical, Chemical and Biological Impacts and Risks (Coastal Response Research Center, University of New Hampshire, and NOAA, 2010).
[160] www.epa.gov/oem/docs/chem/ammonia.pdf
[161] http://www.osha.gov/SLTC/etools/ammonia_refrigeration/ammonia/index.html

Below are six approaches: (1) the Lockheed Platform[162], (2) the Solar Assisted OTEC (SA-OTEC) Energy Island, (3) the Sea Solar Power Platform, (4) the "Alfred Yee" approach, (5) EnergyIsland and the (6) Pearl Harbor "Golf Ball."

Lockheed Platform[163]

[162] http://news.softpedia.com/newsImage/Advanced-Conversion-Based-Power-Plant-Gets-New-Funds-2.jpg/
[163] http://www.lockheedmartin.com/data/assets/ms2/images/OTEC-Pilot-Plant.jpg

Solar Assisted OTEC (SA-OTEC) Energy Island[164]



The energy island would have wind, ocean current, ocean wave, photovoltaic arrays, and concentrating solar thermal systems generating electric, hydraulic and thermal energy.

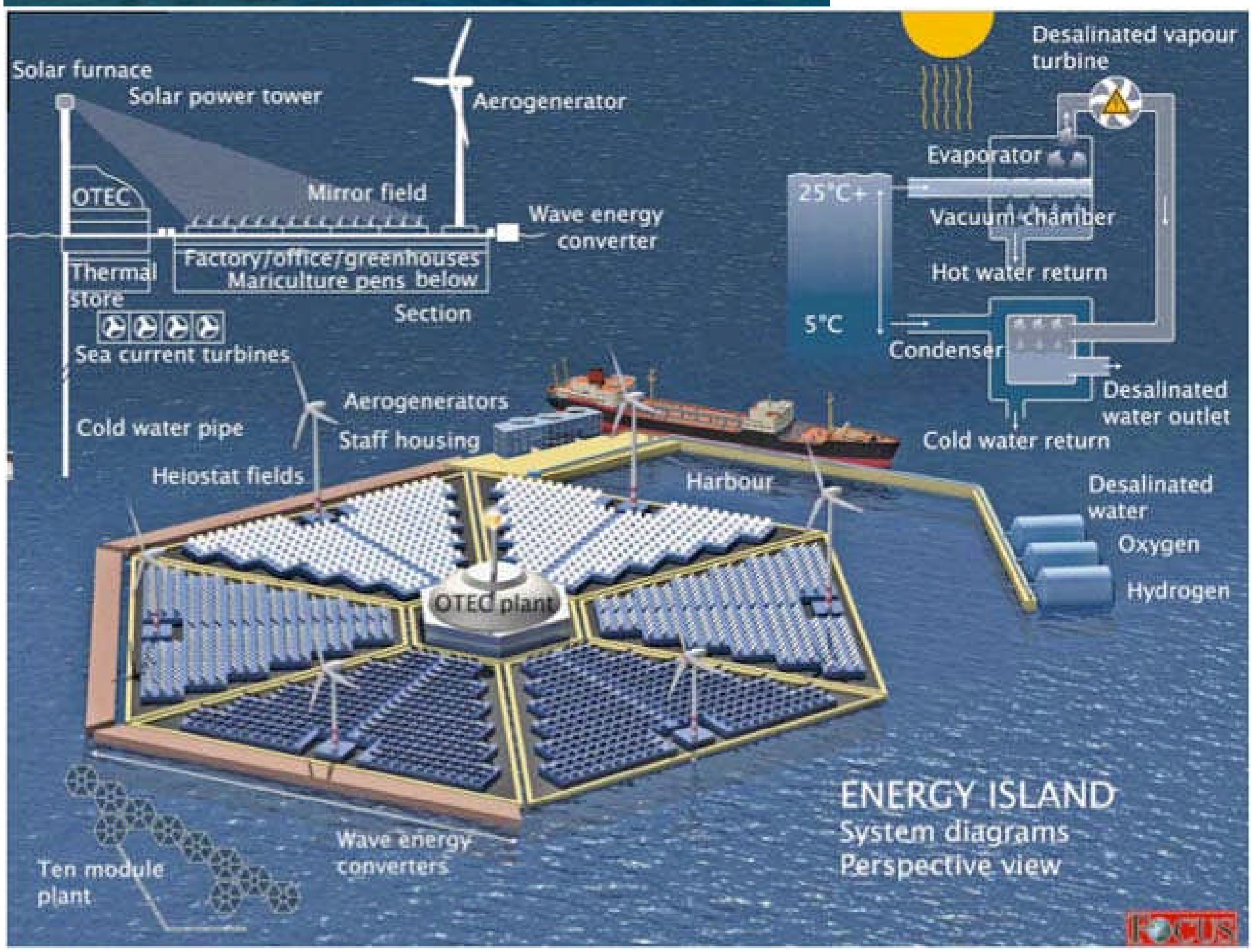
The thermal energy would be used to increase the temperature of water coming from the warm surface water, thus increasing the delta T (the temperature differential between the cold and warm water inputs), thereby increasing the efficiency of the OTEC facility.

The energy produced would be 265MW (gross) and about 200MW (net).

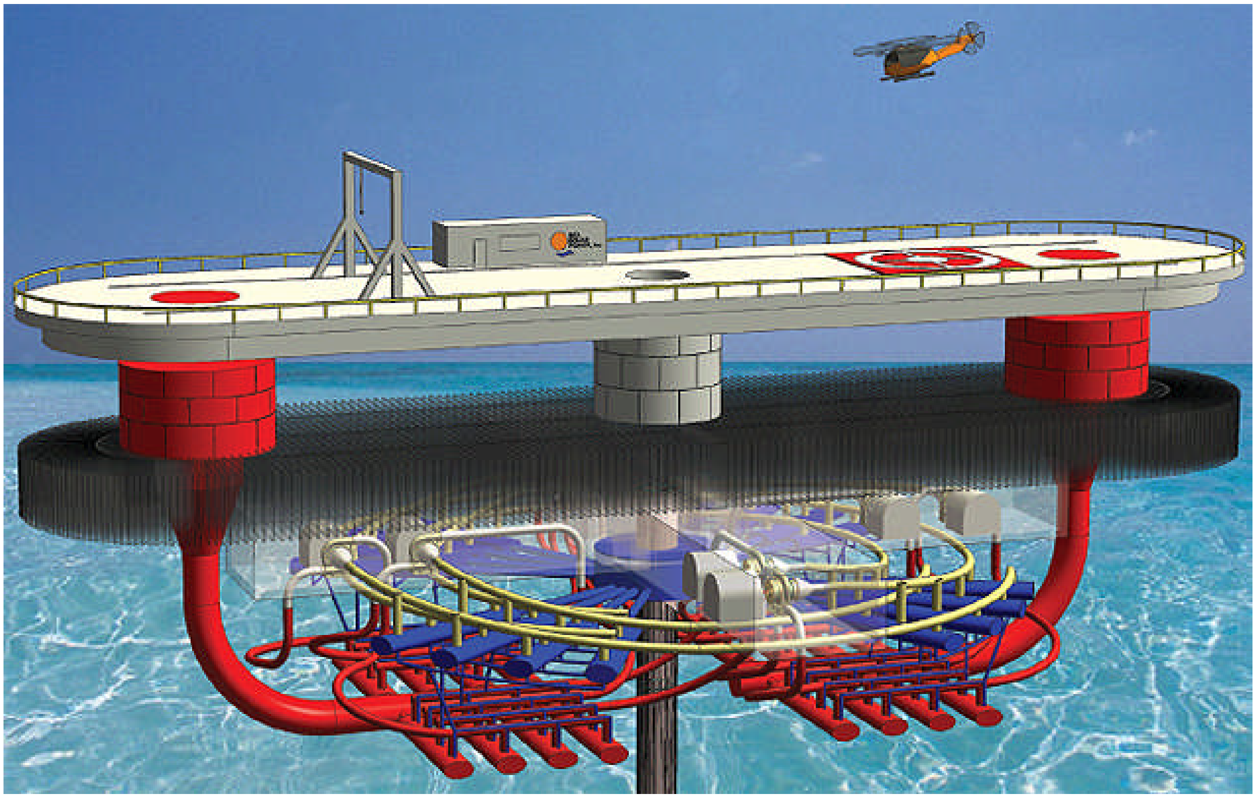
The Energy Island is therefore capable of creating electrical generation, hydrogen, oxygen, distilled water, plant growth and marine enhanced life produce. It can also incorporate human habitation, with the possibility of sea borne dwellings, and related activities, forming a novel pattern of living.

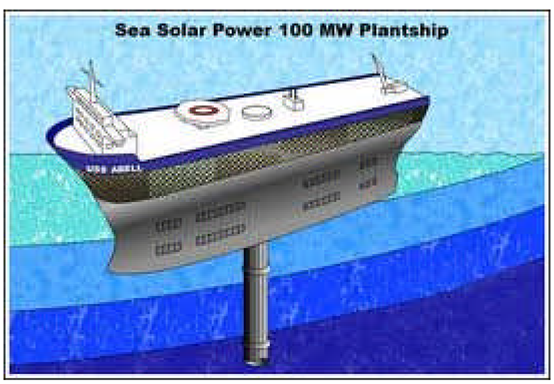
---

164 *Dominic Michaelis. MA Cantab, MSc Cornell, RIBA*. Article published in the International OTEC Association Summer 2002 Newsletter. http://www.solarenergyltd.net/energy%20island.htm


Solar furnace
Solar power tower
Aerogenerator
OTEC
Mirror field
Wave energy
converter
Thermal
store
Factory/office/greenhouses
Mariculture pens below
Section
Sea current turbines
Cold water pipe
Aerogenerators
Staff housing
Heiostat fields
Harbour
Desalinated vapour
turbine
Evaporator
25°C
Vacuum chamber
Hot water return
5°C
Condenser
Desalinated
water outlet
Cold water return
Desalinated
water
Oxygen
Hydrogen
OTEC plant
ENERGY ISLAND
System diagrams
Perspective view
Wave energy
converters
Ten module
plant

Sea Solar Power[165]





Plantship[166]

[165] Designing a "Green" Power Alternative for the Tropics By Laura Carrabine, Senior Editor. 3D technology helps designers create floating solar energy plant. http://solarpowerengineering.com/2010/07/designing-a-%E2%80%9Cgreen%E2%80%9D-power-alternative-for-the-tropics/
[166] http://www.meleassociates.com/assets/images/otec2.jpg

Precast Design (Alfred Yee)[167]

Dr. Alfred Yee[168] developed and patented an award winning ocean-based reinforced concrete platform consisting of an integrated cylindrical cell honeycombed core in composite action that has pre-stressed top and bottom slabs and side walls. Two examples of these structures are (1) the ROFOMEX I (260x110x24 feet), constructed in Singapore, outfitted in California, and used as mobile phosphate processing facility; and (2) the first mobile concrete island drilling system (SUPER CIDS). This facility was used on the North Slope of Alaska for offshore oil exploration for almost twenty years without any sign of damage.

The facility would be six stories high (25 meters) with dimensions of 356 meters x 72 meters. The facility would house five subsystems of 25 MW each. It would be based on Dr. Yee's patented honeycomb system for precast/pre-stressed concrete vessels.

[167] http://precastdesign.com/projects/platforms-barges/125_MW_OTEC_platform_gallery.php#6_125_MW_OTEC_Platform/100MW_1.jpg
[168] Dr. Yee has been a Hawaii-registered structural engineer since 1955. His first precast, pre-stressed concrete mass production facility was developed in 1955. The Hawaii Council Of Engineering Societies warded Dr. Yee with the "HCES Lifetime Achievement Award" in 1997.

EnergyIsland[169]

The energy island facility would focus on OTEC, but could also generate energy from solar, aerogenerator (wind), wave energy converter, sea current turbines, heiostat fields (moving mirrors used to concentrate light to generate heat or electricity), and wave energy converters.

There would be a protected harbor, factory, offices, and staff housing as well as a desalination plant, an electrolysis facility for creating oxygen and hydrogen, mariculture pens cooled by cold ocean water, and greenhouses.

[169] Team: Energy Island Ltd; Vega Consulting; Halcrow Group Ltd; Noble Denton Group Ltd; Parsons Brinckerhoff Inc.; School of Engineering Sciences, Univ. of Southampton, UK.

Sea-Based X-Band Radar (SBX) aka the Pearl Harbor Golf Ball[170]

The SBX is part of the U.S. Defense Department Ballistic Missile Defense System. It is a floating, self-propelled, mobile radar station designed to operate in Pacific Ocean winter storms with high winds (greater than 100 mph) and high waves (exceeding fifty feet). The radar unit is mounted on a fifth generation Norwegian-designed, Russian-built CS-50 semi-submersible twin-hulled oil-drilling platform. The facility houses seventy-five crew members. The twin-hulled propulsion system can travel at eight mph.

The sea-based X-band radar is based on a converted oil well and has frequently been seen in Pearl Harbor.

[170] Image from http://en.wikipedia.org/wiki/Sea-based_X-band_Radar

Undersea Transmission Line & Wave Hubs

Prevailing thought used to be that each off-shore system needed its own cable connecting it to a land-based system; there are now two more modern concepts. One concept is an offshore linear transmission line which would go from system to system, interconnecting multiple systems with the shore. But this would make each system dependent upon every other system, much like the older type of Christmas tree string lights would burn out when one bulb failed. The newest concept is connecting a transmission cable to one or more underwater power strips, where each system could plug into its own socket.

The current vision for KMRP is to have two undersea corridors, with a high voltage undersea cable going from the Kahe Transmission Substation to a seabed socket 3 miles off the coast. A second high voltage undersea cable will go from the first seabed socket to a second seabed socket adjacent to it. A third transmission line ("tail") will go from this second socket to the facility. Using horizontal directional drilling, the transmission lines would go under the beach and the coral reefs. Thus there will be a total of six transmission segments and four seabed sockets. The cost of the transmission lines and sockets is small compared to the total cost of the facility.

While it could function with a single transmission line from the Kahe Transmission Substation to the facility, any fault on the line would cut off use of the facility until ocean repairs could be made; this could take months. The strength of having two unused sockets and two partially used sockets is that other ocean energy systems could easily be interfaced in the ocean grid without disturbing the coast or the seabed, thus significantly reducing environmental impacts and the length of time needed to acquire regulatory permits.

Cornwall Wave Hub

"*July 16, 2009 -- LITTLEPORT, Cambridgeshire, England -- JDR Cable Systems Ltd., a provider of custom designed and manufactured subsea power cables, umbilical systems and specialized marine cables, has been awarded a contract by the South West RDA [Regional Development Agency] for the supply of subsea power cables for the UK's ground-breaking Wave Hub project.*

Wave Hub is a major marine renewables infrastructure project that will create an electrical 'socket' on the seabed in approximately 50 meters of water some 10 miles off the coast of Cornwall in South West England, and connected to the National Grid via a subsea cable. Wave Hub will have an initial maximum capacity of 20MW (enough electricity to power approximately 7,000 homes) but has been designed with the potential to scale up to 50MW in the future.

The scope of contract awarded to JDR includes 25km of 33kV three-phase power cables which will provide the essential link between the Wave Hub and the onshore control room. The Wave Energy Convertors are connected back to the Wave Hub by four additional 300m three-phase power cables and dry mate connector sets. All cables include fiber optics and will be subject to rigorous integration testing. JDR will also supply the 'Wave Hub' assembly consisting of subsea terminations and a complete subsea protection structure. The package of equipment will be delivered in the second *quarter of 2010 from JDR's new deepwater quayside facility at Hartlepool Dock. The first wave energy devices are expected to be deployed in 2011.*

The Wave Hub project draws on JDR's wealth of experience in the design and manufacture of subsea cable and umbilical systems to produce a solution that will meet the demanding requirements of this innovative application," states Patrick Phelan, managing director of JDR Cable Systems Ltd. "Our new quayside facility at Hartlepool dock is ideally sized for the manufacture and load-out of this 1500 tonne cable system, and we look forward to supporting the installation process with our team of qualified offshore service technicians.

The 100,000 sq. ft. facility is the only site in the UK designed specifically to manufacture subsea power cables for the growing offshore renewable energy market and the increasingly complex oil and gas sector."[171]

In September, 2010, the undersea wave hub was successfully deployed off Cornwall, the system was integrated into the mainland grid and successfully tested in November, 2010.

Transmission Line

An Undersea Transmission Line would be constructed under the beach and the reefs using Horizontal Directional Drilling (HDD). Examples of Hawai`i-based HDD will be discussed, specifically a Honolulu Wastewater Project, Military Wastewater Project, Interisland Telecommunications project, and HECO electric transmission lines.

Cold Water Pipe (CWP)

The Cold Water Pipe (CWP) is a key component of an OTEC system.

Wind facilities in Hawai`i are often located on the coast, and experience has shown that salt from the ocean can corrode traditional building materials, so new materials have developed to meet specific industrial needs; these include composite materials, alloy steels, fiber-reinforced plastic (FRP), glass-reinforced plastics (GRP) and reinforced concrete conduits (RCC).

Composite materials (composites) consist of two or more materials which are stuck together but remain distinct (just as mud and straw were used to make bricks for houses). Modern composites include highway pavement (steel and cement or asphalt), fiberglass (used in sport boats) and carbon-epoxy composites (used for structural elements in aircraft). The characteristics of the constituent materials maintain their distinct physical and chemical properties at the macroscopic or microscopic scale within the finished structure.

[171] http://www.interconnectionworld.com/index/display/article-display/366346/articles/connector-specifier/industry-news/2009/07/jdr-cable-systems-to-design-manufacture-subsea-power-cables-for-uk-wave-hub-project.html

The cold water pipe (CWP) would run about 3,000 feet long. Numerous technical questions must be answered: should the CWP be rigidly attached to the ship or gimbaled (shipboard compasses, gyroscopes, and drink holders use gimbals to keep them upright with respect to the horizon despite the ship's pitching and rolling)?; should the CWP be assembled on-shore or on-site (the Lockheed Martin approach is to build a single long seamless pipe at the site)?; should it be one piece, or several pieces using bonded or mechanical joints; and what material should be used (composite, steel, fiberglass)?

"*The CWP is used to transport cold water from depths of 1,000m/3,300 ft. to the floating OTEC plant at the surface. The cold water condenses the exhaust vapor and allows a closed cycle. The pipes must be extremely strong, stiff, and durable to survive the wave-driven platform motions, ocean currents and pressure forces.*

Lockheed Martin's innovative approach fabricates the pipe directly off of the OTEC platform, infusing fiberglass fabric with resin in a stepwise molding process to produce a 1,000m/3,300 ft. long seamless, low-cost CWP not requiring risky deployment operations. The sandwich-wall pipe design has been optimized to resist all of the loadings at minimum cost.

Janicki Industries (JI) is fabricating several major components of the apparatus, which will then be tested at the Corporation's facility in Sunnyvale, CA. Janicki Industries has extensive expertise with large scale composite fabrication and infusion processes, a history of designing and producing large complex machines, and a willingness to work collaboratively with Lockheed Martin through the challenges of innovation."[172]

From "Thermal Energy from the Deep"[173] (August 3, 2009, an interview with Alan Miller, Lockheed Martin)*:*

"*The challenges faced by any cold water pipe are threefold: deployment, survivability and sustainability. By manufacturing the pipe on the platform itself they have done away with any deployment issues. In the area of survivability, since the 1970s a lot of advances have been made in low-cost composites manufacturing and they are exploiting those modern methods of fabricating large composites structures.*

The preliminary analysis indicates that no fatigue failure is expected for a cold water pipe that is rigidly connected to the OTEC platform. The analysis carried out includes a full spectrum of sea states that the platform is expected to be exposed to in its 50-year life.

"Finally, in terms of scalability, the flexible mould approach scales OK to large sizes and we don't have any issues about scalability," Miller says. "Obviously we can demonstrate at a larger scale, but there is nothing inherent in the process that will not scale."

[172] http://www.janicki.com/lockheed-martin-awards-janicki-industries-contract-on-ocean-thermal-energy-conversion-project
[173] http://kn.theiet.org/magazine/issues/0914/energy-from-the-deep-0914.cfm

The cold water pipe is constructed with a double wall sandwich, outer face sheets and inner face sheets. In between them there is a lightweight material that does not have the same mechanical properties as the facing sheets have. Such composite sandwiches are commonly used in applications such as commercial airliners.

"We started off with elements of this core that are called planks," Miller explains. "So these are partial circumference regions of finite length. What we then do is assemble those core planks into a complete core ring. The core ring is in fact discrete core pieces, but then the outside and the inside of the core are the face sheets that are essentially continuous down the length. The only interruptions are the change in fabric rolls."

In choosing the actual material, Lockheed carried out a national quantitative trade study in which they explored quantitatively what it would cost if it were made of any of the four primary candidate materials - fibreglass, carbon-fibre deposit, steel and high-density polyethylene. "Fibreglass came out to be the lowest cost, with carbon not far behind, but we know that in carbon fibres we will get some galvanic issues," Miller says. "So all things being equal the research sent us in the direction of fibreglass.

"Both fibreglass and carbon-fibre deposit met all the requirements. Very briefly, the principle requirements that the design has to meet is first of all external pressure; it's a suction pipe so right up near the platform you have actually got half an atmosphere of negative pressure that means you are putting half an atmosphere net external pressure on a 33ft diameter pipe.

"The second principle driver is WIM (wave-induced motion): platforms rocking back and forth attached to the cold water pipe that would just as soon sit there and mind its own business, so you can generate reasonable levels of strain especially at the interface areas, between the platform pole and pipe." So with all that considered, fibreglass came out on top.

Cold Water Piping must meet a number of requirements:[174]

Quantifiable technical drivers:	Anticipated quantitative loading	*Dominant Driver?*	Basis
Buckling from net external pressure	7.5 psi suction inside CWP at top	Yes	FEA
Bending fatigue from platform motions, including knockdown for long-term seawater immersion	Approx. +/- degrees of pitch or roll, plus surge and sway motions	Yes	Prelim. Hull And Riser/mooring Program (HARP) analysis (10 MW plant) + prelim. test data on fatigue after high-pressure seawater

[174] http://www.crrc.unh.edu/workshops/otec_technology_09/presentations/millercwpoverview.pdf

			conditioning to saturation
Buckling from platform motions	Same as preceding	No	FEA
Fatigue from Vortex-Induced Vibration (VIV)	Sheared current profile, approx. 4 fps surface velocity	No	Several analyses indicate no excitation of CWP in sheared currents
Tensile failure from clump weight and streaming current	CWP + clump weight; current profile	No	Bending and tension strain calculations
Core collapse from high pressure at 1000m depth	1500 psi	Yes	Venting of hollow core eliminates net pressure on core
Wet weight must be positive but not excessive	CWP & clump weight	Yes	CWP wet density is same as fiberglass/vinyl ester laminate
Corrosion	30-year immersion in seawater at depths to 1000m	Yes	Industry experience with fiberglass/vinyl ester composites
Also			
Behavior in service must be very reliable	CWP is single point of failure for OTEC plant	Yes	One-piece CWP eliminates maintenance / repair / failure of joints
Deployment must be low-risk	Very large consideration - Previous OTEC failures have been dominated by CWP deployment	Yes	Fabrication directly from the platform eliminates large risks associated with transport assembly upending, etc.
Cost must fit within OTEC plant budget	Electricity cost less	Yes	Minimum-cost design through optimization.

profile	than or equal to $0.25/kwh for 100 MW OTEC plant in Hawaii		Materials costs from supplier quotes; recurring fabrication costs from large wind turbine blade data

UNDERSEA HIGH VOLTAGE TRANSMISSION LINE

Horizontal Directional Drilling

Horizontal Directional Drilling (HDD or "directional boring") is a trenchless method of installing underground pipes, conduits and cables. Basically a slanted tunnel is dug from two ends with sometimes a level section in between. HDD is often used for sensitive environments, crossing rivers, harbors, and main roads, and for going under beaches and coral reefs. HDD has been used in lengths exceeding one mile and with boreholes having a diameter as great as five feet. Pipes made of iron, steel, polyethylene or PVC are pulled through the borehole. Then whatever the hole is to house is inserted.

Horizontal Direction Drilling: Hawai`i Examples:

Honolulu Sewage Project

In Kalihi the water main between the Hart Street Wastewater Pump Station (Hart Street is three blocks long and crosses Kalihi Street two blocks mauka of Nimitz Highway) and the Sand Island Wastewater Treatment Plant, which served nearly one-third of the Honolulu population, needed replacement. To replace the main required that it cross a major coastal highway and the busiest docks in Honolulu Harbor. So trenchless horizontal directional drilling was chosen, and using HDD, 46-inch steel casings were pulled through the borehole. Installed within the 46 inch casing was 36-inch diameter high-density polyethylene (HDPE) pipes, which serve as the force mains. Fiberglass reinforced plastic (FRP) were used for fittings.[175] The project designer was Wilson Okamoto & Associates of Honolulu (now Wilson Okamoto Corp.), and Modern Continental of Cambridge, Massachusetts served as the general contractor; HOBAS Pipes was a subcontractor.[176]

Military Sewage Project

In 2001-02 HMS Construction used HDD to construct a new wastewater line on Ford Island, which has numerous historic sites and is in active use by the military. A borehole started at Hospital Point in Ford Island's Naval Shipyard area, ran for 2,000 feet at a depth of 100 feet, and went under Honolulu Harbor through silt, limestone,

[175] Microtunneling in Hawaii by Philip R. Snyder, Public Works Magazine (February 1, 2005) http://www.pwmag.com/industry-news.asp?sectionID=775&articleID=271406
[176] Hobas Pipes www.hobaspipe.com/

coral cobble, coral voids, and volcanic tuff. The technology used 20 inch high density pipes.[177]

Interisland Telecommunications

Sandwich Isle Communications is building a telecommunication network uniting all DHHL properties state-wide. Seven boreholes are being dug under the beaches and reefs, extending from the shore to an area of the ocean 2,000-4,000 feet offshore and 60 feet deep. Clearcom Inc. is the general contractor, with subcontractors Henkels & McCoy, Inc. and Environmental Crossings, Inc. (ECI).[178]

HECO: East Oahu Transmission Project (2005)

"At the request of the City and County of Honolulu, horizontal directional drilling technology was evaluated as a construction option to minimize impacts. While temporary impacts of directional drilling would not be significant, noise levels and particularly traffic disruption would be greater than those under the open trenching option. Because directional drilling equipment needs to remain in the road 24 hours a day until work is completed (approximately three to four weeks per drill segment), unlike open trenching, peak hour traffic would be affected. During the afternoon commuting period at Kalākaua Avenue and King Street, directional drilling could result in the formation of traffic queues, long delays, and diversion of several hundred vehicles per hour to parallel routes such as Kapiʻolani Boulevard and the H-1 Freeway. For these reasons, horizontal directional drilling is not a preferred option."[179]

HECO: Ford Island 46kV Transmission Line (2006)

“Although Pearl Harbor's subsurface is comprised of dense shell sand with crushed coral and is generally favorable for directional drilling, this drill length is not exceptional for typical infrastructure installations. But, there were two principal complicating factors for this installation. First, Pearl Harbor is an active naval harbor, which meant ocean-going vessel traffic could affect the drill-head navigation system. Second, if the drill head veered too far off course, it could hit a recently installed 28-inch (711-mm) HDPE water line, which was a mere 20 ft (6 m) from the planned drill route. Any mistake would be costly. [] The 46-kV underground transmission project at Ford Island proved once again that any challenge can be overcome through teamwork and trust”[180].

[177] Delicate Drilling under Pearl Harbor, Trenchless Technology, December 2002 http://www.hmsconco.com/projects_drilling_pearl_article.html
[178] http://www.ecihdd.com/projects/view/12
[179] Environmental Assessment for the 46kV Phased Project, East Oahu Transmission Project http://www.heco.com/vcmcontent/FileScan/PDFConvert/EOTP_Draft_EA_ExecSummary_081304.pdf
[180] HECO's Mile-Long Cable Pull by Rodney Chong (project manager for Hawaiian Electric Co. Inc.) and Jerry Johnson (senior project engineer for POWER Engineers) T&D World (Oct 1, 2006) http://tdworld.com/overhead_transmission/power_hecos_milelong_cable/index1.html

Hawai`i Expertise

The Hawaii Council of Engineering Societies (HCES) and the Hawaii Society of Professional Engineers (HSPE), with the assistance of the College of Engineering of the University of Hawaii at Manoa (UHM), gave the 2010 Engineer of the Year to Dr. James Kwong, the *"principal investigator and trenchless designer for over 100,000 feet of microtunnel pipelines, including over 150 shafts, and over 70,000 feet of horizontal directional drilling pipelines in challenging ground conditions and in urban areas. Dr. Kwong recently inspected over 12 miles of water tunnels for earthquake damage, deep inside the remote Waipio Valley of the Big Island".*[181]

High Voltage Alternating Current (HVAC) Transmission Lines

Underground electric transmission lines use many different technologies. The main types are: High-Pressure, Fluid-Filled pipe (HPFF), High-pressure, gas-filled pipe (HPGF), Self-contained fluid-filled (SCFF), Cross-linked polyethylene (XLPE) and Gas-Insulated Lines (GIL).

High-Pressure, Fluid-Filled pipe (HPFF) has historically been the choice in the U.S. and has a solid reliability record. The pipe has a long life and requires little maintenance.

Cross-linked polyethylene (XLPE) is an emerging technology that has or soon will become the dominant technology used in the U.S. It is cheaper, easier to repair, has lower line loss and has no leakage problem.	 XLPE Cable[182]

High Voltage Direct Current (HVDC) Transmission Lines

Historically there are two technologies used for underground HVDC transmission lines: Self-Contained Fluid Filled (SCFF) and Mass Impregnated (MI), although SCFF is being phased out.

Mass Impregnated (MI) is a solid type paper insulated cable in which "the paper tape insulation is impregnated with a very high viscosity dielectric fluid, which does not

---

181 http://hces.us/awards/awards10.html
182 http://www.nexans.us/eservice/US-en_US/navigate_201586/CU_XLPE_SWA_PVC_BS_5467_3_Core.html#top

drain at moderate operating temperatures thus avoiding the need for fluid pressurization."[183]

AC vs. DC

Moving large amounts of energy over distance can be done by either alternating current (AC) or direct current (DC) and most grids around the world use alternating current (AC). The advantage of using HVDC is that it is cheaper, and has lower line loss; the disadvantage is the cost of the AC-DC converter stations.

Electro Magnetic Fields (EMF)

Current has to flow to generate magnetic fields, and as noted earlier, appliances can generate electric fields even if no current is flowing. Direct Current (DC) produces static time-varying electromagnetic fields while Alternating Current (AC) produces time-varying electromagnetic fields. A major characteristic of an EMF is its frequency or wavelength.

Submarine Cable Impacts

"Components of submarine cables that may result in environmental impacts include the type of insulation, number of conductors (e.g., single versus "three-core" cables), screening, sheathing (which, because it is often metallic, helps ground the cable and creates a moisture barrier), and armor. Armor is the overall jacket, to which corrosion protection is applied. Corrosion protection may include a biocide."[184]

Siting of Transmission Lines

The ideal place to install OTEC offshore is an area where deep water is located close to the shore, minimizing the length of cable needed, and hence minimizing the cost of the cable. This occurs where the undersea floor falls sharply away from the coast. In such areas there can be substantial seabed instability.

There are conflicting views of what caused the damage to telecommunication cables makai of Kahe following hurricane Iwa.

"Off southwest Oahu, Hawaii, an array of current sensors recorded four successive episodes of downslope displacement associated with high-speed near-bottom currents of up to 200 cm/s and elevated water temperatures. These episodes coincided with the maximum storm effects of hurricane Iwa. Sensors from four moorings recorded increases in depth of as much as 220 m, implying downslope movement of as much as 2.4 km at speeds up to 300 cm/s. A succession of slope failures at or above the 110-m shelf break, each resulting in a turbidity current event, is the favored explanation."[185]

---

[183] http://www.energy.alberta.ca/Electricity/pdfs/TransmissionSystemsStudy.pdf
[184] http://ocsenergy.anl.gov/documents/fpeis/Alt_Energy_FPEIS_Chapter3.pdf
[185] Geo-Marine Letters , Volume 4, Number 1, 5-11, DOI: 10.1007/BF02237967
Turbidity currents generated by Hurricane Iwa (1984) by A. T. Dengler, P. Wilde, E. K. Noda and W. R. Normark. http://www.springerlink.com/content/p285tq8q21l7w428/

"Six submarine telecommunications cables on the steep insular slope off southwest Oahu were damaged or broken by a combination of debris slides and large-block talus movement or, for the shallowest cables, wave induced chafe. These problems were caused by the sea floor's response to high surface energy produced by Hurricane Iwa. An examination of all available data does not support the concept of failure by turbidity currents."[186]

Not all the cables in the Kahe region were impacted.[187] A great deal has been learned since then about how to secure underwater transmission lines.

Life of the Land proposes a redundant loop consisting of two lines following two separate paths.

---

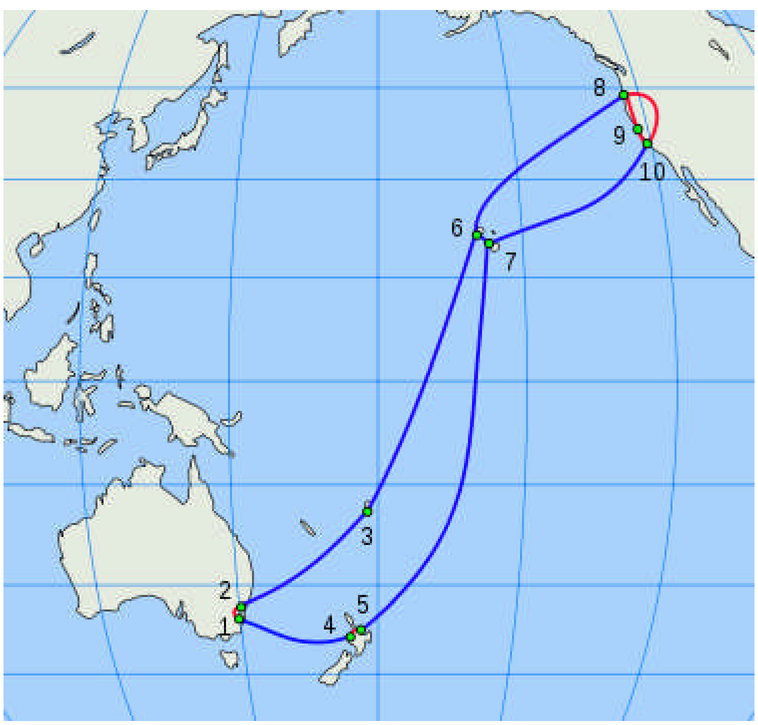
[186] Title: Cable failures off Oahu, Hawaii caused by Hurricane Iwa by Charles D. Hollister (1984) Woods Hole Oceanographic Institution (WHOI) Technical Report WHOI-84-31. https://darchive.mblwhoilibrary.org/handle/1912/2933
[187] Ibid. p.23

Transoceanic Telecommunication Cables

There are several transoceanic telecommunication cables which leave the West Coast and go through the Hawaii Island Chain including Southern Cross - northern route (Nedonna Beach, OR), Japan-US (Morro Bay, CA), Southern Cross - southern route (Morro Bay, CA), Trans-Pacific Cable (TCP 5) (San Luis Obisbo, CA), and TyCom Pacific (Grover Beach, CA). Two of them land at Kahe: Tyco Transpacific and Southern Cross.[188] Segment F1 goes between Oregon and Kahe Point. Segment G1 goes between Kahe Point and Fiji.[189]

In addition, there are at least three state systems: the GTE Hawaiian Telephone Company's Hawaii Inter-Island Cable System (HICS);[190] the Sandwich Isles Communications and Paniolo Cable Company; and the Hawaii Inter-Island Fiber Network[191] (HIFN), owned by Wavecom Solutions. HICS became operational in 1994 and one of the six landing points is the Ko Olina Terminal at Kahe Point. Only the HICS lands at Kahe.

Southern Cross Cables Limited (New Zealand) operates the Southern Cross Cable Network (SX), a trans-Pacific network of telecommunications cables commissioned in 2000. The network has 1600 km of land-based fiber optic cables and 28,900 km of submarine fiber optic cables.



Southern Cross Cable Network (SX)

---

188 Eyeballing Transpacific Cable Landings Western US. http://cryptome.quintessenz.at/mirror/eyeball/cablew-eyeball.htm; See also Eastern Pacific Cable Database: http://www.iscpc.org/cabledb/Eastern_Pacific_Cable_db.htm

189 http://en.wikipedia.org/wiki/Southern_Cross_Cable;

190 en.wikipedia.org/wiki/Hawaii_Inter-Island_Cable_System

191 www.808netfone.com/about/

Heat Exchangers (HX)

“Conduction” is the transfer of thermal energy between a hotter and a colder region, and metal is a chemical element that is a good conductor of both electricity and heat.

“Convection” refers to any movement of fluid, and “forced” convection refers to fluid movement due to an outside force such as fans and pumps.

“Convective heat transfer” actually describes the combined effects of conduction and convection, or fluid flow, thus, convective heat transfer is the transfer of heat from one place to another by the movement of fluids.

When water is heated on a stove, the heat interacts with the bottom layer of water. The bottom layer heats up, expands, and rises. The colder, denser, upper layer falls and the water mixes.

Extensive research has been done in the past few decades on heat transfer, driven primarily by the energy and high tech industries (petroleum, liquefied natural gas (LNG), geothermal, cryogenic, and aerospace), and focused primarily on large temperature differentials. New materials are being used (titanium, aluminum-alloys and plastics replacing stainless steel), and designs have changed. Rough surfaces have replaced smooth surfaces, and new fabrication methods and automation have transformed the industry.

There are three types of heat exchangers (HXs): (1) shell and tube; (2) plate and frame; and (3) aluminum plate fin.

Heat Exchanger (HX) units are critical components of OTEC applications and can consume close to 25% of the total costs. HX units need to be (1) to be easily integrated into the offshore platform, maintained and removed; (2) able to handle large fluid flows; and (3) have a high heat transfer coefficient. Cutting edge research is currently being conducted by Makai Ocean Engineering and Lockheed Martin.

During the past two years, the Hawaii Natural Energy Institute (HNEI), the Office of Naval Research (ONR), Naval Facilities Engineering Command, and the Hawaii Technology Development Corporation (HTDC), have funded ($6.5 million) the design and building facilities to test for corrosion and performance OTEC Heat Exchangers. The facility is located at NELHA and companies participating include Makai Ocean Engineering and Lockheed Martin.[192]

Steam Engines

Scottish engineer and physicist **William John Macquorn Rankine** (1820-72), a pioneer in the field of thermodynamics, developed the “Rankine Cycle” to convert heat

[192] Design of OTEC Heat Exchanger Test Facility by Joe Van Ryzin, Makai Ocean Engineering; See also http://www.otechawaii.com/e-otec.htm

into work.[193] This process accounts for about 80% of all the power generated in the world, and is used in solar thermal, coal, biomass, and nuclear power plants.

The Rankine Cycle has four steps: (1) a working fluid, usually water, is pumped from low to high pressure; (2) an external heat is applied to the working fluid via a heat exchanger; (3) the vapor expands through a turbine generating power; and (4) the vapor condenses. Modern steam plants operate with a large delta T (the temperature differential between cold and warm water inputs.

OTEC facilities rely on either the Rankine Cycle or a newer cycle, the "Kalina Cycle," which uses an ammonia-water mixture as the working fluid. Unlike water, the ammonia-water mixture boils at a variable temperature, and the mixture circulates in different combinations in different parts of the cycle.

THE KMRP BUSINESS MODEL

Should the KMRP move forward, the following elements are essential:

Transparency

Data collection will be open, transparent, and available.

There will be seven underwater video cameras and data collection systems associated with the facilities. The videos will take live feeds. The data collection system will measure temperature, flow, salinity, CO_2 levels and other water characteristics. The system would include passive sonar. The seven video systems will be located at critical areas: two at the cold water intake location (one at the intake itself, the other on the ocean floor), one at the warm water intake location, one at the water discharge location, two downstream from the water discharge area (one on the surface, the other on the ocean floor), and one under the OTEC Platform. The videos would be able to monitor impingement, entrainment, attraction, avoidance, etc. The data collected will be available live on the internet and be open source, transparent, free and in the public domain.

The data will be transmitted via high speed dedicated telecommunication systems (using antennas or satellites) to the University of Hawai`i at Manoa, UH West O`ahu, Leeward Community College and Wai`anae High School.

Management

KMRP will be overseen by a Board. Meetings will be open, live-streamed and videotaped.

Public Commons

The commons refers to resources that are collectively owned or shared between the public. The commons traditionally included forests, atmosphere, rivers, fisheries and

[193] Work means transferring energy to an object. This includes electricity and mechanical energy which is used for lifting, grinding etc.

grazing land. Today it also includes public space, public education, health, literature, music, arts, design, film, video, television, radio, air, sunlight, rain, space, life, creations, thoughts, feelings, ideas, words, numbers, cultural heritage and information.

Although information is becoming ‘gated’ through the commodification of information via non-disclosure agreements, confidential business agreements, intellectual property laws, contract laws, and copyright laws, all raw data gathered at this facility will be in the public commons.

Video

Passage of the Public, Education and Governmental (PEG) access system established that community members have channels/airtime on their local cable systems as the cable company’s ‘rent’ for using the public commons (i.e. streets and rights-of-way). Since 1989, ‘Ōlelo Community Media has provided PEG access services on O‘ahu. ‘Ōlelo Community Media provides access to video production training and equipment, studio space, edit facilities and air time for persons interested in delivering non-commercial messages to their communities.

‘Ōlelo believes “that the free exchange of ideas, reflected in the basic tenets of free speech and exercised using PEG access, can and does contribute to stronger, healthier, more engaged communities. Diverse ideas can be shared and non-commercial community voices can utilize the powerful medium of cable television—without the constraints and cost of commercial television. We strive to ensure a diversity of voices and programming on our channels, to contribute to an informed and engaged community and viewers, to promote lifelong learning, and to build community. Additionally, we continue to develop and support initiatives aimed at increasing civic participation in the democratic process.”[194]

Several schools offer education and training in video and TV including developing skills in lighting, audio, location & studio production, directing, editing, camera operation, and television graphics; including extensive hands-on use of state-of-the-art digital video technology and equipment, emphasizing video equipment operation, storytelling, application and mastery of equipment, and aesthetics.

Schools involved in video training include the University of Hawai`i at Manoa, Kapiolani Community College (KCC), Honolulu Community College (HCC), Leeward Community College (LCC), Leeward Community College Wai‘anae (LeewardCCW), UH West O‘ahu, and Wai‘anae High School.

`Olelo producers will have free access to the data and can repackage it for airing on TV.

Academic Facilities and Opportunities

The Research Facility will house classrooms, labs, dorms, etc. to house marine biologists, marine chemists, marine physicists, high school, college and graduate

[194] www.olelo.org/about_mission.htm

students, environmentalists, and cultural practitioners. Since all data collected will be open source, transparent, free and in the public domain, no classified research would be conducted. KMRP will share data with local educational institutions with programs focusing on environmental, cultural and ocean issues. These include the University of Hawai`i at Manoa School of Ocean and Earth Science and Technology (SOEST); Hawaii Pacific University Department of Natural Sciences; Chaminade University's Environmental Studies Program; and the University of Hawai`i Kamakakuokalani Center for Hawaiian Studies.

In addition, KMRP will seek collaborative efforts with the following facilities:

- The Center for Microbial Oceanography: Research and Education (C-MORE) which facilitates a greater understanding of microorganisms in the sea, ranging from the genetic basis of marine microbial life to their ecological place in the marine environment. The Center's activities are coordinated by the University of Hawaiʻi and shared by its five partner institutions: Massachusetts Institute of Technology (MIT),Woods Hole Oceanographic Institution, Monterey Bay Aquarium Research Institute, University of California, Santa Cruz (USSC) and Oregon State University (OSU).

- The Hawaiʻi Institute of Geophysics and Planetology (HIGP), a multi-disciplinary institute engaging in advanced research, teaching, and service in cutting-edge oceanographic, atmospheric, geophysical, geological, and planetary sciences.

- The Hawaiʻi Institute of Marine Biology (HIMB), a world-renowned research institute situated on Coconut Island in Kane'ohe Bay, which focuses on tropical marine science. Research areas include coral ecology, biogeochemistry, evolutionary genetics, marine diseases, and microbial organisms. Coconut Island is surrounded by 64 acres of coral reef designated by the state of Hawaiʻi for research activities only as the Hawaiʻi Marine Laboratory Refuge.

- The Hawaiʻi Natural Energy Institute (HNEI) focuses on researching energy possibilities.

- The Hawaiʻi Undersea Research Laboratory (HURL) researches deep water marine processes in the Pacific Ocean.

- The International Pacific Research Center (IPRC) focuses on understanding climate variation and predictability in the Asia-Pacific region.

- The Joint Institute for Marine and Atmospheric Research (JIMAR) conducts oceanic, atmospheric, and geophysical research, including climate and global change, equatorial oceanography, tsunamis, and fisheries oceanography.

- The Sea Grant College Program which engages leaders, policymakers, researchers, business, and the general public in ways to improve the understanding and stewardship of marine and coastal resources in the state, region, and nation through innovative efforts.

- Department of Natural Sciences, Hawaii Pacific University.[195]

- Environmental Studies, Chaminade University.[196]

- Kamakakuokalani Center for Hawaiian Studies, University of Hawai`i at Manoa.[197] “The mission of the Hawaiʻinuiakea School of Hawaiian Knowledge is to pursue, perpetuate, research, and revitalize all areas and forms of Hawaiian knowledge[.] We seek to accomplish this mission with a Native Hawaiian perspective that recognizes the holistic aspects of this knowledge, its diversities, and the importance of practical applications.”[198]

- The Pacific Institute of Ocean Law: KMPR will house the first commercial OTEC facility in the world, and will respect and celebrate the technological developments made in Hawai`i. Because OTEC is not regulated, KMRP will fund the establishment of a new law clinic[199] at the William S. Richardson School of Law School[200]. The law clinic, the Pacific Institute of Ocean Law, shall be affiliated with the Ka Huli Ao Center for Excellence in Native Hawaiian Law.[201]

---

[195] "Students in the marine science program at Hawaii Pacific University gain a rigorous scientific understanding of the world's oceans and the life that they contain. Along with a theoretical framework for in the basic and applied sciences, students get hands on experience in laboratory and field based experimentation. Undergraduates as well as graduate students have opportunities to participate in research projects with HPU faculty members. The marine science program at HPU features the BS Marine Biology and BS Oceanography Majors, as well as a Masters of Science in Marine Science. Marine science faculty and researchers in the College of Natural Sciences and the Oceanic Institute currently work in many fields critical to the understanding and sustainable use of marine resources and systems including aquaculture, marine biogeochemistry, marine natural product chemistry, benthic ecology, spatial ecology, coral reef ecology, inorganic carbon cycle dynamics, phycology, environmental microbiology, toxicology, marine mammal physiology, and ichthyology.” http://www.geosciences.com/institution/oceanography/740

[196] "The environmental studies degree at Chaminade University of Honolulu responds to the growing need of society for conscientious, knowledgeable stewards of the environment. With a curriculum developed from input from over forty environmental professionals, a Chaminade degree in environmental studies is a multi-disciplinary approach that allows students to examine environmental issues from a variety of perspectives, including: Policy and Law, Science, Economics, and Ethics and Values. This major prepares students for careers in environmental service, including careers in the ever-growing sectors of government and non-profit environmental organizations. Career directions could include environmental policy, law, economics, communications & information, consulting, science, ethics, and health.” See http://www.chaminade.edu/environment/

[197] “Kamakakuokalani Center for Hawaiian Studies (HWST) recognizes its kuleana to nurture and educate community leaders, teachers, and scholars who will lead Hawaiʻi into the future. Kamakakuokalani offers bachelor’s and master’s degrees that ...crucial issues such as sustainable economic development, training students in land and resource management that is consistent with the geography and history of Hawaiʻi, indigenous pedagogy and epistemology, and creating the political, economic, and governmental infrastructure for a Hawaiian nation.” See http://www.catalog.hawaii.edu/schoolscolleges/hawaiian/kamakakuokalani.htm

[198] http://www.catalog.hawaii.edu/schoolscolleges/hawaiian/general.htm

[199] http://www.law.hawaii.edu/programs-clinics-institutes

[200] http://www.law.hawaii.edu/

[201] "Ka Huli Ao Center for Excellence in Native Hawaiian Law is an academic center that promotes education, scholarship, community outreach and collaboration on issues of law, culture and justice for Native Hawaiians and other Pacific and Indigenous peoples [which] focuses on education, research and scholarship, community outreach, and the preservation of invaluable historical, legal, and traditional and customary materials. ...Ka Huli Ao facilitates discourse between the legal community, the Native Hawaiian community, and the community at large. Law students and faculty – through workshops, symposia, and

Aquaculture

KMRP will offer students hands-on experience in aquaculture, an approach pioneered by the Natural Energy Laboratory of Hawaii Authority (NELHA),[202] where deep cold ocean water to support aquaculture ventures focused on the production of fish, shrimp, algae, nori, clams and coral.

A small amount of the deep cold ocean water would be diverted to aquaculture facilities run by three educational non-profits: (1) Hoa 'Aina O Makaha[203] (The Farm) named by Puanani Burgess and managed by Father (Fr.) Luigi (Gigi) Cocquio; (2) The Learning Center at Ka'ala,[204] co-founded and directed by Eric Enos; and (3) Ma`o Farms[205], a Community Supported Agriculture (CSA) farm overseen by Executive Director Kukui Maunakea-Forth & Managing Director Gary Maunakea-Forth.

These non-profits work with Wai`anae High School, Leeward Community College, Leeward Community College, Wai`anae, Kapi'olani Community College's (KCC) award-winning Culinary Arts associate's program, and the UH West O'ahu Culinary Management program.

Financial Costs

Specific financial data on energy systems is very difficult to obtain. As noted earlier in this document, in practically all regulatory proceedings data is considered confidential and is only made available to other parties who are non-competitors and who sign a Protective Order - a legally-binding, court-enforceable, non-disclosure document. Current and future governmental actions have an enormous impact on project viability: income tax rate, property tax, production tax credits, and depreciation rate. The "cost" of the money borrowed is a key issue based on the percentage of debt, interest rate, and discount rate. Critical project costs are: capital purchase costs, land, installation costs, insurance costs, interconnection costs, and engineering costs.

The Rand Corporation presented an analysis of the cost of an OTEC system in a technical paper at the 8th Annual Ocean Energy Conference in 1981 that included costs for different components. The heat exchangers would account for one-fourth of the total cost of an offshore system. A Hawaii offshore OTEC facility was estimated to have capital costs of $2,790 per electric kilowatt of capacity.[206]

In 2005, Offshore Ports proposed a 100MW offshore system in Kona to be placed on a 5.1 acre platform. The cost was estimated at $800 million. The cost to generate the electricity would be 15 cents/kWh, which would be sold to the utility for 17.25

---

meetings – inform and educate, and are educated and informed by, the community about significant Native Hawaiian issues, history, and law." See http://www.law.hawaii.edu/kahuliao

[202] www.nelha.org

[203] http://www.hoaainaomakaha.org/

[204] http://www.k12.hi.us/~waianaeh/HawaiianStudies/kaala.html; http://www.prel.org/products/paced/nov02/ms_kaala.htm

[205] http://www.maoorganicfarms.org/index.php?/mao_farms/our_farm/

[206] http://www.rand.org/content/dam/rand/pubs/notes/2007/N1788.pdf

cents/kWh.[207] Offshore Infrastructure Associates, Inc. estimated in 2008 that the first 75MW OTEC facility for Puerto Rico could generate electricity for $0.135 kWh (competitive with $65-70/per barrel of oil)[208] and that the costs would drop for successive units; the fifth OTEC facility (100 MW) could generate electricity for $0.09 kWh (competitive with $35 to $40/per barrel of oil).[209]

Sites for Additional OTEC Facilities

Natural Energy Lab of Hawaii (Keahole, Kailua-Kona, Big Island)

Keahole, Natural Energy Labs of Hawai`i (NELHA) The State's first on-shore and off-shore OTEC facilities were tested here. NELHA Photo [210]	

The world's first closed-cycle self-sustaining ocean-based OTEC system was called Mini-OTEC. It was located at NELHA and produced net power in 1979. A 210kWh facility off the island of Hawaii, designed, built and operated from 1993-1998. The offshore Keahole environment is less benign than the Kahe OTEC environment.

"Noda et al. (1981b) compared the two oligotrophic Hawaiian ecosystems [and] suggested that differences in the nature and magnitude of temporal variations between the Keahole and Kahe environments may be related to the physical environments. The Keahole system, which is adjacent to the deep Alenuihaha Channel over which wind strength increases due to the Venturi effects caused by high mountains, is exposed to large, rapid fluctuations in wind force, wave height, and water movement. Variability in these processes is thought to produce the complex biological systems that were observed in the environment. In contrast, Kahe is exposed to less intense winds that blow over the Kauai Channel. Because wind intensity is associated with divergence and upwelling, it is reasonable to expect that these processes are less intense off Keahole than off Kahe. The isolation of the Kahe system from severe weather and

[207] http://www.lifeofthelandhawaii.org/doc2/Offshore_Ports_Kona_OTEC.pdf
[208] In Hawai`i a majority of the cost of electricity is the cost of oil. If oil cost $65-70/per barrel then an oil-fired generator would produce electricity for about $0.135/kWh.
[209] green.uprm.edu/pres/pres_Marti&Plocek.pdf
[210] www.nelha.org/image/subpage/arial.jpg

intense wave action results in less variability of the physical components and more gradual and systematic temporal cycles in the biological components."[211]

Kaneohe Marine Air Corps Station

The facility would be built makai of the Kaneohe Marine Air Corps Station. The Makai Pier in Waimanalo would house the support facilities. The Makai Pier is located just a little north of Sea Life Park and Makapuu Beach Park in Waimanalo. The pier is a long, concrete structure built by the State to support marine research efforts in the Hawaiian Islands. This pier houses several commercial marine engineering firms such as Makai Ocean Engineering and research facilities and the University of Hawaii's Hawai'i Underwater Research Laboratory (HURL). The HURL's facilities include two deep-diving (2000 meter) submersibles, remotely operated vehicles. A sub-surface transmission line could be easily connected to the end of the pier.

	
Mokapu Peninsula, Kaneohe Marine Air Corps Station. KMAS Photo[212]	Makai Pier, Waimanalo[213]

[211] http://www.pifsc.noaa.gov/adminrpts/1983/SWFC_Admin_Report_83-13.pdf. See also Noda, E.K., P.K. Bienfang, W.J. Kimmerer, and T.W. Walsh. 1981. OTEC environmental benchmark survey, Kahe Point, Oahu; Noda, E.K., P.K. Bienfang, and D.A. Ziemann. 1982. OTEC environmental benchmark survey off Keahole Point, Hawaii.
[212] http://hawaii.gov/hawaiiaviation/aviation-photos/1960-1969/marine-corps-air-station-kaneohe/NAS%20Kaneohe%201.jpg/image_preview
[213] www.makai.com/images/pier.jpg

CHAPTER 5: TRANSPORTATION

GROUND TRANSPORTATION

Although addressing Hawai`i's dependency on fossil fuels has taken on much urgency in the past few years, with much attention devoted to electric generation, the truth is that over 70% of fossil fuel use in our state is in transportation, both on the ground and in the air.

Perhaps more focus is given to replacing electricity with renewables because it is easier to replace fossil fuel with renewable sources of energy to make electricity than it is to find a liquid fuel replacement for gasoline. Nonetheless, LOL believes that replacing the century-old gasoline-burning automobile with electric vehicles would go far in weaning the state from fossil fuels.

Electric generators are not very efficient, as most of the oil burned by a utility to make electricity is lost in the form of heat: up the smokestack or out the outfall into the ocean. Even so, electric generators are much more efficient than car and truck engines. And the modern use of electric cars can, but will not necessarily, reduce greenhouse gas emissions, since cars powered by a typical U.S. mainland grid derive half of the power used from coal. However, replacing the gasoline powered internal electric engine with renewable energy charged batteries is a solution to fossil fuel use.

Consider this: if you flip on ten 100-watt light bulbs, you are burning 1 kilowatt of power. If these lights remain on for an hour, you will have used 1 kilowatt-hour of energy. In general terms, that same amount of energy—1 kilowatt-hour—will move an electric car about four miles down the road. When you also consider that "on average 95 percent of all cars are parked at any given time, one hour a day of car usage is the average in America,"[214] then adding an electric vehicle to the photovoltaic panel on your roof could have the added value of a Net Energy Metering (NEM) or Feed-In Tariff (FiT) "Car" Contract.

Vehicles powered only by batteries are called Battery Electric Vehicles (BEV). A vehicle powered by rechargeable batteries as well as a gas tank/internal combustion engine is called a Hybrid Electric Vehicle (HEV). HEVs that can be recharged by plugging into a standard wall socket are called a Plug-in Hybrid Electric Vehicle (PHEV). If the vehicle is able to import energy from and export energy back to the electric grid, then it is called Vehicle-to-Grid (V2G). Ideally, a V2G could accept power from cheap excess night-time wind sources, and export energy to the grid during the high peak energy period. If Time of Use Rates (TOUR) is employed, then the vehicle car owner would pay a low fee for electricity and also receive a high fee for electricity sold.

.

[214] http://www.newswise.com/articles/view/535841/

In many places night wind power is curtailed. Tawhiri, the wind farm at South Point on the Big Island, produces night-time power but HELCO is not able to use it. In 2007 twelve million kilowatt-hours of wind energy were curtailed, and by 2008 the amount grew to eighteen million kilowatt-hours. Electric vehicles could easily tap into the power grid at night, absorbing energy produced from wind power.

A recently proposed model for electric vehicle infrastructure was made by Better Place. Not only would electric charging stations be built throughout a region, but existing gas stations could host a network of fully-automated battery exchange stations, where drivers could exchange a low battery with a fully charged one; such stations could process vehicles made by many different manufacturers.

An alternative option is to recharge vehicles at night in parking lots and home garages. The car can be hooked up to a standard outlet, and for each hour that the car is plugged in, the battery charges enough for the vehicle to drive twenty miles ("20 miles per hour"). Costco offers free electricity for electric cars for its members in California, as the cost of electricity is relatively cheap compared to the amount of money the customer will spend in the store.

A third model requires the car to use a special patented electric cord and allows energy companies to set a special rate for recharging vehicles.

Electric vehicles can provide battery storage for renewable energy, primarily through rechargeable lithium ion batteries. These are currently in widespread use in laptops, cell phones and power tools, and can reliably deliver driving distances of over 100 miles on a single charge. Ideally, a rooftop micro-wind, photovoltaic cells (solar), concentrated solar power, and car battery would be part of one system, providing continuous, reliable power.

Annual vehicle miles of travel (2009)[215] MW required[216]

County	Million Miles	MW
Honolulu	6,276	287
Hawaii	1,676	77
Maui	1,369	63
Kauai	774	36
Total	10,095	461

In California in 2007 Pacific Gas And Electric Company pioneered utility support for V2G to enable off-peak renewable resources to be available during on-peak periods.[217]

---

215 Table 18.17: Motor Vehicle Fuel Consumption and Vehicle Miles, 1990 to 2009, and by County, 2008 and 2009. State of Hawaii Data Book (2009). http://hawaii.gov/dbedt/info/economic/databook/

216 Assumption; Electric cars get 2.5 miles per kWhr. 1 million miles = 400,000 kWhr = 400 MWhr = 0.0457 MWyr.

217 **http://theirearth.com/index.php/news/vehicle-to-grid-v2g-technology-pacific-gas-and-electric-company-pg-e**

Delaware passed a law in 2009 that requires utilities to compensate electric car owners for electricity sold back to the grid at the same rate they paid for the electricity to power their vehicles.[218]

In 2010 a Toyota Scion xB became the first electric car that supports the vehicle-to-grid (V2G) concept.[219]

The first charging station opened in Honolulu on January 23, 2010.

Plug-In America offers a monthly update of virtually every major auto manufacturer in the world and their current and planned electric vehicles.[220]

AVIATION

There are a number of technologies being considered for jet fuel. These include small-scale virgin oil biofuel, waste oil biofuel, and algae-based biofuel. With technological knowledge doubling every seven years it is reasonable that renewable energy solutions will be developed for air travel. However, since our Report focuses on Hawai`i being 100% energy self-sufficient by 2030, if alternatives have not been developed for air travel by 2025, then a large OTEC plant should be built off Pearl Harbor to manufacture aviation fuel using OTEC. There are some OTEC Companies currently investigating this type of technology.

[218] http://www.evworld.com/news.cfm?newsid=21800
[219] **http://www.physorg.com/news185779836.html**
[220] http://www.pluginamerica.org/vehicles/

CHAPTER 6: ENVIRONMENTAL IMPACTS

Water Flows

Below are warm water intake volumes for various sized OTEC facilities, using the Natural Energy Laboratory of Hawai'i (NELHA) and San Onofre Nuclear Power Plant as reference points.[221]

Facility	Million Gal/day	Gal/min	Ft3/Sec	m3/sec	m3/min	Million m3/day
NELHA 40 in CW	19	13,400	30	0.8	51	0.07
NELHA 55 in CW	39	27,000	60	1.7	102	0.15
5MW plant min	342	237,750	530	15.0	900	1.30
5MW plant max	571	396,250	883	25.0	1,500	2.16
100MW plant min	6,847	4,755,000	10,593	300.0	18,000	25.92
100MW plant max	11,412	7,925,000	17,655	500.0	30,000	43.20
400MW plant min	27,389	19,020,000	42,373	1,200.0	72,000	103.68
400MW plant max	45,648	31,700,000	70,621	2,000.0	120,000	172.80
San Onofre Nuclear Power Plant	2,580	1,791,667	3,991	113.0	6,782	9.77

Plantship Size

"In the 1990s, it was determined that to be cost competitive OTEC plants larger than about 50 MW were required in the USA Market. [ ] Conceptual designs for 50 MW OTEC plants utilizing either closed cycle (CC) or open cycle (OC) technology are summarized herein. [ ] The CC-OTEC plant would require a 198 meter long ship-shaped platform with a 39 meter beam and an operating draft of 16 meters resulting in 120,600 tonne (metric ton) displacement."[222]

Ship	Size[223] (acres)
Ultra Large Crude Carrier	8
Very Large Crude Carrier	4
Titanic (1,112 feet x 116.5 feet)	3
Queen Elizabeth 2 (963 feet x 105 feet)	2.5
Pride of Hawai`i (2006) (965 feet x 105 feet)	2
Pride of Aloha (1994) (853 feet x 106 feet)	2
Pacific Princess (1999) (594 feet x 83 feet)	1

---

[221] Ocean Thermal Energy Conversion (OTEC) Workshop: Assessing Potential Physical, Chemical and Biological Impacts and Risks. A Primer, Table 1.

[222] First Generation 50 MW OTEC Plantship for the Production of Electricity and Desalinated Water By Luis A. Vega (National Marine Renewable Energy Center at the University of Hawaii) and Dominic Michaelis (Energy Island Ltd. UK). This paper was prepared for presentation at the 2010 Offshore Technology Conference held in Houston, Texas, USA, 3–6 May 2010.

[223] The size can be calculated from the shape of the boat and the waterplane area coefficient (CWP) which refers to the ratio of the area of the waterplane (AWP) to the area of a circumscribing rectangle (area = length times width\beam). (CWP = AWP/LxB).

Trace Materials

All discussions regarding "sustainability" must begin with an analysis of component parts, and the source of the ingredients that are used to make or produce something. Are the components produced locally or must they be imported? Are they extracted in a sustainable manner? Are the components considered so valuable that a war or military action might result? Are there any violations of human rights involved in the extraction process?

Gold is a material that has historically had significant political impact in its extraction. Examples are South Africa, from which half the gold ever extracted originated and which accounted for seventy-nine percent of world production in 1970, and the Soviet Union, which ranked second in gold extraction since World War II. In the past, gold provided backing to currency; under the gold standard used in monetary policy, currency could be converted into gold. Many think that if the gold standard had remained, neither the Soviet Union nor South Africa would have undergone regime change, as both countries could have continued to prop up their economies by using "slave" labor in gold mining. Today, gold is used in electronics because it is a great conductor of electricity and it resists oxidative corrosion.

Extraction of copper, diamonds, gold, tin, and especially coltan (colombo-tantalite) has caused years of turmoil in the Democratic Republic of Congo (DRC). A large African country, almost one-quarter the size of the United States, the DRC was plagued by militias who financed themselves and their operations by controlling the flow of minerals. The Second Congo War (1998-2003), also known as Africa's 'World War', involved armies of eight nations and over twenty armed groups. The conflict is the deadliest since World War II, with over five million dead and rampant human-rights abuses.

At the beginning of 2000 a pound of unprocessed coltan sold for $30-$40 per pound, but by the end of the year the price had risen to $400 per pound; the rising popularity of cell phones, play stations and wireless devices led to a surge in demand. Coltan is converted into tantalum powder by just three companies: Cabot Inc. (U.S.), HC Starc (Germany) and Nigncxia (China). At one point the Rwandan Army was making twenty million dollars a month from coltan mining in the DRC.

There are numerous elements besides coltan which are essential to daily life in the wireless telecommunication age in which we now live. Bromine, cobalt, lithium, manganese, nickel, vanadium, and zinc are all used in batteries; cerium, lanthanum and europium are used in energy efficient light bulbs; cadmium, gallium, germanium, indium, tellurium, and silicon are used in photovoltaic cells; and a neodymium-iron-boron (NdFeB) alloy is used as magnets in wind engine motors. In 2003, Australia produced 31% of the world's 4,221 tons of titanium (the premium industrial material used in heat exchangers), followed by South Africa at 20%, Canada at 18%, Norway at 9%, Ukraine 8% and an amalgam of other sources (14%).

History has shown that as the demand for trace elements increases, the pressure on local economies and populations can be devastating. It is important when we talk about sustainability that we not lose sight of from where these elements come, and insure that social justice practices are followed.

Climate Change

Climate refers to the average weather conditions in a region over a long period of time. The climate of a location is affected by its latitude and terrain, as well as by any nearby ocean and ocean currents. Specific climate types can be described based on characteristics such as temperature and rainfall.

Climate change is a long-term change in the statistical distribution of weather patterns over periods of time that range from decades to millions of years. It may be a change in the average weather conditions or a change in the distribution of weather events with respect to an average, for example: greater or fewer extreme weather events. Climate change may be limited to a specific region, or may occur across the whole Earth. In recent usage, especially in the context of environmental policy, climate change usually refers to changes in modern climate. It may be qualified as anthropogenic climate change, more generally known as global warming or anthropogenic global warming (AGW). The most general definition of climate change is a change in the statistical properties of the climate system when considered over periods of decades or longer, regardless of cause. Accordingly, fluctuations on periods shorter than a few decades, such as El Niño, do not represent climate change.

Hawai`i's climate is characterized by two seasons: summer (May through September) and winter (October through April). In general, the islands have relatively mild temperatures and moderate humidity throughout the year (except at high elevations), with persistent northeasterly trade winds and infrequent severe storms. However, summer is typically warmer and drier, with minimal storm events. The trade winds are prevalent 80 to 95 percent of the time during the summer months, when high-pressure systems tend to be located north and east of Hawai`i. During the winter months, the high-pressure systems are located farther to the south, decreasing the prevalence of the trade winds to about fifty to eighty percent of the time. Despite the strong marine influence resulting from Hawai`i's insularity, some mountainous areas exhibit semi-continental conditions. Combined with the rugged and irregular topography, the result is diverse climatic conditions across the various regions of the State, including significant geographic differences in rainfall amounts, which range from 20 inches to 300 inches annually.[224]

"Island communities are especially vulnerable to a warming and more energetic climate system. Climate vulnerabilities exist at three tiers: exposure, sensitivity, and adaptive capacity. The former, exposure, is determined by climate forecasting based on sound science, while the latter two are determined by the strength of the existing policy and planning infrastructure. As the only U.S. state located in the tropics, and the only one surrounded entirely by water, scientists expect climate change to affect the Hawaiian Islands in ways unlike anywhere else in the country. Some key vulnerabilities for Hawai`i due to climate change include availability of fresh water,

[224] This paragraph comes from the Auwahi Wind Farm EISPN (2010), Kawailoa Wind Farm EISPN (2010) and this Hawaii Interisland Cable EISPN (2010) and may be originally from UH's Hawaii Water Resources Research Center (2010).

exposure to coastal hazards, including sea level inundation, and negative impacts of climate change to coastal and marine ecosystems"[225]

The featured OTEC Project proposed herein is not expected to affect natural climatic conditions or weather patterns. However, the Ocean Project EIS will include a more thorough evaluation of potential impacts to climatic conditions or weather patterns associated with climate change. On the other hand, future ocean development projects are expected to have a beneficial impact on climate change by decreasing fossil fuel consumption. The burning of fossil fuels results in the emission of several green house gases (GHG), mainly carbon dioxide, methane, and nitrous oxide, all of which contribute to climate change. Renewable electricity generated by ocean energy facilities does not create GHG, therefore replacing fossil fuel use with ocean energy would result in the reduction of GHGs being emitted into the atmosphere and would be associated with a concurrent reduction in climate change impacts.

Health Impacts

Life of the Land's twenty-year proposal would phase out all commercial scale fossil fuel generators. The oil refineries would probably be converted to biofuel facilities, although some may be closed.

Fossil fuel burning facilities currently release particles, soot, and chemicals into the air which causes asthma, emphysema, lung and heart diseases, respiratory allergies, difficulty in breathing, wheezing, and coughing. The health costs associated with fossil fuel burning is thought to be huge but is largely undocumented.

According to the U.S. Environmental Protection Agency (EPA) Toxic Release Inventory (TRI),[226] Hawai`i businesses released a total of three million pounds of toxic chemicals into the environment in 2009. This data excludes transportation and household emissions. The Inventory noted that two sectors dominated in toxic emissions in Hawai`i: Fossil Fuel Electric Power Generators (72%) and Petroleum Refineries (10%).

In measuring releases by weight rather than toxicity, the emissions primarily went up the smokestack. In millions of pounds, release into the air was 2.23, into water 0.22, onto on-site land 0.15, and off-site 0.34. Off-site transfers include recycling, garbage-to-energy facilities and landfills.

Again, by weight rather than toxicity, the two primary chemicals released were sulfuric acid aerosols (1.4 million pounds), and hydrochloric acid aerosols (0.3 million pounds)

The Top 10 emitters were: HECO's Kahe Generating Station; (2) HECO's Waiau Generating Station; the AES Kalaeloa Coal Plant (used to generate electricity); (4) Pearl Harbor; (5) MECO's Kahului Generating Station; (6) Chevron's Refinery (Campbell

---

225 A Framework for Climate Change Adaptation in Hawaii: A collaborative effort of the Ocean Resources Management Plan Working Group with the assistance of the University of Hawaii, Center for Island Climate Adaptation and Policy (November 2009)
http://hawaii.gov/dbedt/czm/ormp/reports/climate_change_adaptation_framework_final.pdf

226 EPA's Toxics Release Inventory (TRI) 2009 Hawaii.
http://www.epa.gov/region9/toxic/tri/report/09/TRI-2009HawaiiReport.pdf;
http://www.epa.gov/region9/toxic/tri/report/09/TRI-2009HawaiiReport.pdf

Industrial Park); (7) HELCO's Hill Generating Station; (8) HELCO's Puna Generating Station; (9) MECO's Maalaea Generating Station; and (10) Tesoro's Refinery (Campbell Industrial Park).

While there are no refineries (Chevron, Tesoro) on the Neighbor Islands, toxic releases are disproportionately higher than for O`ahu, likely due to aging plant operations.. For example, HELCO facilities on the east side of Hawai`i Island were originally built before the Clean Air Act or were subsequently given emission exemptions. Many of them burn dirty diesel fuel.

Emissions from HELCO generators at Hill/Kanoelehua (Hilo) and Puna (Keaau) account for less than five per cent of the electricity produced in the State, yet these facilities released a combined 330,000 pounds of toxics into the environment; they represent just over 10% of the emissions from all reporting facilities in the State.[227]

MECO has two main generation facilities on Maui: the older, smaller one is at Kahului and the newer, larger one is at Ma`alaea. The Kahului Generation Station consists of four generators installed between 1948 and 1966. The facility has a normal net peak output of 32 M, and supports local loads since it is not fully integrated into the grid. The Ma`alaea Generation Station consists of nineteen generators built between 1971 and 2006, and the facility has a normal peak output of 210 MW. The facility is fully integrated into the grid and provides power to loads from Hana to Lahaina.

Most of Maui's electricity is generated at Ma`alaea while most of the air pollution is generated at Kahului; MECO's Kahului Generating Station is the neighbor island's top emission site.[228]

[227] HELCO IRP-3 Report 2007 – 2026 (May 2007) (PUC Docket 04-0046)
http://www.heco.com/vcmcontent/HELCO/RenewableEnergy/IRP/HELCO_IRP3_Report_Final.pdf
[228] MECO IRP-3 (April 2007) (PUC Docket 04-0077) Table 5.6-1 Summary of MECO's Maui Division Existing Units, page 5-19.
http://www.heco.com/vcmcontent/MECO/RenewableEnergy/IRP/MECO_IRP3_Report_Complete.pdf

Environmental Organizations & Individuals: Views on OTEC

Pat Shutt, President of the League of Women Voters of Hawaii (1980)[229]

"The League of Women Voters has a position supporting research and development of all types of alternate energy sources, and we therefore support continued research and development of OTEC.

It is our opinion that OTEC should become one of a mix of natural energy sources necessary to decrease Hawaii's dependence on imported oil. Hawaii is an ideal location for continued research into ocean thermal energy conversion for two major reasons: No. 1, deep ocean water is available near the shore; number two, the year-round mild climate insures a good temperature difference between the deep, cold water and the warmer surface water. OTEC's potential for continual availability upon demand, as opposed to solar and wind which produce intermittent energy, makes OTEC desirable for direct hookup with the utilities.

Environmental protection is of great concern to the League, and we are pleased to see that this bill[230] addresses the environmental impact of any proposed facility. We would also like to emphasize the need for consistency with the Coasted Zone Management Act

The bill should allow the Governor to deny licenses which he feels are not consistent with the State Coasted Zone Management pro-gram, pending an appropriate Federal action to override his denial. It is not clear whether the bill permits this."

Life of the Land, Hawai`i (1980)

"Hawaii is the best place in the United States to build an OTEC site. [ ] It is imperative that OTEC be considered as an important step to Hawaii's goal of energy and economic self-sufficiency.

However, there are important environmental concerns such as: the effects of thermal stress which would be introduced into the immediate area; the effect of additional nutrients to coastal waters (creating the possibility of biostimulation of marine life due to increased levels of food sources); and water quality standards as related to temperature and nutrient changes.

Another environmental concern is ammonia leakage into the ocean due to corrosion in the heat exchange system. One way to assure that this does not happen is to design the plant with a rotating maintenance schedule; in other words, to allow for a portion

---

[229] US Senate Committee on Commerce, Science, and Transportation re Ocean Thermal Conversion Act of 1980

[230] The Ocean Thermal Conversion Act of 1980

of the plant to be shut down for maintenance and still maintain optimum capacity of the plant.

Observation of existing data and conclusions show that with further studies and research, OTEC can become environmentally acceptable as an energy alternative for Hawaii. [ ] It has been shown that three commercial OTEC plants could produce enough energy for all of Hawaii."[231]

Dennis Callan, Board Member, Life of the Land (1980)[232]

"Life of the Land is grateful that Congress, led by our Senators, is facilitating this energy alternative with the Ocean Thermal Conversion Act of 1980. We not only support the bill, we want it to move along at maximum speed. Just in the last few months we have seen the energy crisis explode into a massive international political emergency, which will probably get much worse as the entire Middle East gets drawn into a long-term revolution. The only effective way that we can fight back is to develop our alternative energy supplies.

Hawaii is more affected by this situation than any other State. We have the most extreme dependence on petroleum, since the common alternatives of coal and nuclear are not practiced in Hawaii, which is lucky for us, since they both produce many environmental poisons. At the same time in Hawaii we have the greatest potential in — and, excuse me if I sound like the earlier speakers, but we all seem to agree — the greatest potential for the new wave of energy alternatives. [ ]

Our environmental organization has been helping to educate the public on the need for alternate energy since our founding in 1970. An example of this is a major article in our current newsletter which explains in some detail what OTEC is and how it can benefit Hawaii. [ ]

At any rate the environmental safeguards written into the OTEC Act of 1980 appear to deal adequately with this situation, particularly since an environmental impact statement will be required along with continual monitoring. In short, we feel the total benefits far outweigh any possible environmental problems, and even those small problems can likely be turned into benefits. Considering this, it is extremely unlikely that Life of the Land would ever take any action to discourage OTEC production in Hawaii. On the contrary, we hope this will develop as soon as possible."

Jon Van Dyke, Associate Dean and Professor of Law, Principle Investigator of Sea Grant Project on Pacific Ocean Legal Issues & Sherry Broder, Attorney at Law (1981)

[231] Alternative Energy: OTEC by Jan Takeyama, LOL Staff Member, Life of the Land Newsletter (March-April, 1980)
[232] US Senate Committee on Commerce, Science, and Transportation re Ocean Thermal Conversion Act of 1980

“We have reviewed the Draft EIS for OTEC and found it to be informative based on available data. We have the following comments on some of the specific areas. [ ] Comparatively speaking, Hawaii has a lower amount of biocide released into ocean waters because heavy industries are almost non-existent. In some areas, the quality of water is exceptionally clean because of the minimal discharge of products that could degrade it. The EIS should include an analysis of this type of situation. NOAA should require licensee to maintain the already existing quality of water to the extent possible. Just because Hawaii has potential sites with superior water quality, higher quantities of biocide discharge or other types of polluting discharge should not be permitted.”[233]

Greenpeace (2007)

“Increased investment in research and development could see other kinds of renewables such as ocean thermal energy conversion, tidal and wave power becoming commercial and widespread over the decades to come.”[234]

National Wildlife Foundation (2009)

“Average energy prices in the U.S. Virgin Islands are among the highest in the nation due to the territory's reliance on oil that must be shipped in from other locations. Promoting the use of renewable power sources to lower costs and help the Virgin Islands achieve long-term energy independence is a key conservation priority of the Virgin Islands Conservation Society.

According to NWF board member Paul Chakroff, “It is our responsibility to reduce our contribution of greenhouse gases to the atmosphere and to sensibly use our natural resources. In 2008 the society helped form a coalition known as the Virgin Islands Renewable Energy Organization (VIREO) to advocate for viable alternatives that don't produce carbon dioxide, such as solar, wind, geothermal and ocean thermal energy. The coalition, which includes NWF, has been reaching out to both citizens and government officials--and making progress.” [235]

Environmental Defense Fund (2010)

“Ocean energy technologies have clear advantages over fossil fuel combustion. They produce no fine particulate pollution, which has been linked to respiratory disease; no sulfur or nitrogen dioxides, which contribute to smog, accelerate weathering of building materials, and create acid rain and nitrogen deposition; and no greenhouse gases. Some ocean energy technologies have the potential to produce secondary

---

[233] Ocean Thermal Energy Conversion: Final Environmental Impact Statement, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Ocean Minerals and Energy (July 1981)

[234] “Futu[r]e Investment” (July 2007) by Greenpeace International, European Renewable Energy Council (EREC) is based on the Global Energy Scenario report “Energy [R]evolution” (January 2007). http://www.greenpeace.org/raw/content/international/press/reports/future-investment.pdf

[235] Affordable Power for the People. http://www.nwf.org/News-and-Magazines/National-Wildlife/News-and-Views/Archives/2009/Action-Report-April-May-2009.aspx

benefits as well. However, if developed at a commercial scale, ocean energy technologies may have adverse impacts unless they are mitigated. [ ]

OTEC is a very old technology with a variety of pros and cons. [ ] Capital costs associated with OTEC are related by a strong inverse exponential correlation to plant size; costs are reduced dramatically as plant size and capacity increases. [ ] Even with subsidized oil prices, it is becoming clear that the economic feasibility of OTEC continues to increase as fossil fuel prices continue to rise and secondary products from OTEC plants become more socially and economically attractive. [ ]

The potential environmental benefits from ocean energy are large and obvious, notably a reduction in local air pollution and greenhouse gas emissions. However, as is the case with any large-scale technology, there are potential environmental impacts associated with ocean energy. [ ]

EDF recommends the adoption of Best Practices and performance standards to minimize the potential adverse impacts of ocean energy development, and the development and enforcement of performance standards that apply to site development, construction, operation, and decommissioning. As is the case with any construction near the coast, it is advisable to avoid sensitive habitats, avoid other major impacts, minimize unavoidable impacts, characterize the residual impacts, mitigate or offset minimized impacts, and monitor for verification.

Ocean energy offers excellent opportunities for clean energy production, as well as numerous ancillary benefits such as freshwater, food, seaweed crops, and refrigeration/air-conditioning in the case of OTEC. The development of ocean energy—if done thoughtfully and in the context of strong environmental standards, enforcement, and incentives—is an unmatched opportunity to help build a healthier world, meeting human needs while at the same time protecting and restoring ocean ecosystems." [236]

NRDC (May 10, 2010)

"OTEC has three main problems; cost, production of power remote from where it is needed, and a perceived need to bring large volumes of deep, cold, water to the surface to condense vapors of the low boiling point fluid used in the heat engine. [ ] Instead of costly, massive, cold water pipes, the much smaller volume of vaporized ammonia vapor vented from the heat engine should be pumped into the depths to be condensed thus overcoming a massive technical problem and lowering the cost of OTEC. [237]

---

[236] Fujita, R., C. Scarborough, and J. Díaz Díaz, editors. Proceedings of the International Workshop on Clean Ocean Energy. April 23–25, 2008, Varadero, Cuba. Environmental Defense Fund 2010, 38 p. Available online at www.edf.org/cuba

[237] John Steelman's Blog. John Steelman joined NRDC is 1994 and is currently the program manager for NRDC's Climate Center.
http://switchboard.nrdc.org/blogs/jsteelman/houston_we_have_alternativesto.html

Life of the Land (Hawai`i) (2010)

Life of the Land responded to the Hawaii Department of Business, Economic Development and Tourism (DBEDT) when it filed an Environmental Impact Statement (PEIS) Preparation Notice (EISPN) for the Hawaiʻi Interisland Renewable Energy Program (HIREP) suggesting that Ocean Thermal Energy Conversion be considered as an alternative.

CHAPTER 7: ECONOMIC ANALYSIS

A fundamental question often asked about the cost of a renewable energy source is: is it cheaper or more expensive than the cost of petroleum?

It is a simple question, but it does not have an easy answer, and requires us to define what we mean by cost: does it include only the cost that ratepayers pay, or also the cost that taxpayers pay? Does it include government subsidies by way of loans and loan guarantees, grants, and tax breaks? Does it include favorable tax treatment, import policies and export policies?

Obviously, current and future governmental actions will have an enormous impact on project viability: income tax rate, property tax, production tax credits, and depreciation rates all factor into a project's overall costs. The cost of money is a key issue and can include the percentage of debt, interest rate, discount rate, capital purchase costs, land, installation costs, insurance costs, interconnection costs, and engineering costs.

And externalities, those impacts which are caused by an entity but which are not reflected in the price of the good sold, may or may not be calculated as costs. Externalities could include as an example, toxic slug in streams and rivers that are the result of contamination from mountain top mining, siltation of reefs from poor farming practices such as sugar cane runoff, and health impacts such as influenza from power plant smokestacks.

One way of comparing projects with different life spans and different cash flow patterns, is to compare their average costs over a 20 year period. These back-of-the-napkin cost estimates vary greatly and are highly dependent upon the assumptions used. This is especially true when comparing two systems, one of which has high initial costs (including most renewable energy systems) and the other has high operational costs (including most fossil fuel systems). Major variables include the interest rate, cost overruns, and tax policy.

The U.S. has spent $1 trillion on Mid East military actions and wars to guarantee the free flow of oil shipments. This "cost" is usually excluded from any comparison of the cost of renewables versus the cost of oil.

Costs Can Be Classified Data

A company typically looks to insure its profits by maximizing government subsidies, minimizing taxes, externalizing costs, and getting the government to subsidize customers buying its products. Some companies readily release information related to their cost structure.

However, as noted earlier in this document, specific financial data on energy systems is very difficult to obtain. In practically all regulatory proceedings data is considered confidential and is only made available to other parties who are non-competitors and who sign a Protective Order which is a legally-binding, court-enforceable, non-disclosure document. And utilities rely upon national security laws, enacted after 2001, to restrict public knowledge of the transmission and distribution grid. This includes the amount of load carried by different transmission lines, distribution lines, and the amount of electricity delivered to different communities. The specific characteristics of each line determine the amount of intermittent energy that the line can carry.[238]

For example, there are two major wind farms on the Big Island, at South Point and at Hawi. The former has a capacity factor of 0.61 while the latter has a capacity factor of 0.37. Each wind farm produces electricity during windy periods and does not produce wind during calm periods. If 1 MW were installed at each site, then on average the South Point wind farm produces 61% of its maximum output, producing 0.61 megawatt-years of electricity. On average the Hawi wind farm produces 37% of its maximum output, producing 0.37 megawatt-years of electricity. Finding sites that have high capacity factors are much sought after, and thus location based data is very valuable and highly protected.

The 2005 Energy Bill

A subsidy represents a transfer of government resources to the buyer or seller of a good or service that has the effect of reducing the price paid, increasing the price received, or reducing the cost of production of the good or service. The mechanism can include investment tax credits, production tax credits, loans, leases, use of government property, special tax credits, deductions, exemptions; favorable depreciation rates, government-industry partnerships, university-developed techniques which are patented by the private sector, tariff treatment, assumption of risk (such as nuclear fallout), sole source contracts, research grants, etc.

Public Citizen estimated that the 2005 Energy Bill provided $6 billion in subsidies to the oil and gas industry (including reduced royalty payments for oil and gas drilling on Alaska's Outer Continental Shelf and in the Gulf of Mexico), $9 billion to the coal industry and $12 billion to the nuclear industry.[239]

Under this Bill, payments would be made to politically connected organizations and they would in turn then dole out subsidies to their friends. Fossil fuel companies would be able to exempt some risky operations from provisions of the Safe Drinking Water Act, the Federal Water Pollution Control Act, the Coastal Zone Management Act and state regulations.

The coal industry receives money for investing in new plants, turning older plants into "clean coal" plants, for research into coal emission sequestration, and for developing new coal mining technologies.

Transmission companies would be subsidized for turning over regulatory control of their lines from states to multi-state Regional Transmission Organizations. The federal

[238] Introductory electronics is based on fifth semester calculus and is beyond the scope of this paper.
[239] http://www.citizen.org/cmep/article_redirect.cfm?ID=13980

government would be able to override state regulations regarding transmission line siting.

Brazilian Ethanol

The essence of free trade is that commodities should be produced where they can be produced for the lowest cost. Brazil can produce ethanol at 40-50% lower cost than American producers, so to protect American farmers from losing business to Brazilian farmers, the U.S. Government has imposed a fifty-four cents/gallon tariff on Brazilian ethanol. However, Brazilian farmers can avoid the tax by passing the ethanol through the Caribbean and getting it into the U.S. duty free via the Caribbean Basin Initiative (CBI).

The CBI, a unilateral and temporary United States program initiated by the 1983 Caribbean Basin Economic Recovery Act (CBERA), and expanded by the 2000 U.S. Caribbean Basin Trade Partnership Act (CBTPA), provides nineteen beneficiary countries with duty-free access to the U.S. market for most goods.

Splash and Dash

A biofuel producer can produce a gallon consisting of a mixture of diesel and biodiesel. Diesel is cheaper to make, but by including at least 1% biodiesel, the producer is eligible for a federal production tax credit for the entire gallon of fuel. The only relevant requirement in the 2004 law is that the 1% biodiesel must be added in the U.S.[240]

Thus, a producer could produce ninety-nine gallons of diesel in Europe, ship it to Houston, add a gallon of biodiesel, ship the hundred gallons back to Europe, and sell it on the market at a lower price than those who chose not to use this trick. The result is that those manipulating the system are undercutting legitimate businesses by using American taxpayer subsidies.

According to the Wall Street Journal (April 1, 2008**):**

"How big a mess is America's biofuel policy? [ ]The U.S. taxpayer forks over a $1 subsidy for every gallon of biodiesel that is blended in the U.S. for export later. The idea was to give a nudge to the U.S. biofuel industry. But it is boomeranging, as the Guardian reports today in the latest installment on biodiesel "splash-and-dash." [ ] Increasingly, traders ship biodiesel from Asia or Europe to U.S. ports, where it is blended with a "splash" of regular diesel, the paper reports. That qualifies the shipment for U.S. export

---

240
"The biodiesel tax incentive was enacted in 2004 as part of the American Jobs Creation Act (P.L. 108-357). The incentive was subsequently extended through December 31, 2008 as part of the Energy Policy Act of 2005 (P.L. 109-190)."
http://www.biodiesel.org/news/taxcredit/docs/Ways&MeansCommittee_NBBTestimony_41410Hearing_TaxIncentives&GreenJobs.pdf
"In 2004, Congress passed a tax credit intended to promote the U.S. biodiesel industry. The tax credit equals a dollar for every gallon of biodiesel blended in the United States. The idea was to encourage marketers of regular diesel to mix in plant-based fuel and, thus, broaden the use of biodiesel. But a loophole has producers on both sides of the Atlantic crying foul."
http://www.npr.org/templates/story/story.php?storyId=14096723

subsidies. Then it is shipped back to Europe where it is also subsidized. European biofuels organizations talk about between $30 million and $300 million in U.S. subsidies being exported that way to Europe. The result? Biofuel's already-tarnished environmental reputation comes under more fire, because round trips across the Atlantic add unnecessary transport emissions to the mix. [ ] That's what sparked an investigation last year by the European Biodiesel Board into a practice that was an open secret among biofuel firms."[241]

Palm Oil Subsidies

The U.S. Government also provided a federal tax credit to those who mowed down tropical rainforests to grow palm oil to export to the West.

U.S. Representative Collin Peterson, Chair of the U.S. House of Representatives Agriculture Committee, made a presentation to the Hawai`i Energy Policy Forum on April 9, 2007. Henry Curtis, Life of the Land's Executive Director, asked him about the wisdom of giving federal tax credits for rainforest palm oil. He said that he opposed it, and would work to close the federal loophole. This did not occur; apparently too many special interests are receiving too much profit from this scheme.

Hawai`i state law defines biofuels to be renewable energy even if they were grown by razing tropical rainforests. In 2006 HECO signed a contract with Imperium Renewables Inc. for palm oil biodiesel. The fuel would have been grown in Malaysia, processed in Seattle, and burned in Hawai`i. The deal failed to materialize for many reasons, one of which included the financial instability of Imperium following the imposition of tariffs by the European Union for using the "splash and dash" procedure to realize U.S. subsidies.

Manipulating Hawai`i State Law and the Hawaii Clean Energy Initiative (HCEI)

The Hawaii Clean Energy Initiative (HCEI) was signed by HECO and the Consumer Advocate in October 2008 and immediately endorsed by DBEDT and the Blue Planet Foundation.

The agreement advocated permit modifications, exemption from certain regulations, financial incentives, favorable land use and employment policies, tax credits for "biofuel products including crude palm oil," government support for centralization of the transmission grid, smart meters, new transmission lines, subsidizing biofuel crops, increased biofuel production tax credits, imposing new rate recovery mechanisms (increasing electric rates), increasing corporate profits, and changing regulatory trigger limits for toxic emissions."

Other provisions called for "a preference for incentives and market-based measures over regulatory penalties" for greenhouse gas emissions, which would allow the utility to muscle into competitive markets where they are currently banned (distributed

[241] http://blogs.wsj.com/environmentalcapital/2008/04/01/us-biofuels-subsidies-not-for-farmers-but-for-europeans/?mod=WSJBlog

generation, energy efficiency), altering EPA Haze Rules regarding vog, expedited permit approval, a presumption of need for utility projects, limiting the ability of outside parties to advocate alternatives in regulatory proceedings, and requiring regulators who reject utility proposals to include an analysis of the "implications of that non-approval on the utility's asset investment and strategic choices for the upcoming three-year period."

One developer who sought to reap personal benefit from the HCEI provisions was Los Angeles billionaire David Murdoch (Castle and Cooke and Dole Foods). Following announcement that he wanted to build a 200MW wind power plant in 2007, he turned to the legislature for help. Concerned that the public might resist his scheme, he supported the introduction of HB 2863 in 2008 that included provisions exempting his Lana`i power plant from most public input. This version of the bill passed the House but died in the Senate.

Consumer Subsidies

Developing nations often subsidize consumers to control internal dissent. Calculating subsidies as the difference between the actual price and the free market price,[242] the International Energy Association (EIA) determined that countries subsidized fossil fuel consumption to the tune of $342 billion in 2007 and $557 billion in 2008.[243] Although subsidy percentages vary by country, in 2008 the percentages were: Iran (89%), Saudi Arabia (79%), Venezuela (72%), Egypt (56%), Libya (52%), Argentina (22%), Russia (22%), and China (4%). In 2008, Iran spent $101 billion on subsidizing fossil fuel prices (1/3 of the country's annual budget); the subsidy amounted to 89% of the free market price.[244]

Producer Subsidies

Free trade countries emphasize subsidized payments to producers. Bloomberg New Energy reported that the worldwide subsidy for clean energy was $43-46 billion in 2009, excluding some subsidies such as payments to farmers. The U.S. led with $18 billion in subsidies; approximately 40% of this was allotted to biofuels, and wind was the next largest recipient.[245]

The New York Times reported in early 2011 that President Obama proposes to end the $4 billion subsidy to oil companies; supports favored tax treatment for solar and wind; favors increasing research for other alternatives; and would provide up to $50 billion in loan guarantees for nuclear power plant construction.[246]

---

242 http://www.worldenergyoutlook.org/methodology_sub.asp
243 http://www.iea.org/files/energy_subsidies.pdf
244 http://www.iea.org/subsidy/index.html
245 http://www.bloomberg.com/news/2010-07-29/subsidies-for-renewables-biofuels-dwarfed-by-supports-for.html
246 http://www.nytimes.com/2011/02/01/science/earth/01subsidy.html

HECO Analysis

Traditionally the Hawaii Public Utility Commission allows a utility to recover expenses from rate payers using a "used and useful" analysis. That is, the utility can recover the cost if the component is being used and is necessary for reliable service. Complicating this approach, the PUC allows surcharges to be imposed, but they must be justified in a rate case, using the "used and useful" methodology.

In a rate case, HECO uses an accounting method called Differential Revenue Requirements (DRR). Using DRR the utility compares portfolios by looking at their total financial cost, rather than analyzing individual components of each portfolio. Within each portfolio, HECO looks at bundled costs. That is, the utility has informed Legislators that they do not look at how much transmission costs or at how much generation costs, etc. Rather they look at the combined costs of doing business. They would find it very difficult to list on ratepayer bills how much is spent on each function. As a general rule, entities who participate at the PUC and who regularly intervene in regulatory proceedings are not permitted to participate in rate cases.

Thus, for all practical purposes, relative pricing for different technologies is not publicly available. Rather, the public may be told from time to time the cost of producing electricity from various fuel sources, but this is selective information released by the utility, for the purpose of furthering specific utility goals.

Consumer Advocate Analysis

In Hawai`i, the Consumer Advocate is charged with representing consumers in rate cases. Their offices are locked, they do not interact with the public, and they do not consider taxpayer impacts or externalities. They dislike cross-examining utility witnesses, preferring to participate in "backroom" dealing. The utility and the PUC both argue that the Consumer Advocate legally represents the consumer in regulatory proceedings and therefore non-utility parties should not be permitted to intervene in most PUC proceedings.

Conclusion

It is very difficult to determine the precise costs of different technologies, although it is generally agreed that in many parts of the country the cheapest forms of renewable energy are geothermal, wind and hydroelectric. Solar is generally on the high end, but when it is placed on rooftops it does not require transmission and distribution lines, can easily be increased in size, and involves the fewest permits.

Energy costs in Hawai`i remain shrouded in mystery. Public utilities aside, it is even harder to determine the profitability of an Independent Power Producer, because it may be able to produce a specific amount of renewable based electricity, but the utility can reject (curtail) the electricity whenever it wants to. Thus a wind farm might have a capacity favor of 0.61 and yet 10% of the time the electricity being generated could be rejected by the utility.

Bottom line: even if one has access to utility numbers, they would not directly show the relative cost of adding 1MW of wind versus 1MW of geothermal.

CHAPTER 8: RENEWABLE ENERGY PENETRATION ANALYSIS

One way to measure the amount of renewable energy on the grid is in the form of a ratio:

$$\text{Renewable Energy Penetration level} = \frac{\text{Renewable Energy (R)}}{\text{Utility Sale of Electricity (E)}}$$

Therefore, if a utility sells 100 units of electricity of which ten units come from a renewable resource, the Renewable Energy Penetration level is10%:

$$\frac{\text{Renewable Electricity}}{\text{Electricity Sold by Utility}} = \frac{10}{100} = 10\%.$$

The more energy efficiency one uses, the lower the utility's sale of electricity. So if customers replace fluorescent bulbs with CFLs, install low flush toilets and solar water heaters, some of the electricity that was needed would be displaced. If a customer installs energy efficiency systems between now and 2015 that would, for example, lower demand to ninety units of electricity with ten units counted as "renewable" and ten counted as "efficiency", then the equation looks like this:

$$\frac{\text{Renewable Electricity + Energy Efficiency}}{\text{Electricity Sold by Utility}} = \frac{10 + 10}{90} = 22\%$$

Hawai`i law considers energy efficiency to be a form of renewable energy only until 2015; thereafter "efficiency" measures are discounted and the equation would change:

$$\frac{\text{Renewable Electricity}}{\text{Electricity Sold by Utility}} = \frac{10}{90} = 11\%.$$

HEAT

A fossil fuel plant typically produces two units of heat and one unit of electricity while in operation. The heat is usually not captured, but is typically discharged up and out a smokestack or out in an ocean pipe. Ironically, the utility usually wastes its heat while selling electricity to customers to generate their own heat.

So if a utility sells 10 units of heat and 100 units of electricity of which ten units come from renewable resources (the Renewable Energy Penetration level is 10%) and ninety from fossil fuels, then the Renewable Energy Penetration level is 20%:

$$\frac{\text{Renewable Electricity + Heat}}{\text{Electricity Sold by Utility}} = \frac{10 + 10}{100} = 20\%.$$

Hawai`i law is confusing in accounting for heat. Some interpretations suggest that the utility *can* count heat in the above equation, if a non commercial power producer sold the heat to the customer, but that the utility *cannot* count the heat if a commercial power producer sells electricity to the utility and heat to the customer. Even energy and utility lawyers are confused about the definitions.

Fossil Fuel

How fossil fuel inputs are dealt with is similarly variable under Hawai`i law. Assuming that a renewable energy is made from a fossil fuel, either alone or in conjunction with a renewable energy source, just as coal and oil can be used to make hydrogen, ethanol and biodiesel, if the resultant renewable energy is used to produce electricity, one way to think about the process is to say the fossil fuel input has to be counted. That is, if you use one part coal plus one part corn to make two units of ethanol, then one unit of the ethanol should count as a renewable energy. A second approach would be to say that since ethanol is renewable then all of the ethanol counts as renewable energy. Under Hawaii law, sometimes one uses the first approach (one unit is renewable), sometimes one uses the second approach (two units are renewable) depending upon the political clout of the companies involved.

Some companies find it easier and more profitable to convince the state to amend the definitions used, i.e. to redefine a corporate product as “renewable” rather than fossil-fuel derived. This permits the corporation to continue business-as-usual practices while “green-washing” its product. In fact, state law in Hawai`i was recently changed so that heat from coal plants and biofuels made from coal are now considered renewable energy. However, hydrogen made from coal is still considered a fossil fuel, perhaps due to an absence of political influence.

Since Hawai`i law has set a goal of increasing the use of renewable energy, companies are proposing that their existing products be labeled “green.” Hence terms like “clean coal” and “green biofuels” are being used to justify business-as-usual, regardless of how renewable or environmentally friendly their products are.

Source

There is a difference between buying a renewable source of power, such as solar or wind based electricity, from the utility, and having an independent power producer build, own and operate a solar or wind facility on a customer’s property.

Assume that a utility sells 100 units of electricity, of which ten units come from renewable resources; the Renewable Energy Penetration level is 10%. But if a customer asks the utility for wind-based electricity and the utility buys a wind farm and sells ten units of wind to the customer, then the utility is credited with selling a total of twenty units, the original ten plus the additional ten produced by the wind facility

On the other hand, if the customer chooses to get wind from an on-site facility produced and operated by a non-utility, the same amount of renewable energy is produced but utility sales drop. Therefore, the Renewable Energy Penetration level is:

Renewable Electricity / Electricity Sold by Utility	= 20 / **90**	= 22%.

While the amount of renewable energy consumed in the above two cases is the same, the wind produced on-site decreases utility sales with the result that the Renewable Energy Penetration level improves.

One can come up with odd results from existing state law. For example, assume that on Kaho`olawe a utility builds a 1 MW coal plant and sells the electricity to a Native Hawaiian facility. The Native Hawaiian facility also installs an on-site coal plant producing three units of electricity and six units of heat. The total energy being used on the island is ten units (1 unit of utility electricity, 3 units of on-site electricity, and 6 units of on-site heat).

The Renewable Energy Penetration level is:

Renewable Electricity (Heat) / Electricity Sold by Utility	= 6 / 1	= 600%.

So while the island has only coal, it is considered 600% renewable. Perhaps more bizarre, it is possible for the island to use sizable amounts of renewable energy but to have a Renewable Energy Penetration level that is significantly below zero.

The State has set five year goals for renewable energy penetration levels, which means that the utility should achieve a renewable energy penetration level of 10% in 2010, 15% in 2015, 25% in 2020, and 40% by 2030.

The HECO Approach

The utility (HECO) thus far has designed a renewable energy portfolio that will just squeak by the state-set renewable energy targets. And the utility is currently telling Legislators that constituents should stop shooting down other's proposals; that all renewable sources will eventually be needed; that the greatest risk is NIMBYism ("Not in My Back Yard"). DBEDT has joined this chorus by telling Legislators that all communities will be affected, some communities will have to accept geothermal facilities, some communities will have to accept biomass facilities, and some communities will have to accept rooftop solar, but it must have all of these renewables eventually.

LOL believes that this "we need it all" approach is nothing more than a smokescreen. While the utility has constructed a portfolio that will just barely meet renewable standards, the total portfolio of all available renewable options is twenty to fifty times larger than what is actually needed to meet the state's targets. It appears that the utility is not interested in what is possible, only in what it has decided it wants.

For example, a few years ago the utility came up with a theoretical upper limit to how much demand could be reduced through energy efficiency and energy displacement technology. This number was the theoretical upper limit, which would then be adjusted downwards depending on economic feasibility, reality and cost. Honolulu Sea Water Air Conditioning is currently installing pipes in downtown Honolulu that will use cold ocean water instead of electricity to cool buildings. Six to seven Sea Water Air Conditioning (SWAC) systems could be installed on O`ahu, and the amount of electricity saved by building just one SWAC facility exceeds the utility's theoretical upper limit for all energy efficiency and energy displacement technologies combined. Was that known when the utility came up with the theoretical upper limit? Yes, it was. Did that affect the numbers? No, it did not.

Similarly, HECO states that there is a maximum renewable penetration level, and that they must deploy all possible renewables to just meet the state goals. Sadly, this is nothing more than saying, "My Way or the Highway" or "There is No Alternative." Many are proposing that the utility's position is not serving the best interests of the state, taxpayers or ratepayers, and disagree with such a short-sighted approach.

Conclusion

What is needed in the state of Hawai`i are clear and uniformly applied definitions that encourage low climate impact, and culturally and environmentally friendly energy sources that minimize electric rates ($/kWh).

What we have, unfortunately, are extremely complex laws aimed at making the state and fossil fuel producers appear more "green" than is the reality: fossil-fuel based utilities continue business-as-usual making electricity from fossil fuels.

CHAPTER 9: CULTURAL IMPACTS

"Resource" is broadly defined as the natural environment, or human practices, values, and traditions and their physical manifestations. Hawaii Revised Statutes (HRS) Chapter 6E (Historic Preservation) establishes a comprehensive program of historic preservation as a means to preserve, restore, and maintain historic and cultural properties, which are more specifically defined as "any building, structure, object, district, area, or site which is more than fifty years old." (HRS Chapter 6E-2)

Unique to Hawai'i environmental review is the constitutional requirement that government agencies have an affirmative obligation to preserve and protect the reasonable exercise of customarily and traditionally exercised rights of Hawaiians to the extent feasible (Article XII, Section 7 of the Hawai'i State Constitution, *Ka Pa'akai O Ka 'Aina v. Land Use Commission*, 94 Haw. 31 (2000). Articles IX and XII of the State Constitution, other state laws, and the courts of the State require government agencies to protect and preserve cultural beliefs, practices, and resources of native Hawaiians and other ethnic groups. To assist decision makers in the protection of cultural resources, Chapter 343, HRS and HAR § 11-200, rules for the environmental impact assessment process, require project proponents to assess proposed actions for their potential impacts to cultural properties, practices, and beliefs.

This process was clarified by the Hawai'i State Legislature in Act 50, passed by the state legislature in 2000. Act 50 recognized the importance of protecting native Hawaiian cultural resources and specifically required that EISs include the disclosure of the effects of a proposed action on the cultural practices of the community and state - and in particular the native Hawaiian community. The Environmental Council specifically suggested a cultural impact assessment (CIA) should include information relating to practices and beliefs of a particular cultural or ethnic groups or groups. Such information may be obtained through public scoping, community meetings, ethnographic interviews, and oral histories.

State law further recognizes that the cultural landscapes on each of the affected islands provide living and valuable cultural resources where native Hawaiians have and continue to exercise traditional and customary practices, including but not limited to hunting, fishing, gathering, and religious practices. With this recognition comes the obligation to preserve and protect those constitutionally guaranteed rights.

The Hawai'i Supreme Court, in *Ka Pa'akai*, provided government agencies an analytical framework to ensure the protection and preservation of traditional and customary native Hawaiian rights while reasonably accommodating competing private development interests.

Ancient History

Captain James Cook's order to the crewmen on the *Resolution* and *Discovery* to drop anchor off the coast of Hawaii on January 25, 1778, set in motion the most profound transformation of Hawaiian society and environment since the arrival of the first Polynesian voyagers centuries before.

Captain Cook and his crew opened the door to the West's penetration of Hawaii's highly developed traditional society, undermining, distorting, and displacing beliefs, practices and institutions developed over the centuries. With this came critical threats both to the indigenous culture of the islands' people, and to the extraordinary natural treasures that this most isolated of island groups -- composed of eight main islands and dozens of smaller atolls, islets, reefs and shoals stretched across 1,500 miles of the Pacific -- offers to us all.

Hawaii's isolation had produced over 10,000 endemic plant, insect and animal species, more than any other area on Earth. Highly susceptible to competition and predation by non-native species, they are disappearing at an alarming rate: one tenth of Hawai`i's plants, more than half of Hawai`i's land snails, and over half of Hawai`i's native birds are now extinct.

The forest, agricultural and coastal habitats that support these species have been besieged by a tidal wave of development that has upset the delicate island ecosystem linking mountain, plain, and ocean together.

As the Kumulipo --the 2,000- line traditional Hawaiian creation chant -- recounts, the Hawaiian people and their chiefs traced their lineage back through all of the creatures of the Earth, sea and sky -- back to "when space turned over, the sky reversed, when the sun appeared standing in shadows -- to the gods themselves."[263] Ancient Hawaiians believed that because the land, sea and everything in them were created by the gods, they must be cared for; care of the land and care of the people were both sacred obligations.

This was a culture of abundance, not scarcity: no matter how much or how little was available, observed Poka Laenui of the Institute for the Advancement of Hawaiian Affairs, "in the sharing there will be enough for all."[264] But abundance also carried strict responsibilities: of respect, caring for, and feeding the food supply.

Concepts of private land ownership were unknown, although the land was an extremely valuable part of life. The word for land ('aina), derived from the word meaning "to eat," and has a much deeper meaning than mere "property." The Hawaiian people thought of themselves as coming from the land: maka`ainana, or "the people who were born from the land" was the name for the common people.

The word 'aina also refers to a person's knowledge and spiritual strength: modern Hawaiian residents call themselves "kama`ainas", which can mean "insider" or "one who understands", and can even refer to the fish commonly found in Hawaiian fishponds.

By the time Cook arrived, the Hawaiian people had developed a capacity to maintain a population of half a million to a million people, which at its peak matched that of contemporary Hawaii. This highly complex society was based on what we now

---

263 http://www.soulwork.net/huna_articles/kumulipo_chant.htm

264 An Introduction to Some Hawaiian Perspectives on the Environment Collected & Presented By Poka Laenui Director, Institute for the Advancement of Hawaiian Affairs. Presented to the Multi-Cultural Center, California State University- Sacramento. Indigenous Peoples and their Relationship to the Environment. October 11, 1993

understand was a system of sustainable land and water management. The key to this system is the ahupua'a, a pie-shaped section of land that reaches from a point at the top of an island's mountain to a broad fan-shaped base along the shore, and then to the reefs. The *Native Hawaiian Rights Handbook* describes an ahupua'a as a self-sufficient unit, providing the people "a fishery residence at the warm seaside, together with the products of the high land, such as canoe timber, mountain birds, and the right of way to the same, and all the varied products of the intermediate land as might be suitable to the soil and climate of the different altitudes from sea side to mountainside or top."[265]

Hawaiians spoke an oral language before being "discovered" but by the 19th century they could boast having one of the highest literacy rates in the world. Dozens of Hawaiian newspapers proliferated and many works were translated into Hawaiian. A hundred treaties were signed with other countries. Public transit began in 1868, and Iolani Palace had hot and cold running water, copper-lined tubs, a dumbwaiter and electricity (preceding the White House in D.C. by four years).

But during the first century after being "discovered," the native population fell from 1,000,000 to 50,000. Hula was discouraged by missionaries and their puritanical beliefs. From 1896-1986 English-only laws resulted in the Hawaiian language being banned in all public and private schools, although it has been continuously taught at the University of Hawaii since 1921. According to the 1990 U.S. Census native speakers numbered fewer than 8,900.

In 1978 the State Constitution was amended to create the Office of Hawaiian Affairs, secure water resources as a public trust resource (which would result in creation of the State Water Code), and designate the Hawaii language as an official language of Hawaii.

The year 1993 saw not only the 100th year anniversary of the Overthrow and subsequent annexation of Hawai`i by the U.S. but a huge protest as well.

"From 1993 to 1998, an amazing shift began to take place among those claiming ownership of *na mea Hawai`i*, things Hawaiian. [ ] A charter school, the first of a number of charter schools that focused on Hawaiian ways of learning, opened on the island of Hawai`i. [ ] University researchers and students of Hawaiian language and history created a surge of in-depth research into Hawaiian Kingdom history and laws. Students began to access information specific to Hawaii Kingdom law and historical documents of all kinds at the State Archives, public libraries, the Richardson School of Law at the University of Hawai`i, and other archival centers. Genealogical research flourished.

During this time, one of the Great Petitions of 1897 surfaced, changing the emotional and political tenor of the movement, and creating for many a personal connection to the turbulent times of the Queen’s reign. Activists on all islands began a movement toward land-occupation, primarily in rural areas and on neighbor islands. Throughout activist circles in and outside of Hawai`i, a number of social justice organizations

---

[265] Native Hawaiian Rights Handbook by Melody Kapilialoha Mackenzie, May 1991,Univ of Hawaii Press

turned their support to the various Hawaiian issues in the sovereignty movement, creating in effect a movement of allies."[266]

The foreign impact to Native Hawaiians is described by Jon Osorio: "[David] Stannard's estimate of a pre-haole population of 800,000[267] is a projection, of course, and has been challenged as extravagant. But even that challenger postulated that a reasonable estimate would have been closer to 500,000, meaning that the depopulation at the end of the nineteenth century would have been 92 percent rather than 95 percent."[268]

As Noenoe Silva recounts: "In 1998, for example, an ad hoc committee of community members, of which I was part, approached the Bishop Museum in Honolulu with an idea to educate the public about the 1897 annexation petition, which during the course of this research I had located in the U.S. National Archives. In response, the Bishop Museum agreed to display a reproduction of all 556 pages of the petition. Because of the publicity generated by the museum to promote the exhibit, the Kanaka Maoli community throughout the islands suddenly knew of the existence of mass opposition to annexation in 1897."[269]

"One of the most persistent and pernicious myths of Hawaiian history is that the Kanaka Maoli (Native Hawaiians) passively accepted the erosion of their culture and the loss of their nation." Dr. Noenoe Silva's book refutes the myth of passivity through documentation and study of the many forms of resistance by the Kanaka Maoli to political, economic, linguistic, and cultural oppression, beginning with the arrival of Captain Cook until the struggle over the "annexation," that is, the military occupation of Hawai`i by the United States in 1898. The main basis for this study is the large archive of Kanaka writing contained in the microfilmed copies of over seventy-five newspapers in the Hawaiian language produced between 1834 and 1948. "[A]ny of the Hawaiian newspapers are political in nature. [ ] Beginning in the mid-nineteenth century, the Hawaiian language was disparaged as inadequate to the task of 'progress'."[270]

Recent History

Despite state constitutional protections, development in Hawaii historically has proceeded without consideration of the direct and cumulative impacts from projects on traditional native Hawaiian practices and customs. The environmental review process governed by state and federal law rarely includes any discussion of how native Hawaiian cultural practices and the natural resources upon which they depend might be affected. The result is the degradation of natural resources traditionally used in native Hawaiian practices, devastating physical alteration and destruction of historically significant areas, and obstruction of access to cultural and religious sites.

Hawaiians are near the bottom in socio-economic indexes; many Hawaiians are homeless in their own homeland. The rising Sovereignty Movement includes both

---

[266] Identity in the Hawaiian Sovereignty Movement 1990-2003. UH Doctoral Dissertation. Lynette Hi`ilani Cruz, 2003. http://scholarspace.manoa.hawaii.edu/bitstream/10125/705/1/uhm_phd_4287_r.pdf
[267] http://www2.hawaii.edu/~johnb/micro/m130/readings/stannard.html
[268] Dismembering lāhui: a history of the Hawaiian nation to 1887 By Jon Kamakawiwo'ole Osorio
[269] Aloha betrayed: native Hawaiian resistance to American colonialism. By Noenoe K. Silva, 2004
[270] Ibid.

scholars (who are unearthing treasures in archival records), and activists, who are transforming the future. By the mid to late 1990s a multi-year struggle bore fruit in a requirement that Environmental Impact Statements include a Cultural Impact Analysis.

However, contemporary notions of watershed and ecosystem management have shown a renewed interest in the traditional ahupua'a concept; without, sadly, the benefit of the tight integration of organization of the land and water into a cultural, political and social life understood by ancient Hawaiians to sustain the life of the people.

We can begin to restore Hawaii's natural wonders, and breathe new life into it by building upon the ahupua'a concept, and using it as both a practical and symbolic approach to the environmental challenges we face.

CHAPTER 10: SOCIAL JUSTICE

Overview

The Environmental Movement arose in the late 1960's among the middle class haole community in Hawai`i to address a growing number of environmental issues.

The Environmental Justice movement was launched in the early 1980's in response to a recognition that most undesirable polluting industries were occurring in minority populated and economically challenged areas. Unwanted land uses ("LULUs") were increasingly being located in economically challenged communities largely populated by minority groups, and in Hawai`i such undesirable industries as power plants, landfills, and chemical facilities were being concentrated in the Waianae area.

Multinational corporations involved in tropical biofuel production tend to seek control of "virgin" land by displacing indigenous communities and employing migrant workers. Few worker protections and rights are offered, and often undocumented immigrants are used.

The following testimony, provided by Trisha Kehaulani Watson for Life of the Land in the Hawaii Public Utilities regulatory proceeding, addressed HECO's proposed 2009 Campbell Industrial Park Biofuel Generator:

"The environmental justice movement began in 1982, when a group of residents in Warren County, North Carolina, who opposed the development of a toxic waste landfill in their community collectively acted to prevent the construction of the site by lying in the middle of the street in front of construction vehicles. This delightful show of non-violent resistance, reminiscent of the passive resistance that took place during the civil rights movement, became an inspiration for an assault against the siting of locally unwanted land uses in low-income and minority communities across the country.

The Warren County incident led to a series of studies into the siting of treatment facilities across the country. The results were startling. The first study, conducted by the United States General Accounting Office ("GAO") in 1983, showed a strong correlation between the ethnic and economic composition of communities in the South and the placement of hazardous waste landfills. Then in 1987, the United Church of Christ's ("UCC") Commission for Racial Justice released a follow-up study that showed race as the more significant factor in the correlation between race, income and the siting of hazardous waste landfills.

The most startling finding of the UCC's study was the discovery that 3/5 of all African-Americans and Hispanic-Americas live near a toxic waste site. After the UCC study, the National Law Journal conducted its own study on the Environmental Protection Agency ("EPA") that showed that the EPA took considerably longer to respond to the environmental needs of low-income and minority communities than to comparable white communities.

The Warren County incident also inspired other communities to ban together to resist the siting of unwanted treatment facilities in communities already over-burdened by existing *power plants, treatment facilities and landfills. The result has been a considerable grassroots uprising against environmental racism and environmental injustice.*

The 1982 Warren County incident simply brought national exposure to a problem that existed long before the nation became aware of it. In 1971, the Council on Environmental Quality acknowledged in their annual report that race and income affected a community's ability to control and better their surrounding environment. In 1979, the first "environmental justice" case had been brought in Texas. In Bean v. Southwest Waste Management[271], town members fought the siting of a landfill in the community. The plaintiffs argued that the state and city were illegally and discriminately placing the landfill in their community, which was mostly African-American and already overburdened with LULUs. The court rejected this argument and denied the petitioners' injunction. While Bean would later become known as the first environmental justice suit in the United States, the case would remain relatively unnoticed until the Warren County incident a few years later.

President Clinton's Executive Order No. 12898 not only addressed the problem of environmental justice in the United States but also directed federal agencies to create strategies for dealing with environmental justice and to take environmental justice concerns into consideration when making agency decisions.

The academic scholarship on environmental justice continues to push for greater emphasis of the plights of minority groups other than African-Americans and Latinos, but it's a hard sell. The bottom line is that most victims of environmental racism are African-American and Latino. This "bottom line" has developed into a consensus that falsely supports the position that environmental justice is about all-Black or all-Latino communities with a number of toxic landfills in their community. The result has been that the legal battles and remedies have focused on these communities to the detriment of other marginalized racial communities who suffer from equally harmful land uses yet receive no attention and no assistance. Like many other cases in which the mainstream minorities have marginalized other ethnic minorities by contributing to a monolithic picture of race in America, environmental justice, in the rare instances in which it occurs for minority groups, seems available only to African-Americans and occasionally Latinos. This poses a serious problem for Native groups whose civil rights issues often differ considerably from the legal problems facing other racial or political communities.

There is little disputing that Hawai'i's racial composition and cultural history creates a markedly different cultural atmosphere than that of the United States mainland. Hawai'i was an independent nation until 1898 at which time the United States forcibly overthrew the reigning monarchy. Most Native Hawaiians saw their ancestral lands stolen by American merchants backed by the American government's political and military force. These same Native Hawaiians were subsequently forced off these lands[272] and subjected to years of cultural and legal oppression by the American government. In addition to its unique cultural and political history, unlike throughout the rest of the United States, there is no racial majority in Hawai'i; most of the residents of Hawai'i are ethnic minorities. This preempts traditional environmental justice claims for most Hawai'i residents. Therefore, any claims brought in Hawai'i would have to be

---

[271] Bean v. Southwest Waste Management Corporation, 482 F. Supp. 673 (S.D. Tex. 1979)
[272] Michael Kioni Dudley and Keoni Kealoha Agard, A Call for Hawaiian Sovereignty,1990

brought under laws other than Title VI or the equal protection clause. The Hawai'i State Constitution is currently the only law under which environmental justice claims could be brought in Hawai'i.

The Hawai'i State Constitution contains a seemingly impressive provision entitling all the residents of Hawai'i to the right to a healthy environment. Article IX of the Hawai'i State Constitution ensures every citizen the right to a "healthful environment." This right to a healthy environment is protected under the Hawai'i State Constitution. Article XI, Section 9 reads as follows:

'Each person has the right to a clean and healthful environment, as defined by laws relating to environmental quality, including control of pollution and conservation, protection and enhancement of natural resources. Any person may enforce this right against any party, public or private, through appropriate legal proceedings, subject to reasonable limitations and regulation as provided by law.'

The language of this section creates a self-executing constitutional provision, which also provides standing for any citizen who takes legal action to enforce this right. In this regard, the Hawai'i Constitution has created legal rights for its citizens not available in many other states. Unfortunately, efforts to enforce this right have yielded mixed results. This provision is often cited in law review articles as progressive. Unfortunately, this right can hardly be considered substantive. There is no evidence to demonstrate that the state has ever taken any action to define what it means to have a constitutional right to a healthy environment or that it actively protects this right. Not all the courts in Hawai'i have been willing to afford plaintiffs this state constitutional right.

Hawaii environmental claims in federal district courts.

Environmental claims have found no success in Hawai'i's federal district courts, where a traditional environmental justice would generally be brought.[273]

Fortunately, the State of Hawai'i's high court has not followed the federal courts' lead in refusing to acknowledge the rights established in Article XI of the Hawai'i State Constitution. As discussed later, this difference may be reason for potential environmental justice plaintiffs to be hopeful about the viability of their claims in Hawai'i courts.[274]

---

[273] In two cases, Stop H-3 Association v. Lewis (Stop H-3 Association v. Lewis, 538 F. Supp. 149 (D. Haw. 1982), rev'd on other grounds, 740 F.2d 1442 (9th Cir. 1984), cert. denied, 471 U.S. 1108 (1985)) and Fiedler v. Clark (Fielder v. Clark, 714 F.2d 77 (9th Cir. 1983)) federal district courts refused to extend Article XI rights to the plaintiffs in those cases.

[274] In Life of the Land v. Land Use Commission of the State of Hawai'i (Life of the Land v. Land Use Commission of the State of Hawaii 623 P.2d 431 (Haw. 1981)), Richard v. Metcalf (Richard v. Metcalf, 921 P.2d 169 (Haw. 1996)) and Kahuna Sunset Owners Association v. Maui County Council (Kahuna Sunset Owners Association v. Maui County Council, 948 P.2d 122 (Haw. 1997)), the Supreme Court of the State of Hawai'i has found that Hawai'i residents do in fact have the right to enforce the right conferred in Article XI of the Hawai'i State Constitution.

<u>*Environmental Justice statute*</u>

Hawai'i has no "environmental justice" statute. Therefore, Hawai'i residents have no statutory right to a healthy environment and no party or entity is required by state law to consider "environmental justice" issues when making land use decisions. The problem with having a constitutional right but no statutory right is that constitutional rights, although substantial because they are conferred by the constitution, are often vague and therefore difficult to enforce in court, as is the case with Hawai'i's constitutional guarantee to a "healthful environment."

Statutory rights are generally more specific as to the rights they ensure, either through the statutory language itself or through the legislative history. The lack of statutory language presents a considerable problem for victims of environmental injustice in that it provides state agencies and county councils a means of circumventing environmental justice considerations when making land use decisions. A few states have experimented with environmental justice statutes (All states have laws regarding environmental standards and procedures. They are generally given this authority under federal statutes and are regulated by the Environmental Protection Agency ("EPA"). Although 'state statutes often contain stricter procedural requirements and provide for greater involvement by affected communities when compared to federal laws,[275]' very few have taken affirmative legislative steps to address environmental justice issues.), allowing parties to obtain relief under state law instead of state constitutions or federal environmental statues. Arkansas, Florida, Tennessee and Virginia have all passed environmental justice statutes within the last ten years.

This is not to insinuate that developers and agencies have no obligation to local communities regarding the environmental impact of their actions. Under the Hawai'i Revised Statutes ("HRS"), agencies are required to determine the significance of all projects undertaken by state and city agencies. Under Section 11-200-12, "agencies shall consider the sum of effects on the quality of the environment." Section (b) provides additional guidance as to determining if action is in fact "significant": "action shall be determined to have a significant effect on the environment if it ...(4) [s]ubstantially affects the economic or social welfare of the community or State." While this language is broad, it has to date not been interpreted to include consideration of environmental justice issues (i.e., any disproportionate impact upon low-income and/or racially targeted communities). Hawai'i's environmental laws therefore fall short of the initiatives taken by some other states to relieve some of the burdens placed upon low-income communities by the siting of LULUs.

For example, the relevant Arkansas statute states: 'The General Assembly also acknowledges that, while solid waste management facilities are essential, certain types of facilities impose specific burdens on the host community. National trends indicate a tendency to concentrate high impact solid waste disposal facilities in lower-income or minority communities. Such facilities may place an onerous burden on the host community without any reciprocal benefits to local residents. The purpose of this

[275] Valerie P. Mahoney, "Environmental Justice: From Partial Victories to Complete Solutions," 21 Cardozo L. Rev. 361, 376 (1999)

subchapter is to prevent communities from becoming involuntary hosts to a proliferation of high impact solid waste management facilities'[276].

To make this law substantive, Section 8-6-1504 of the Arkansas environmental justice law creates a rebuttable presumption against the siting of "any high impact solid waste management facility" within twelve miles of any other such facility. This statute is particularly effective because it does not require a claimant to show any racial or class discrimination; it only requires a plaintiff to show that one facility will be or has been placed within twelve miles of a similar facility. It completely circumvents the burdensome discriminatory intent requirement discussed in the previous chapter, thus making it easier for communities to bring environmental injustice claims in state court and successfully have hazardous facilities placed elsewhere. Such a law is bold and unique, and clearly without a counterpart in the City and County of Honolulu.

Despite the lack of protective measures available in Hawai'i, residents are theoretically not completely without legal safeguards. While limited, there are potential legal remedies available for communities discriminatorily burdened by the placement of undesirable land uses, although they have yet to be employed by local residents in an "environmental justice" claim. As previously stated, the Hawai'i Constitution grants its residents "the right to a clean and healthful environment." (Hawai'i Constitution, Article IX, Section 9). The constitution also includes language concerning standing (i.e., the right to bring a claim before a court), therefore parties have more latitude in this state than in others in regards to what they can bring a claim for. Further, as stated, the Hawai'i Supreme Court has already addressed the issue of standing under this provision of the state constitution and found that plaintiffs need only state a claim in the "interest of justice" in order to have standing.

Therefore, considering the broad interpretation of standing available in Hawai'i, environmental justice litigation claims, despite the lack of environmental justice litigation to date, retain substantial potential to address any discriminatory land use patterns in this state. And considering the growing social concern over the land use siting decisions occurring on the Leeward Coast of the Island of O'ahu, the environmental right conferred under Article IX of the Hawai'i State Constitution has yet to be tested in an environmental justice claim.

<u>The Leeward Coast</u>

The Leeward Coast includes the island from Waipahu to Ewa Beach and Barbers Points on the south point of the Island of O'ahu and from Waipahu to Kaena Point on the west point on the island. The statistics of the Leeward Coast are startling. The lack of legal protection has arguably seen the disproportionate siting of undesirable land uses on the Leeward Coast of O'ahu. Located on the Leeward Coast of O'ahu are the following undesirable land uses: six power plants (of seven located on the island), two major wastewater treatment facilities (of eight located on the island), and all three active landfills on the island, one of which is currently set for expansion. There are two slaughterhouses in this area, as well as a considerable amount of noise nuisance from the Honolulu International Airport.

---

[276] Arkansas Code Annotated §8-6-1501

There are a total of eighteen sewage treatment plants, active landfills and power plants on the island of O'ahu. Eleven of those facilities are located in the Ewa District on the Leeward Coast. Correlate the siting of these eleven facilities with the racial composition of these communities and it becomes clear that there is a suspicious correlation between the over-representation of low-income ethnic groups and LULUs on the Leeward Coast. And now the Hawaiian Electric Company ("HECO") wants to place yet another power plant on this already over-burdened community.

Traditional Paradigm

Residents on the Leeward Coast do not fall into the traditional paradigm of persons injured by environmental injustice. They are not predominately African American or even predominantly Latino. They are, however, predominately poor.[277]

Therefore, the comparatively simplistic correlation between race, wealth and power that exists on the mainland simply does not apply to Hawai'i. While Anglo-Americans control a great deal of the land and power in Hawai'i, they are not the only ethnicity to disproportionately control wealth and power in Hawai'i. Along with Anglo-Americans, the Japanese similarly retain a significant amount of political and economic power in Hawai'i.[278]

Hawai'i's unique immigration history led to the establishment of a pluralistic society many years before multiethnic communities began to crop up on the Continent. By the middle of the 20th century, the Japanese were beginning to gain control over land, wealth and power in Hawai'i. This control still exists today, resulting in environmental injustice that is better explained by the segregation by wealth, power and race, instead of only race. When one analyzes the distribution of wealth and income in Hawai'i, it is the Japanese and Caucasian populations whose average income exceeds Hawai'i's median income.[279] *And law simply does not provide relief for the victims of discrimination in a society that has no "minority" race or to a "minority" group victimized by another "minority" group, as discussed later in this chapter.*

Federal Guidelines

Federal law makes assumptions about race that do not apply to Hawai'i's multiethnic population. Therefore, it is unlikely that the environmental injustice that continues on the Leeward Coast will receive legal support for resistance in the near future, despite considerable public opposition. Residents are keenly aware of the problem occurring in their community, even if it seems that no one has yet to use the phrase "environmental injustice." One fairly recent example of the public's awareness of environmental injustice was the public outrage over the proposal to expand the Waimanalo Gulch Landfill, which

---

[277] For a review of the district's average wealth and income statistics, see Assessment Resource Center Hawai'i, "School Status and Improvement Report: Leeward District," available at http://arch.k12.hi.us/school/ssir/2001/leeward.html
[278] See generally, George Copper and Gavan Daws, Land and Power in Hawai'i (1990).
[279] Jeffrey L. Crane and Alton M. Okinaka, "Social Dynamics of the Aloha State: The Population of Hawai'i," in Politics and Public Policy in Hawai'i (Zachary A. Smith and Richard C. Pratt ed., 1980)

demonstrated the city's intent to continue to place LULUs on the Leeward Coast despite social and environmental concerns.[280]

Built as a replacement for the Kailua landfill, which reached capacity and closed in 1992, the idea of siting the Waimanalo Gulch landfill was originally sold to the community as a temporary site that would not remain in operation past 2002. This past year, the city proposed to expand Waimanalo Gulch and leave it open until 2006.

Immediately, the surrounding community opposed the idea. There have already been complaints that the landfill's emission of ash and dust into the air caused the suspicious rise in the number of children suffering from debilitating and chronic asthma in the surrounding communities.[281] *Residents were concerned that leaving the landfill open and expanding it would only lead to further health problems from residents in nearby communities. At a community meeting held to address public concern, the city confirmed that despite the fact that forty-two sites were originally considered for housing a new landfill, only three options remained: expand the existing site, or build a new site at one of two alternate locations. Both alternate locations were located in the Ewa District on the Leeward Coast.*[282]

Rectifying the Past

Under Life of the Land's proposed plan, intermittent renewable energy resources (photovoltaic, wind) facilities would only be built on rooftops and in open areas and only in areas where there was full acceptance by all sectors of the society. Baseload energy facilities would be built three to four miles off the coastline.

Current fossil fuel generators, which now are placed in mostly industrial areas and in minority populated and economically challenged communities, would be removed and replaced with parks, open space, and community centers.

The Kahe Generation facility would be an ideal place for a telecommuting facility where residents from Waianae could work, connected to downtown businesses through high speed internet facilities. Locating business in a clean environment closer to home will strengthen communities and allow parents more time for their children instead of spending inordinate amounts of time commuting.

---

[280] O'ahu Landfill Community Discussion Group, Meeting Notes, available at http://www.opala.org/TECH/WaimanaloGultchMeetingNotes2-20-01.pdf (last visited April 20, 2002)
[281] James Gonser, "Asthma Cases Blamed on Landfill," Honolulu Advertiser, available at http://the.honoluluadvertiser.com/article/2001/Oct/07/ln/ln19a.html (last visited April 20, 2002).
[282] O'ahu Landfill Community Discussion Group, Meeting Notes, available at www.opala.org/TECH/WaimanaloGultchMeetingNotes2-20-01.pdf (last visited April 20, 2002)

CHAPTER 11: KANALOA

Tangaroa (Takaroa) is the Māori god of the sea. Tangaroa is a son of Ranginui (Sky Father) and Papatuanuku (Earth Mother), and grandfather of Ikatere (the ancestor of fish) and Tu-te-wehiwehi or Tu-te-wanawana (the ancestor of reptiles).

Kanaloa was the Tahitian creator of the universe and man.

In Hawai`i, Kanaloa is god of the ocean and all within. He is the god of seamen and fishermen.

The kinolau (body form) of Kanaloa includes the whale, porpoise, shark, turtle, stingray, and the manta ray.

Charles Kauluwehi Maxwell Sr. said of Kanaloa, "The whale is the largest ocean form, and a majestic manifestation of Kanaloa. From the ivory of this creature, the highly prized niho palaoa was worn by the Ali`i (Chiefs) of high rank. The scarcity and beauty of the niho lei palaoa and its connection to Kanaloa brought mana (spiritual power) to the carver, to the pendant itself, and eventually to the wearer of the pendant."[283]

Dr. Pualani Kanaka`ole Kanahele said, "The first mention of the fish form in the Kumulipo is that of another of Kanaloa's great forms, the nai`a or porpoise. The nai`a is again a visual reminder of Kanaloa and his benevolent, nimble and playful characteristics. The second ocean form cited is the shark. The niuhi or white shark was also a kinolau or body form of Kanaloa."[284]

"The eight tentacles of the he'e [octopus] when stretched out exhibit the eight compass points, the eight directions of the air and ocean currents, the rays of the sun. The compass points, wind and ocean currents are all elements critical for [] navigation. Therefore, the relationship between Kanaloa, the he`e, the wind and ocean currents, the compass points and navigation are all one and the same."[285]

"The island of Kanaloa has the image of a whale or porpoise floating on the water. ...The island ...was endowed with the name of the god whose image it bore."[286]
Ola i ke kai a Kanaloa ("to live in the sea of Kanaloa"), ke akua o ka he'e ("god of the octopus.")

Christian missionaries expelled Kanaloa from heaven and made him the Devil.

---

[283] THE KOHOLA IN HAWAI`I: Humpback Whales and the Hawaiian By Charles Kauluwehi Maxwell Sr.
[284] Kukulu Ke Ea A Kanaloa: The Cultural Plan for Kanaloa Kaho`olawe. by Dr. Pualani Kanaka`ole Kanahele, Edith Kanaka`ole Foundation (February 1, 2009) http://www.sacredland.org/PDFs/Kukulu%20Ke%20Ea%20A%20Kanaloa.pdf, p80
[285] Ibid. page 84.
[286] Ibid. page 90.

BIBLIOGRAPHY: WEB BASED OTEC SOURCE MATERIAL

Bellinger, Reb. Expert Testimony, PUC Docket 2005-0145.
http://www.lifeofthelandhawaii.org/Proposed-2009-plant/Bellinger.pdf

Coastal Response Research Center, University of New Hampshire, and NOAA: "Technical Readiness of OTEC". (2009)
http://www.crrc.unh.edu/workshops/otec_technology_09/otec1_final_report_full.pdf

Coastal Response Research Center, University of New Hampshire, and NOAA: "Ocean Thermal Energy Conversion: Assessing Physical, Chemical and Biological Impacts and Risks" (2010)
http://www.crrc.unh.edu/workshops/otec_2/OTECII_effects_withappendix.pdf

Coastal Response Research Center, University of New Hampshire, and NOAA, "Ocean Thermal Energy Conversion (OTEC) Workshop: Assessing Potential Physical, Chemical and Biological Impacts and Risks. A Primer" (2010)
http://www.crrc.unh.edu/workshops/otec_2/a_primer_v3.pdf

Cohen, Dr. Robert "Energy from the Ocean" Philosophical Transactions of the Royal Society, London A 307, 405-437 (1982)
http://www.offinf.com/CohenEnergyFromOcean.pdf

Curtis, Henry, Ililani Media Videos: Interview with Dr. Ted Johnson, Director, Alternative Energy Programs Development for Lockheed Martin's MS2 Undersea Systems. http://www.vimeo.com/12568409

Curtis, Henry, Ililani Media Videos: Interview with Dr. Hans Krock, OCEES International**,** http://www.vimeo.com/12369586

Curtis, Henry, Ililani Media Videos: Interview with Dr. David Rezachek
http://www.vimeo.com/12387494

Curtis, Henry, Ililani Media Videos: Interview with Dr Luis Vega (former head of the OTEC project at NELHA), Reb Bellinger (Makai Ocean Engineering, a local company heavily involved in sea water air conditioning and OTEC), and David Robichaux, an energy consultant. http://www.vimeo.com/12723004

Eskom: Energy Management "Desert-ocean thermal energy conversion" (2008)
http://www.erc.uct.ac.za/emnews/EMN-08-03.pdf

Finney, Karen Anne, University of Guelph, Guelph, Ontario, N1G 2W1, Canada "Ocean Thermal Energy Conversion", Guelph Engineering Journal, (1), 17 - 23. ISSN: 1916-1107. ©2008 http://www.soe.uoguelph.ca/webfiles/gej/articles/GEJ_001-017-023_Finney_Ocean_Thermal_Energy.pdf

Gatdula, Donnabelle L., The Philippine Star (October 26, 2009) "US-Pinoy group to build 1st ocean power facility in RP" http://www.philstar.com/Article.aspx?articleid=517489

Gill, A.T., Energy Analyst, State of Hawaii Department of Business, Economic Development and Tourism, and Richard E. Rocheleau, Director, University of Hawaii at Manoa, Hawaii Natural Energy Institute, "Advances in Hawaii's Ocean Energy RD&D" http://www.see.ed.ac.uk/~shs/Wave%20Energy/EWTEC%202009/EWTEC%202009%20(D)/papers/273.pdf

Hawaiian Electric Company, Ocean Energy Development Guidelines (July 2007) http://hawaii.gov/dcca/dca/web_references/other_sites/ocean-energy-development-guidelines-final-word.pdf

Johnson, Mansur "Shamcher: A Memoir of Bryn Beorse & His Struggle to Introduce Ocean Energy to the United States" 1991 & 2006 Editions http://shamcher.files.wordpress.com/2008/10/mansurshamchermemoir.pdf

Krock Ph.D., Hans, Expert Testimony, PUC Docket 2005-0145. http://www.lifeofthelandhawaii.org/Proposed-2009-plant/Krock.pdf

Lai, Cheng I, Researcher, STPI, NARL. "The Input Analysis of Ocean Thermal Energy Conversion R&D Projects in Taiwan" http://thinktank.stpi.org.tw/English/Columns/Pages/Column_EN_8.aspx

Landmesser, C.W., Dr. H.E. Sheets and R.H. Richmond "Symposium on Ocean Thermal Energy Conversion (OTEC)" United Nations Economic and Social Commission for Asia and the Pacific, Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas. Proceedings of ECOR/IOC - CCOP/SOPAC (1976) http://dev.sopac.org.fj/VirLib/CR0006.pdf

Magesh, R. (Coastal Energen Pvt. Ltd., Chennai, Tamilnadu, India) "OTEC Technology- A World of Clean Energy and Water" Proceedings of the World Congress on Engineering 2010 Vol II (WCE 2010), June 30 - July 2, 2010, London, U.K. http://www.iaeng.org/publication/WCE2010/WCE2010_pp1618-1623.pdf

Makai Ocean Engineering "Deep Pipelines for Ocean Thermal Energy Conversion" http://www.makai.com/p-otec.htm

Martí, José A; Thomas J. Plocek; Manuel A.J. Laboy, Offshore Infrastructure Associates, Inc. "Commercial Implementation of Ocean Thermal Energy Conversion (OTEC): Social and Economic **Implications for Puerto Rico,"** Presentation to COHEMIS**,** International Conference on Green Communities**,** UPR Mayaguez Campus (2008) http://green.uprm.edu/pres/pres_Marti&Plocek.pdf

Myers, Edward P. et al, U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS); "NOAA Technical Report" NMFS 40 (1986): http://spo.nwr.noaa.gov/tr40opt.pdf

Nicholson, III, Robert J. "Public Comment by Sea Solar Power International, LLC.", U.S. Commission on Ocean Policy Meeting. Washington, D.C., January 24, 2003 http://www.oceancommission.gov/publicomment/janmtg/nicholson_comment.pdf

Nihous, Gérard C. UH Department of Ocean and Resources Engineering. "Mapping available Ocean Thermal Energy Conversion resources around the main Hawaiian Islands with state-of-the-art tools" Journal of Renewable and Sustainable Energy 2, 043104 (2010); doi:10.1063/1.3463051 (9 pages) http://jrse.aip.org/jrsebh/v2/i4/p043104_s1

Piersol, Mike Offshore Ports LLC, "Executive Summary for Kona Co-Op 100 Megawatt Ocean Thermal Energy Conversion (OTEC) Project" http://www.lifeofthelandhawaii.org/doc2/Offshore_Ports_Kona_OTEC.pdf

Plocek, T.J. and M. Laboy, Offshore Infrastructure Associates; J.A. Martí, Technical Consulting Group, "Ocean Thermal Energy Conversion (OTEC): Technical Viability, Cost Projections and Development Strategies" (2009) http://www.offinf.com/OIA_at_OTC.pdf

Rapier, Robert. "OTEC: http://robertrapier.wordpress.com/2008/08/23/ocean-thermal-energy-conversion/

Rezachek Ph.D., David. Expert Testimony, PUC Docket 2005-0145. http://www.lifeofthelandhawaii.org/Proposed-2009-plant/Rezachek.pdf

Swathi A., P.Srivalli Sneha, Prasad V. Potluri Siddhartha Institute of Technology, Affiliated to JNTU, Hyderabad. “Ocean Thermal Energy Conversion: A seminar report” by http://www.seminarprojects.com/Thread-ocean-thermal-energy-conversion?pid=27252#pid27252

Takeda, Brian, Department of Urban and Regional Planning, University of Hawaii. “Ocean Thermal Energy Conversion at Kahe Point: An Attempt at Community Dialogue” (November 1986). Program on Conflict Resolution (PCR), Matsunaga Institute for Peace, University of Hawai`i at Manoa. Prepared for the Hawaii Natural Energy Institute (HNEI) and the State of Hawaii Department of Planning and Economic Development (DPED). Working Paper Series: 1987-03 http://www.peaceinstitute.hawaii.edu/2-site-media/6-pdf-downloads/5-papers/Ocean-Thermal-Energy-Conversion-at-Kahe-Point.pdf

Takahashi, Patrick, "On the Blue Revolution: The Coming of OTEC" Huffington Post (November 21, 2008) **http://www.huffingtonpost.com/patrick-takahashi/the-coming-of-otec_b_145634.html**

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Ocean Minerals and Energy “Ocean Thermal Energy Conversion: Final Environmental Impact Statement (July 1981) http://coastalmanagement.noaa.gov/otec/docs/otec_feis1981.pdf

Uchida, Richard N. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, “Summary of Pertinent Biological Characteristics of Potential Ocean Thermal Energy Conversion (OTEC) Sites in the Pacific Ocean” (August 1983) http://www.pifsc.noaa.gov/adminrpts/1983/SWFC_Admin_Report_83-13.pdf

Van Ryzin, Joe. “Design of OTEC Heat Exchanger Test Facility”, Makai Ocean Engineering; http://www.hitdv.com/TechEnterprise_2009/HTDV%20Company%20Presentations/07.%20HTDV.MakaiOceanEngineering.Ryzin.pdf

Vega, Luis A, National Marine Renewable Energy Center at the University of Hawaii and Dominic Michaelis, Energy Island Ltd. UK. “First Generation 50 MW OTEC Plantship for the Production of Electricity and Desalinated Water” OTC 20957 Copyright 2010, Offshore Technology Conference. This paper was prepared for presentation at the 2010 Offshore Technology Conference held in Houston, Texas, USA, 3–6 May 2010. http://www.energyisland.com/assets/06_press/LVDM_50MWOTECPS.pdf

Vega, Luis “Ocean Thermal Energy Conversion (OTEC)” http://www.otecnews.org/articles/vega/01_background.html

APPENDIX 1: HISTORY OF OTEC

Jules Verne

The 19th century author, Jules Verne, came up with the idea of ocean thermal energy conversion (OTEC). The first documented reference to the use of ocean temperature differences to produce electricity is found in Jules Verne's "Twenty Thousand Leagues Under the Sea" published in 1870.

Jacques Arsene D'Arsonval

Eleven years after Jules Verne, Jacques Arsene D'Arsonval proposed to use the relatively warm (24 °C to 30 °C) surface water of the tropical oceans to vaporize pressurized ammonia through a heat exchanger (i.e., evaporator) and use the resulting vapor to drive a turbine-generator. The cold ocean water transported (upwelled) to the surface from 800 m to 1000 m depths, with temperatures ranging from 8 °C to 4 °C, would condense the ammonia vapor through another heat exchanger (i.e., condenser). His concept is grounded in the thermodynamic Rankine cycle used to study steam (vapor) power plants. Because the ammonia circulates in a closed loop, this concept has been named closed-cycle OTEC (CC-OTEC).

Georges Claude

Forty years after D'Arsonval, Georges Claude, another French inventor, proposed to use the ocean water as the working fluid. In Claude's cycle the surface water is flash-evaporated in a vacuum chamber. The resulting low-pressure steam is used to drive a turbine-generator and the relatively colder deep seawater is used to condense the steam after it has passed through the turbine. This cycle can, therefore, be configured to produce desalinated water as well as electricity. Claude's cycle is also referred to as open-cycle OTEC (OC-OTEC) because the working fluid flows once through the system.

Cuba (1930)

Georges Claude demonstrated this cycle in Cuba (Claude, 1930) with a small land-based plant making use of a direct contact condenser. It has been reported by NOAA that "the facility produced a net 22 kilowatts electrical (kWe) for 11 days before the facility was destroyed in a storm"[295] and reported by Dr. Vega that "the plant failed to achieve net power production because of a poor site selection (e.g., thermal resource) and a mismatch of the power and seawater systems. However, the plant did operate for several weeks."[296]

[295] Technical Readiness of OTEC, p.6
[296] Ocean Thermal Energy Conversion (OTEC) by L. A. Vega, Ph.D., Hawaii, USA. http://www.otecnews.org/articles/vega/01_background.html

Brazil (1930s)

Claude, subsequently, designed a 2.2 MW floating plant for the production of up to 2000 tons of ice (this was prior to the wide availability of household refrigerators) for the city of Rio de Janeiro. Claude housed his power plant in a plantship about 100 km offshore. Unfortunately, he failed in his numerous attempts to install the vertical long pipe required to transport deep cold ocean water to the ship and had to abandon his enterprise in 1935. His failure can be attributed to the absence of the offshore industry, and ocean engineering expertise that is presently available.

Ivory Coast (1956)

French scientists designed a 3-megawatt OTEC plant for Abidjan, Ivory Coast, West Africa. The plant was never completed because of cost considerations.

US (1950s)

"In 1950's Norwegian-American engineer Bryn Beorse and Professor Everett D. Howe founded the Sea Water Conversion Laboratory at University of California and obtained government funds for research. An open-cycle plant was proposed for water desalination, but government was not receptive."[297]

US (1962-73)

"In 1962 Hilbert Anderson and his son James H. Anderson, Jr. began full scale design analysis of OTEC systems. Soon after, in 1970, they were joined by William E. Heronemus from the University of Massachusetts along with Clarence Zener of Carnegie-Mellon University ...Their research was funded by the National Science Foundation through a grant awarded in 1972 to the University of Massachusetts in order to allow for a complete study of the technical and economic feasibility of the OTEC process. Another grant soon followed awarded again by the National Science Foundation in 1973 to the Carnegie-Mellon University to further investigate other elements of OTEC systems. ...Unfortunately their efforts were wasted as the energy board paid little attention to their published findings assuming that coal and nuclear power would supply the future energy requirements."[298]

"In September 1973, during President Nixon's "Operation Energy Independence", I [Robert Cohen] left my scientific career at NOAA/Boulder in favor of becoming the first ocean energy program manager within the budding U.S. federal solar energy R&D program, then headquartered at NSF/RANN. Ocean energy R&D was later moved to DOE. The initial federal ocean energy R&D program was mainly focused on OTEC technology, in view of that technology's potentially large energy payoff. Indeed,

---

297 Presentation to COHEMIS, International Conference on Green Communities, UPR Mayaguez Campus (June 17, 2008) José A. Martí, Thomas J. Plocek, Manuel A.J. Laboy, Offshore Infrastructure Associates, Inc.

298 Ocean Thermal Energy Conversion, Karen Anne Finney, University of Guelph, Guelph, Ontario, N1G 2W1, Canada, Guelph Engineering Journal, (1), 17 - 23. ISSN: 1916-1107. ©2008 http://www.soe.uoguelph.ca/webfiles/gej/articles/GEJ_001-017-023_Finney_Ocean_Thermal_Energy.pdf

assuming that OTEC-derived ammonia or other OTEC-derived energy carriers become competitively viable, OTEC technology could provide the largest payoff of any renewable energy source.
Soon after arriving at NSF, I initiated an RFP seeking an objective evaluation by industry of OTEC's viability, to get their take on what four groups of OTEC advocates (three of which were in academia) were saying about OTEC. That RFP led to our funding two parallel, buffered studies, which were conducted by Lockheed and TRW starting in 1974. Both studies independently reached favorable conclusions as to the prospects for the technical and economic viability of commercial OTEC plants."[299]

Japan (1974-78)

"OTEC study in Japan began in 1974 with the launch of the Sunshine Project by the Japanese government. The primary focus of this project was to research and develop Ocean Thermal Energy Conversion systems. In 1977, Saga University successfully constructed an OTEC plant known as Shiranui 3, which managed to produce 1 kW of energy. Experiments were carried out in 1978 in order to test the performance of the condenser and evaporator in both shell and tube type heat exchangers. In the following year, a plate type heat exchanger was also tested using a different type of Freon as the working fluid."[300]

"Saga University succeeded with 1 kW experimental plant [1977]"[301] "In 1977, a 750W experimental electrical plant was implemented in the Electro technical Laboratory. Using Freon 114 as the working fluid, the necessary data for the design of a commercial OTEC plant was obtained."[302]

Hawai`i (1975)

Hawai`i, in partnership with TRW, submitted an OTEC proposal to the U.S. Energy Research and Development Administration (ERDA). ERDA was subsequently restructured as the Department of Energy (DOE).

Hawai`i (1978-81)

The State of Hawaii, through its 1978 Hawaii State Plan, mandated ocean energy research and development.

---

299 Robert Rapier's Blog. http://robertrapier.wordpress.com/2008/08/23/ocean-thermal-energy-conversion/
300 Ocean Thermal Energy Conversion, Karen Anne Finney, University of Guelph, Guelph, Ontario, N1G 2W1, Canada, Guelph Engineering Journal, (1), 17 - 23. ISSN: 1916-1107. ©2008 http://www.soe.uoguelph.ca/webfiles/gej/articles/GEJ_001-017-023_Finney_Ocean_Thermal_Energy.pdf
301 http://www.xenesys.com/english/otec/history.html
302 Development and Prospective of Ocean Thermal Energy Conversion and Spray Flash Evaporator Desalination by Haruo UEHARA (Faculty of Science and Engineering, Saga University, Japan) and Tsutomu NAKAOKA (Department of Ocean Mechanical Engineering, National Fisheries University, Simonoseki City, Yamaguchi, Japan) http://www.ioes.saga-u.ac.jp/VWF/general-review_e.html The document refernces T. Kajikawa et. al., Proc., 5th OTEC Conf., V164, (1978)

In 1979 the State of Hawaii Ad Hoc Committee for the Advancement of OTEC for Hawaii was formed in anticipation of future DOE OTEC projects. The Committee was headed by the Hawaiian Electric Company (HECO) and the Dillingham Corporation. Supporting committee members included the University of Hawaii, the Office of the Marine Affairs Coordinator, and the State Department of Planning and Economic Development (DPED). By 1980 the committee decides the best site for OTEC is offshore from HECO's Kahe Point power plant on Oahu.

In 1981 (September to December) the State of Hawaii installed a deep cold-water pipeline and pumping facilities at NELH laboratory at Keahole Point, on the island of Hawaii. NELH was the only facility in the world which can conduct research with deep cold ocean water.

Westinghouse (1979)

A study by the Westinghouse Electric Corporation (1979) indicated that Claude cycle turbines could be designed at reasonable cost by incorporating turbine-blade technology resulting from experience in the aerospace industry with helicopters and wind machines.

Mini-OTEC (1979)

In 1979 D'Arsonval's concept was successfully demonstrated when the state of Hawaii and a consortium of U.S. companies produced more than 50 kW of gross power, with a net output of up to 18 kW from a small plant mounted on a barge off Hawaii The next major milestone came in 1979 when a project dubbed "mini-OTEC" was launched, and marked the first successful operation of a closed-cycled OTEC facility. Mini-OTEC produced a net 15 kWe for three months before its planned shutdown, and was widely considered a success. In 1980 – 1981 the experimental OTEC-1 facility was tested.

Taiwan (1979)

"Taiwan is so adjacent to the "Warm Pool", the highest temperature marine in the world, that Taiwan possesses geological superiority for tapping OTEC energy. In 1979, the University of Hawaii conducted an investigation and then concluded that eastern Taiwan marine was the optimal site for exploiting OTEC energy in the whole world."[303]

Natural Energy Laboratory of Hawaii (NELH) (1979)[304]

The Natural Energy Laboratory of Hawaii was established by Act 236 of the 1974 State Legislature for the purpose of conducting research and developing alternate energy resources such as solar energy, ocean thermal energy conversion, and biomass conversion. Act 236 also provided that the Laboratory be located in the area under consideration because of the availability of cold deep ocean water; a warm ocean

[303] The Input Analysis of Ocean Thermal Energy Conversion R&D Projects in Taiwan. Cheng I Lai / Researcher, STPI, NARL
http://thinktank.stpi.org.tw/English/Columns/Pages/Column_EN_8.aspx
[304] Hawai`i Land Use Commission, Docket A78-448, Decision and Order (July 12, 1979). http://luc.state.hi.us/cohawaii/a78-448dlnr_dot.pdf

surface layer, not subjected to strong seasonal cooling; high annual solar radiation; and adequate quantities of undeveloped land suitable for mariculture and aquatic bioconversion. Natural Energy Laboratory of Hawaii will be acting as a landlord for the subject property and be responsible for providing the access road and basic utilities (electricity, sewer, water and telephone) to various interested research organizations utilizing the area for their projects.

The three major natural energy research programs being considered for the site are as follows: (a} Ocean Thermal Energy Conversion: This project proposes to install a plant that would utilize the thermal difference between the surface and deep ocean waters to generate electrical power. (b) Biomass Conversion (Aquaculture): This project would utilize the cultivation and harvesting of plant and animal forms either as a food source or for thermal conversion of the material to produce energy. (c) Solar: This project proposes to test various direct solar energy systems that will be developed in the future.

The subject property is presently being used by the Natural Energy Laboratory of Hawaii under a Conservation District Use Permit to conduct alternate energy research projects and has been graded to some extent to accommodate its existing facilities.

The property and facilities surrounding the subject property include the unmanned Ke-ahole Point lighthouse, Ke—ahole Airport and barren lava fields.

Life of the Land, Hawai`i (1980)

"Hawaii is the best place in the United States to build an OTEC site. ...It is imperative that OTEC be considered as an important step to Hawaii's goal of energy and economic self-sufficiency.

However, there are important environmental concerns such as: the effects of thermal stress which would be introduced into the immediate area; the effect of additional nutrients to coastal waters (creating the possibility of biostimulation of marine life due to increased levels of food sources); and water quality standards as related to temperature and nutrient changes.

Another environmental concern is ammonia leakage into the ocean due to corrosion in the heat exchange system. One way to assure that this does not happen is to design the plant with a rotating maintenance schedule; in other words, to allow for a portion of the plant to be shut down for maintenance and still maintain optimum capacity of the plant.

Observation of existing data and conclusions show that with further studies and research, OTEC can become environmentally acceptable as an energy alternative for Hawaii. ...It has been shown that three commercial OTEC plants could produce enough energy for all of Hawaii."[305]

---

[305] Alternative Energy: OTEC by Jan Takeyama, LOL Staff Member, Life of the Land Newsletter (March-April, 1980)

U.S. Legislation (1980-81)

Two legislative acts were passed by Congress to facilitate the commercial development of OTEC: The Ocean Thermal Energy Conversion Research, Development, and Demonstration Act (1980); and the Ocean Thermal Energy Conversion Act of 1980. The purpose of the OTEC Research, Development, and Demonstration Act (P.L. 96-310) is to accelerate OTEC technology development; the designated lead agency is the U.S. Department of Energy. The purpose of the OTEC Act of 1980 (P.L. 96-320) was to create a legal regime that would facilitate the commercialization of OTEC in a manner compatible with the protection of the marine environment and other marine resources; the lead agency is the National Oceanic and Atmospheric Administration.

Under its responsibilities of the OTEC Act of 1980, NOAA has issued regulations for licensing commercial OTEC plants, an environmental impact statement on the licensing of commercial plants, a technical guidance document on the environmental requirements of the regulations, and a research plan for assessing environmental effects that may accompany the commercialization of OTEC.

Hawaii Hearings (1980)

US Senate, Committee on Commerce, Science, and Transportation, Hearings re S. 2492 Ocean Thermal Conversion Act of 1980. Held in Honolulu, Hawaii. April 10 & May 1, 1980. Senator Daniel Inouye, Chair.

To regulate commerce, promote energy self-sufficiency, and protect the environment, by establishing procedures for the location, construction, and operation of Ocean Thermal Energy Conversion facilities and plantships to produce electricity and energy-intensive products of the coasts of the United States; to amend the Merchant Marine Act, 1036, to make available certain financial assistance for construction and operation of such facilities and plantships; and for other purposes.

Senator Inouye

“Although estimates of potential output from OTEC plants vary, experts suggest that the process could be commercially operational for island baseloads by the mid-1980's. ...Clearly OTEC offers real promise of holding down or even reducing costs of electricity in Hawaii and elsewhere. ...I believe that OTEC has immense potential as an alternative, clean, and renewable source of energy. It promises to be a technology capable of fulfilling a significant percentage of our energy needs in the next 20 years.”

Hideto Kono, Director of the Department of Planning and Economic Development representing Governor George Ariyoshi

“The development of ocean thermal energy conversion — OTEC — is of great importance to the State of Hawaii. ...We are aware of the many advantages which OTEC has to offer. ...It appears at present that OTEC plants will have no major negative environmental impacts. While there are problems to be solved, no major technological breakthroughs are necessary for commercialization. Floating OTEC plants can be moved from place to place, thus providing flexibility in meeting our future energy needs. Floating OTEC plants conserve our land, a limited and precious resource. We in Hawaii are committed to the development of OTEC."

<u>John Shupe, Dean of the School of Engineering, University of Hawai`i at Manoa; Chair the Governor's Advisory Committee of Alternate Energy Development.</u>

"Hawaii initiated research and development programs on its indigenous energy resources, including OTEC, early in the 1970s, well before the Middle East oil embargo and resulting energy shortfall. ...Our first major OTEC proposal submitted to the Energy Research and Development Administration (ERDA) in August of 1975, was in partnership with TRW. This proposal was a precursor to Hawaii's Seacoast Test Facility, and had it been funded in 1975 would have shortened the lead time required to develop OTEC technology by 3 years.

Mini-OTEC was a joint venture of the State of Hawaii with Dillingham, Lockheed, and other industrial concerns. The encouragement provided to the private sector by including the incentives and provisions of the Merchant Marine Act of 1936 to floating OTEC plants should help assure the continuing participation and leadership from industry in making OTEC work. ...OTEC is the renewable energy resource with probably the highest potential for providing massive amounts of baseload power to energy deficient nations throughout the tropical and semitropical areas."

<u>Dr. John Craven, of Marine Programs at the University of Hawaii at Manoa</u>

"OTEC plants constructed with today's technology should be economically competitive with electrical energy generated by nuclear power or fossil fuel. Even as these calculations were made, the results of mini-OTEC demonstrated conclusively that the calculations are conservative. The ratio of net power to total power in mini-OTEC was far beyond our most optimistic expectation. The implications of these very recent analytical and experimental results are thus enormous; for if electrical energy produced by OTEC is economically competitive by conservative economic calculations — that is, by calculations which amortize the plant in less than 20 years — then OTEC is an energy resource of world significance.

Following on that theme, four phases can be identified: First, the generation of electricity for use by coastal and island communities; second, the relocation of energy-intensive industry to OTEC sites; third, the production of hydrogen and ammonia for use as fuel: hydrogen as a fuel for commercial aircraft, and ammonia as a fuel for major power grids relying on the ammonia fuel cell; and finally, the substitution of ammonia as the best synthetic fuel replacement for gasoline and alcohol in internal combustion engines."

<u>Dr. Doak Cox, UH Environmental Center</u>

"I think there's little doubt that in the net the social environmental impacts will be considered beneficial, and probably overwhelmingly so. And from the evidence available to date, it does not seem that among the physical impacts there will be any major unreduceable detriments. With respect to the latter, I wish to point out that it is important to assess the physical impacts, not in terms of their magnitude, but in terms of their humanistic implications. And this should be recognized in determining what physical environmental standards should be applied to OTEC regulations.

The water drawn from depth in the ocean, as Dean Craven has pointed out, is not only cold but nutrient rich. The nutrients are conventionally regarded as pollutants in our Environmental Management program. The convention is appropriate in some environments, but we should not let it determine our decisions regarding nutrient transfers permissible in OTEC operations.

The offshore waters in most parts of the ocean are nutrient-deficient and increases in rates of production of the organisms on which fish live, and hence the fish themselves, will result in nutrient increases through transfer from depth.

In summary: First, from an environmental standpoint, the promotion of OTEC R. & D. and of eventual commercial OTEC that would be provided through S. 2492 is very appropriate; second, investigations of the potential environmental impacts of OTEC operations have already been undertaken in connection with R. & D. efforts, and further investigations of the impacts may be anticipated and should be encouraged in future R. & D. efforts; and third, environmental standards applied in the regulation of OTEC operations should reflect humanistic evaluations pertinent to the environments of the operations."

Pat Shutt, president of the League of Women Voters of Hawaii.

"The League of Women Voters has a position supporting research and development of all types of alternate energy sources, and we therefore support continued research and development of OTEC.

It is our opinion that OTEC should become one of a mix of natural energy sources necessary to decrease Hawaii's dependence on imported oil. Hawaii is an ideal location for continued research into ocean thermal energy conversion for two major reasons: No. 1, deep ocean water is available near the shore; number two, the year-round mild climate insures a good temperature difference between the deep, cold water and the warmer surface water. OTEC's potential for continual availability upon demand, as opposed to solar and wind which produce intermittent energy, makes OTEC desirable for direct hookup with the utilities.

Environmental protection is of great concern to the League, and we are pleased to see that this bill addresses the environmental impact of any proposed facility. We would also like to emphasize the need for consistency with the Coasted Zone Management Act

The bill should allow the Governor to deny licenses which he feels are not consistent with the State Coasted Zone Management pro-gram, pending an appropriate Federal action to override his denial. It is not clear whether the bill permits this."

Dennis Callan, Board Member, Life of the Land

"Life of the Land is grateful that Congress, led by our Senators, is facilitating this energy alternative with the Ocean Thermal Conversion Act of 1980. We not only support the bill, we want it to move along at maximum speed. Just in the last few months we have seen the energy crisis explode into a massive international political emergency, which will probably get much worse as the entire Middle East gets drawn into a long-term revolution. The only effective way that we can fight back is to develop our alternative energy supplies.

Hawaii is more affected by this situation than any other State. We have the most extreme dependence on petroleum, since the common alternatives of coal and nuclear are not practiced in Hawaii, which is lucky for us, since they both produce many environmental poisons. At the same time in Hawaii we have the greatest potential in — and, excuse me if I sound like the earlier speakers, but we all seem to agree — the greatest potential for the new wave of energy alternatives. ...

Our environmental organization has been helping to educate the public on the need for alternate energy since our founding in 1970. An example of this is a major article in our current newsletter which explains in some detail what OTEC is and how it can benefit Hawaii. ...

At any rate the environmental safeguards written into the OTEC Act of 1980 appear to deal adequately with this situation, particularly since an environmental impact statement will be required along with continual monitoring. In short, we feel the total benefits far outweigh any possible environmental problems, and even those small problems can likely be turned into benefits. Considering this, it is extremely unlikely that Life of the Land would ever take any action to discourage OTEC production in Hawaii. On the contrary, we hope this will develop as soon as possible."

Chamber of Commerce, Hawaii

"OTEC as an alternative energy source has been tested successfully using current technology. It is not a futuristic dream. Its translation from the successful research stage to commercial application is feasible today. ...The ability to move quickly into this new area of energy production will accelerate the development of sophistication in this new industry. Such a benefit cannot be overstated, for the sooner this technology becomes refined to a marketable level, the sooner OTEC plantships can be built and exported to under-developed countries throughout the Pacific and elsewhere, thus providing significant alternative energy sources for nations whose geographic situation permits the production of OTEC power."

Richard E. Bell, VP, Hawaiian Electric Company

"I am the vice president-engineering of Hawaiian Electric Co., Inc. I am also chairman of the OTEC coordinating committee, which is composed of members from private industry, the scientific community and the State government, and is organized to encourage the development in Hawaii of OTEC systems. The views expressed in my testimony will reflect Hawaiian Electric Co.'s interest and concern for reliable and economic development of sources of alternative energy in Hawaii; accordingly, my views will not conflict with those held by the OTEC coordinating committee.

OTEC development is at a very early stage. It will be several years before one could expect to find an OTEC plant included as an item in Hawaiian Electric Co.'s capital construction budget. I point this out by way of explaining that the measures included in S. 2492 that will encourage or enable OTEC plant construction will not be useful to Hawaiian Electric Co. for several years to come. ...Clearly, then, we aren't depending on OTEC alone to produce our future energy requirements. However, we see in a successful and timely OTEC development the opportunity to purchase firm power in quantities that can fit remarkably well with our future requirement. But, if OTEC is to produce some of our future energy requirements, it has a long way to go; and this bill, if enacted, will hasten and assure this progress."

U.S. (1980)

Office of Technology Assessment[306] (OTA) Recent Developments in Ocean Thermal Energy (April 1980)

This Technical Memorandum was prepared in response to a request from the Chairman of the Subcommittee on Energy Development and Applications of House Committee on Science and Technology. The Committee requested that the Office of Technology Assessment provide an update of its study of Ocean Thermal Energy Conversion (OTEC), which was published in May 1978.

This Technical Memorandum reviews the status of OTEC technology developments as of April 1980.

The federal Department of Energy is sponsoring a major effort to develop the OTEC system as a future source of energy. Much additional work has been done on OTEC since OTA's original report

OTA's 1978 report noted that no one had undertaken total assessment of the ocean's thermal resources and their relationship to the amount and kind of energy needed in specific locations. It did not appear that a commercialization strategy for OTEC could be developed without, having more detailed information and analysis of the potential thermal energy resource.

Since that report, it does not appear that DOE has completed even a preliminary assessment of this kind which could be used in their own planning and commercialization of OTEC power systems.

It has been estimated that over 20 million square miles of suitable ocean area exists worldwide for OTEC sites. The DOE estimates the upper extractable limit of this renewable resource as 200 quads (1015 Btu) per year. (One quad per year of electrical output is roughly equivalent to11,000 megawatts operating 100% of the time). The magnitude of the thermal resource available to the United States for exploitation has been estimated by DOE to be tens of quads per year. These resource numbers have not

[306] OTA was an office of the United States Congress from 1972 to 1995.

been documented by DOE; it has not identified the sites for each estimate; and it has not stated the assumptions used in making these estimates.

...OTEC seems well-suited to the U.S. island market because the cost of alternative incremental generation capacity is so high for islands.

...The OTA report in 1978 detailed the history and background of the development of the OTEC concept. As stated in 978, no technological or scientific breakthroughs are needed for OTEC to become a commercial reality.

However, there are still formidable engineering development challenges in getting from the present state of development to many, large economically competitive commercially operating systems.

Two basic uses have been proposed: baseload electrical generation and the power supply for manufacture of an energy-intensive product such as ammonia. These have been the most thoroughly examined of the potential OTEC uses. There are conceptual designs of systems for both applications which have changed only slightly since 1978 Regardless of the design and end use, each OTEC would require an ocean platform, a heat exchanger and a cold water pipe.*

If the system were to provide electricity to a busbar, it would require underwater transmission lines and a mooring system. An OTEC used to produce a product such as ammonia would probably have a propulsion system enabling it to move from site to site, thus capitalizing on areas where the greatest differences of temperature exist between water at the surface and at the cold water pipe inlet. A large commercial system would be of about 400 megawatt capacity.

The present program is directed primarily at developing the technology which could be incorporated into future possible commercial systems.

Within a logical technology development process, the construction and operation of a pilot plant would be very desirable to fully test a total system design under seagoing conditions. Only after a pilot plant test program is well underway can any accurate estimates of long term commercial, economic and technical feasibility be established. Unfortunately for such systems as OTEC, even a pilot plant program is likely to be very costly.

OTEC technology has been developed to the stage where a moderately sized (10-40 MW) pilot plant can probably be designed and constructed. The most significant technical risks are in the areas of cold water pipes, heat exchangers and electrical transmission cables. ...

Platforms

Of the various OTEC components, the platform represents relatively few technological problems. The platform for a 100-400 MW commercial OTEC power plant is approximately the same size as very large oil drilling platforms.

The building material can be reinforced concrete or steel; such platforms have been built in a number of industrial countries. Thus, the size and design of the platform does not represent new concepts or technology.

However, long-life and survivability represent factors which require additional attention. The station-keeping and mooring will require specific data and designs for a site. A system for mooring large commercial plants in deep water is beyond the state-of-the-art and engineering development maybe required. Numerous engineering studies of platforms and moorings have been completed over the past few years; however, except for Mini-OTEC and OTEC-1 testbeds, none have been constructed.

Cold Water Pipe

The fabrication, deployment, and connection of the cold water pipe to the platform will require a substantial engineering effort. For the Mini-OTEC plant, the 24 inch polyethylene cold water pipe performed satisfactorily. It can also be expected that for

OTEC pilot plants, in the 10 to 40 megawatt range, the cold water pipe may not be a insurmountable problem. However, for large plants (400 MW) where the cold water pipe can be approximately 100 feet in diameter and up to 3000 feet long, it will be considerably more difficult to design and build a pipe which can be subjected to movements in all three axial directions and in rotation about several axes. A substantial amount of work is presently being undertaken for cold water pipe design and analysis. Several configurations and materials have been proposed as feasible candidates. However, long lifetime requirements and survivability are presenting uncertainties for the large pipes.

Dynamic loadings on the pipe due to wave action and stresses due to platform motions are recognized as problems affecting pipe design. At this time, rigid materials such as reinforced concrete and steel are being analyzed together with more compliant materials such as a variety of plastics with reinforcements and possibly nylon- reinforced rubber. It is also quite possible that the design of the cold water pipe will be location-dependent, similar to the cooling water discharge pipes from the condensers of existing central station power plants. Considerable physical oceanographic data will be required to optimize the location of the OTEC plant to determine the best cold water pipe design, once a successful design for the cold water pipe has been established, there will be a need for production engineering and the establishment of manufacturing facilities for the cold water pipe.

Pipe materials will be an important consideration and their selection may be affected by size and volume. Advanced handling procedures will be needed for the large cold water pipes. It will be important to undertake ocean testing of the cold water pipe.

Heat Exchanger

The heat exchanger for the closed cycle OTEC plant represents the most important component because of its size, weight, and cost. A variety of designs have been proposed and tested. Some of these units are of the shell and tube type with the sea water inside the tubes and the evaporating ammonia on the shell side. Various types of heat transfer enhancement techniques, such as flutes to promote local turbulence, have *been analyzed and tested on both the water and ammonia sides of tubular heat exchangers.*

Plate heat exchangers have also been tested with ammonia side enhancement. As a result of the many analytical and experimental data which have been accumulated during the last two years, substantial progress has been made. An OTEC heat exchanger with a total heat transfer coefficient of about 1000 can be expected in a modern heat exchanger design.

This type of design would have no system to enhance heat transfer on the water side so that it can be easily cleaned for fouling purposes. This total heat transfer coefficient is about two to three times the value attainable two or three years ago. If the heat exchanger has no enhancement on the waterside there is no increase in pumping power. It can be expected that the same high heat transfer coefficient will be achieved with the plate and fin type heat exchanger. The experimental confirmation of the high heat transfer coefficient performance is a significant advancement in heat exchanger technology. If a chemical fouling countermeasure is used, then additional enhancement on the waterside can be used, possibly further increasing the overall heat transfer coefficient.

At this time, titanium promises the greatest reliability for an OTEC heat exchanger. Stainless steel and aluminum offer opportunities for less expensive heat exchanger materials and also result in lower fabrication cost. However, additional studies and experimentation are needed for these materials to guarantee the same reliability and long life as titanium when subjected to the anti-fouling countermeasures. Other working fluids besides ammonia have been suggested. These include various combinations of hydrocarbons and freons. For these fluids copper-nickel could be used in the heat exchanger and thus the problems of fouling and corrosion would be substantially reduced.

Some basic work on additional fluids may be justified so that large potential changes in performance are not overlooked. Plastic heat exchangers have been suggested. Such units may offer the potential of lower cost. However it may take several years for these new materials to meet all the tests for endurance overall, considerable progress has been made in heat exchanger design and performance. Its technical performance can now be estimated with greater confidence than before. Long-range development of a lower cost heat exchanger material will be desirable. Additional tests to optimize cleaning methods will be needed to minimize the cost of cleaning while meeting performance and environmental requirements.

Power System Components

The power turbine is a component which has received only limited attention. This appears justified in view of such major problems as heat exchanger design and fouling. However, the power turbine with ammonia as a working fluid in the sizes contemplated for a commercial plant has never been built. Since the heat of evaporation for ammonia and the enthalpy drop through the turbine are considerably less than those of existing steam power turbines, there may be a need to study turbine stability as well as turbine control. In addition, it may be desirable to study the effects of ammonia leaks on the entire power plant system.

Pumps may require special attention because they will deliver large amounts of salt water against a relatively low head. It has been proposed to have two or more of these pumps operating in parallel. Such high specific speed pumps may be difficult to operate satisfactorily in parallel unless they are provided with a special control system. The pumps and their power requirements critically affect a total power demand to start the OTEC plant. Considerable attention must be given to the starting requirements of the OTEC plant and the associated power supply. ...

Technologically , this cable must be considered as two distinct parts: the ocean floor cable that runs from shore to the OTEC site and the riser cable that connects the OTEC plant to the ocean floor cable. The ocean floor portion will require fewer technological advances as compared to the riser cable. Deeper depth operating capability than present experience (1000 m to 1500 m as compared to 550 m) will probably be achieved for the ocean floor cable without major difficulty.

The technological advances required however for developing a long life riser cable are considered to be significant. The riser cable will be subject to continual accelerations induced by the platform motion in response to the sea as well as its own response to ocean conditions. These accelerations, pressures differentials, and specific weight and other physical differences of the various elements of the riser can result in early failure of the insulation. The development of reliable splicing techniques for connecting the riser to the ocean floor cable and for repairs will also require development and extensive life testing. A further complexity will be introduced for transmission lines that are over 50 miles long (most Gulf of Mexico sites fall within this category).

These transmission lines will probably have to be designed for very high voltage DC rather than AC to minimize power losses. This will affect the selection of insulations as well as the internal cable construction. In view of the foregoing, it will be necessary that the cable design take into account system aspects such as expected sea conditions, ... OTEC-1 includes a cold water pipe, pumps, and an ammonia evaporation/ condensation loop. The cold water pipe consists of a bundle of three 48 inch diameter polyethylene pipes each 2100 feet long with a steel cable running through to a weight on the bottom.

The first heat exchangers to be tested on OTEC-1 are one megawatt, conventional titanium shell-and-tube designs for evaporation and for condensing furnished by TRW under contract to DOE.

Each is about 50 feet long by 10 feet in diameter and contains 6,000 tubes. ... The actual expenditures for the design and conversion of OTEC 1 are now projected to be about $7 million more than the original budgeted amount of $33 million. This was caused by a number of factors including difficulties encountered after the mothballed tanker was carefully inspected to see which systems needed replacement. Such an overun is not unusual in large engineering development projects and it might be expected that future overuns could occur when the much more difficult OTEC technology development and testing work is undertaken. ...

A somewhat different approach to OTEC plant design has been suggested by Sea Solar Power, Inc. of York, Pennsylvania. They have concentrated R&D attention on a system using a halocarbon instead of ammonia as a working fluid and incorporating their *patented high performance heat exchanger. They have built and tested a small working model and have prepared a conceptual design for a 100 megawatt plant. Much of their work has been funded internally. Some of their concepts deserve development attention in future OTEC designs because breakthroughs in heat exchangers could be the most significant factor for future economic viability.*

OTEC EIS (1981)

NOAA publishes Draft EIS (February 1, 1981) and Final EIS for OTEC (July, 1981)[307]

India (1980-84)

"Conceptual studies on OTEC plants for Kavaratti (Lakshadweep islands), in the Andaman-Nicobar Islands and off the Tamil Nadu coast at Kulasekharapatnam were initiated in 1980. In 1984 a preliminary design for a 1 MW (gross) closed Rankine Cycle floating plant was prepared by the Indian Institute of Technology in Madras at the request of the Ministry of Non-Conventional Energy Resources."[308]

Japan (1980-89)

"Off-shore experiment by Saga University took place off coast of Shimane prefecture in Japan. [1980] Tokyo Electric Co., and its subsidiary undertook successful experiment of a 120 kW OTEC in the Republic of Nauru. [1981] Kyushu Electric Co., of Japan succeeded with their 50kW OTEC in Tokunoshima Island. [1982] A 75 kW experimental OTEC plant was installed at Saga University. [1985]"[309]

"In 1977, a 750W (ETL-OTEC-II) experimental electrical plant was implemented in the Electro technical Laboratory (Japan). Using Freon 114 as the working fluid, the necessary data for the design of a commercial OTEC plant was obtained."[310]

"In 1981, Tokyo Electric Company et al. constructed and studied a plant with electricity output of 100kW in Republic of Nauru. This plant employed with Freon 22 as the working fluid and obtained 120kW in maximum output power."[311]

---

[307] http://coastalmanagement.noaa.gov/programs/media/otec1981feis.pdf
[308] OCEAN THERMAL ENERGY CONVERSION: A seminar report by A.Swathi P.Srivalli Sneha, PRASAD.V. POTLURI SIDDHARTHA INSTITUTE OF TECHNOLOGY, Affiliated to JNTU, Hyderabad. http://www.seminarprojects.com/Thread-ocean-thermal-energy-conversion?pid=27252#pid27252

[309] http://www.xenesys.com/english/otec/history.html
[310] Development and Prospective of Ocean Thermal Energy Conversion and Spray Flash Evaporator Desalination by Haruo UEHARA (Faculty of Science and Engineering, Saga University, Japan) and Tsutomu NAKAOKA (Department of Ocean Mechanical Engineering, National Fisheries University, Simonoseki City, Yamaguchi, Japan) http://www.ioes.saga-u.ac.jp/VWF/general-review_e.html The document refernces T. Kajikawa et. al., Proc., 5th OTEC Conf., V164, (1978)

[311] Development and Prospective of Ocean Thermal Energy Conversion and Spray Flash Evaporator Desalination by Haruo UEHARA and Tsutomu NAKAOKA. The document refernces H. Setani, Shigen, 19, (1980) [in Japanese]

“In 1982, Tokunoshima plant was constructed by Kyushu Electric Company [23]. The closed loop cycle was used and electricity was generated utilizing the waste heat of diesel engine where the electricity output was 50kW.”[312]

“In 1989, an OTEC plant was constructed and experiments were carried out in the sea of Toyama bay.”[313]

Rankine & Kalina Generators (1981)[314]

In 1981 a new method for using the temperature differences in the ocean to produce power was proposed. This was known as the Kalina cycle after its inventor Dr. Kalina. Up until 1981 the primary focus of study had been on the well-known Rankine cycle. The Kalina cycle was able to use a mixture of ammonia and water to operate, which gave it an advantage over the Rankine cycle that requires a pure substance (such as ammonia)

U.S. DOE / Hawai`i (1981-85)

In September, 1981 as provided under PL 96-310, the DOE announced a Program Opportunity Notice (PON) for the design, construction, deployment, and operation of a closed-cycle OTEC pilot plant.

Three proposals were submitted for Hawaii. In 1982, the DOE decided on two contractors proposing OTEC plants off Kahe, O`ahu: General Electric (with an OTEC facility to be located 1.6 km offshore) and Ocean Thermal Corporation (with an OTEC facility to be located 180 m offshore). Both proposed facilities were to be sited off Kahe Point, Oahu, with a transmission line to the HECO Kahe Point power grid.

The OTC proposal was in initially to be located on an artificial island approximately 180 m offshore connected to land with a rubble causeway; this was modified to 550 m offshore connected to land by a concrete trestle.

In 1983 DOE decided to defund the project in 1985. In 1984 OTC conducted community meetings. See Brian Takeda “Ocean Thermal Energy Conversion at Kahe Point: An Attempt at Community Dialogue” in later appendix.

---

[312] Development and Prospective of Ocean Thermal Energy Conversion and Spray Flash Evaporator Desalination by Haruo UEHARA and Tsutomu NAKAOKA. The document refernces H. Uehara, Kaiyou-ondosa-dokuhon, Ohm-sya, Tokyo (1982) [in Japanese]

[313] Development and Prospective of Ocean Thermal Energy Conversion and Spray Flash Evaporator Desalination by Haruo UEHARA and Tsutomu NAKAOKA

[314] Ocean Thermal Energy Conversion, Karen Anne Finney, University of Guelph, Guelph, Ontario, N1G 2W1, Canada, Guelph Engineering Journal, (1), 17 - 23. ISSN: 1916-1107. ©2008 http://www.soe.uoguelph.ca/webfiles/gej/articles/GEJ_001-017-023_Finney_Ocean_Thermal_Energy.pdf

U.S. Fish Studies (1983-88)

Characteristics of Potential Ocean Thermal Energy Conversion (OTEC) Sites in the Pacific Ocean (1983)[315]

The Potential Impact of Ocean Thermal Energy Conversion (OTEC) on Fisheries (1986)

"The potential risk to fisheries of OTEC operations is not judged to be so great as to not proceed with the early development of OTEC. Due to the lack of a suitable precedent, there will remain some level of uncertainty regarding these initial conclusions until a pilot plant operation can be monitored for some period of time. In the meantime, further research on fisheries should be undertaken to assure an acceptable level of risk regarding the larger commercial OTEC deployments"[316]

Effects of Cold Shock on Egg, Larval, and Juvenile Stages of Tropical Fishes: Potential Impacts of Ocean Thermal Energy Conversion (1988)[317]

"Thermal pollution, depending upon the magnitude, may be either lethal or sublethal to aquatic organisms. High temperatures, such as those encountered in typical nuclear or oilfired electrical generation operations, have been shown to have potentially negative impacts upon early life history stages of marine fishes ... These studies, however, have typically been conducted in temperate regions, where fishes may be more eurythermal than in tropical regions. Concern over cold shock in these regions has mainly related to mortality of animals in warm effluent plumes during periods of electrical plant shutdown in winter ...these impacts are typically of short duration and occur locally.

Fish kills from either cold weather or intrusions of cold water have been documented in tropical regions ...demonstrating that tropical fishes generally have less tolerance to low temperature shock than temperate fishes. Furthermore, acclimation to low temperature is typically slower than to high temperature ...cold shock may exert a strong negative effect upon early life stages of tropical fishes ... Our results suggest that the thermal stresses alone will not result in such high mortality, but synergism of thermal effects with the other direct impacts ...may result in high mortalities before the larvae leave the system in the effluent. ...mortality and hatchability are not sufficiently good criteria of thermal shock in eggs, since thermal shock increased larval deformities. Such sublethal effects, including developmental anomalies, deformation, increased vulnerability to predation, and displacement from feeding areas are all possible impacts from lowered temperature not considered relative to OTEC operations."

---

[315] Richard N. Uchida. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu

[316] Edward P. Myers et al, U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS); NOAA Technical Report NMFS 40: http://spo.nwr.noaa.gov/tr40opt.pdf

[317] Yara Lamadrid-Rose & George W. Boehlert, Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA Marine Environmental Research 25 (1988) 175-193

Environmental Defense Fund (1990)[318]

"Ocean thermal energy conversion is a promising new source of renewable energy ("Tapping Ocean's Cold for Crops and Energy," Science Times, May 22). Although the pilot facility in Hawaii you describe has not drawn protests from environmentalists, this does not mean the technology is completely benign.

Some plans call for the use of R-22, a chlorofluorocarbon that is not completely ozone-friendly. It is also a powerful greenhouse gas. Planners should investigate fluids that are environmentally harmless.

The potential for ecological disruption by ocean thermal energy conversion is enormous. It will work best in tropical regions, where the temperature difference between surface and deep water is greatest. Even when mixed with warm surface water to ameliorate environmental effects, the effluent carries a double shock to tropical marine ecosystems that have evolved within narrow temperature fluctuations and extremely low nutrient levels: the effluent is both cold and rich in nutrients.

Ocean energy conversion will bring deep water very rich in carbon dioxide to the surface. Some carbon will escape to the atmosphere, perhaps ex-acerbating the greenhouse effect. We also need to know how pumping large amounts of ancient deep water to the surface will affect ocean circulation and heat distribution.

Proponents of ocean energy conversion should study the feasibility of an integrated mariculture system to reduce levels of nutrients and increase the temperature of the effluent. The concept would be to grow salmon or some other cold-water, high-value fish in the effluent. This has worked very well at the pilot plant in Hawaii.

While the water is still cold, nori, the seaweed used to make sushi (which has also been demonstrated to grow well in the Hawaiian system), could be grown in the salmon effluent to remove nutrients and add oxygen. The water could simply be stored and allowed to return to surface temperature or used to grow warm-water species of animals and plants so that even more of the nutrients are removed.

This effluent is virtually free of disease organisms, which should improve public acceptance. A mariculture system using ocean thermal energy conversion effluent could produce valuable crops and release a nutrient-free, high-oxygen, low-carbon effluent at temperatures similar to those of receiving waters, minimizing the environmental impact of discharge and maximizing economic feasibility."

OTEC-1 (1993-98)

This facility was designed as a platform to test various OTEC-related technologies, and was not designed to generate electricity. OTEC-1 reached several important milestones, including successful deployment of a 670 m long cold water pipe, and

---

[318] Rodney M. Fujita, Staff Scientist, **Environmental Defense Fund**, Letter to the Editor (June 4, 1990), New York Times.
http://query.nytimes.com/gst/fullpage.html?res=9C0CEEDC1531F937A35755C0A966958260

mooring in 1,370 m of water in the waters off Hawaii. The cold water pipe from OTEC-1 was subsequently re-used for a land-based facility on the island of Hawai'i, which successfully operated from 1993 – 1998, and produced a net 103 kW, and still holds the world record for OTEC output.

A small OC-OTEC land-based experimental facility was built in Hawaii. The turbine-generator was designed for an output of 210 kW for 26 °C warm surface water and a deep water temperature 6 °C. A small fraction (10 percent) of the steam produced was diverted to a surface condenser for the production of desalinated water. The experimental plant was successfully operated for six years (1993-1998). The highest production rates achieved were 255 kWe (gross) with a corresponding net power of 103 kW and 0.4 l s-1 of desalinated water.

Taiwan (1993)

"A Master OTEC Plan for the Republic of China (MOPR) [was] executed in 1993. The theoretical reserve of OTEC power generation is around 30,000 MW within 30km off eastern Taiwan coast."[319]

Japan (1995)

"Saga University (Japan) built 75 kW (1984) and 9 kW (1995) gross power closed-cycle Lab Models at Saga in Japan. Since 1998, National Institute of Ocean Technology (NIOT), Government of India and Saga University in Japan were involved in the design, development and demonstration of a 1 MW (gross) OTEC floating plant demonstration project off the Tuticorin coast in Tamil Nadu, which will be the first ever MW range plant established anywhere in the world. The unit situated 60 km from Tuticorin, is installed on a 68.5 m barge, the Sagar Shakthi, which houses a Rankine Cycle based power plant."[320]

India (1997)

"The National Institute of Ocean Technology (NIOT) proposed the establishment of the 1 MW plant in 1997. "NIOT signed a memorandum of understanding with Saga University in Japan for the joint development of the plant near the port of Tuticorin (Tamil Nadu). It has been reported that following detailed specifications, global tenders were placed at end-1998 for the design, manufacture, supply and commissioning of various sub-systems. The objective is to demonstrate the OTEC plant for one year, after which it could be moved to the Andaman & Nicobar Islands for power generation. NIOT plan is to build 10-25 MW shore-mounted power plants in

[319] The Input Analysis of Ocean Thermal Energy Conversion R&D Projects in Taiwan. Cheng I Lai / Researcher, STPI, NARL
http://thinktank.stpi.org.tw/English/Columns/Pages/Column_EN_8.aspx
[320] OTEC Technology- A World of Clean Energy and Water by R. Magesh (Coastal Energen Pvt. Ltd., Chennai, Tamilnadu, India) Proceedings of the World Congress on Engineering 2010 Vol II (WCE 2010), June 30 - July 2, 2010, London, U.K.

due course by scaling-up the 1 MW test plant, and possibly a 100 MW range of commercial plants thereafter."[321]

"In 1998, Makai was contracted by the National Institute of Ocean Technology (NIOT) in Madras, India, for the conceptual design of the deep water intake pipeline, the effluent pipeline, and the mooring system for an experimental floating OTEC Plant. The analysis included dynamic modeling of pipe bending, shown at right. The NIOT OTEC barge is scheduled to be 72 meters long and will be supplied 1415 kg/s of deep cold seawater through a 1 meter diameter pipeline from a minimum depth of 1000 meters. The mooring is 1220 meters deep."[322]

OTEC for Small Islands (2004)

"The economies and social structure of the vast majority of what is now considered Small Island Developing States (SIDS) were developed under colonial rule. When the majority of these countries became independent nations in the latter half of the twentieth century, they inherited economies that were based principally on providing commodities to the former ruling nations. Independence did not bring about any significant change in the nature of the economy or trading relationship, although in some cases there were changes in ownership of land, brought about through purchase, hand-over from ruling country government to newly elected government, and in some cases nationalization.

The combination of high year-round sea surface temperature, relatively short distance from shore and excellent thermal profile of the oceans as shown in Figure 5, represent the ideal conditions for OTEC. While there are other renewable energy resources such as solar photovoltaic (PV) and wind power in SIDS, these cannot compete with the potential of OTEC. The wind power, for example, is limited in the amount of energy because of site requirement; PV is very costly for SIDS, and available only during sunny daytime. Neither wind power nor PV can provide reliable base load power compared to OTEC. Additionally, they have no direct linkage with water and food production. Clearly, OTEC is in a class by itself as the best renewable energy resource for SIDS."[323]

U.S. (2005-06)

The Hawai`i Public Utilities Commission opened a docket (a quasi-judicial contested case hearing) to examine HECO's proposed 2009 power plant at Campbell Industrial Park.[324] Life of the Land presents ocean energy alternative centered on OTEC, including testimony by Henry Curtis,[325] Dr. David Rezachek,[326] Reb Bellinger,[327] and Dr. Hans Krock.[328]

---

321 OCEAN THERMAL ENERGY CONVERSION: A seminar report by A.Swathi P.Srivalli Sneha, PRASAD.V. POTLURI SIDDHARTHA INSTITUTE OF TECHNOLOGY, Affiliated to JNTU, Hyderabad. http://www.seminarprojects.com/Thread-ocean-thermal-energy-conversion?pid=27252#pid27252

322 Deep Pipelines for Ocean Thermal Energy Conversion http://www.makai.com/p-otec.htm
323 Potential and Future Prospects for Ocean Thermal Energy Conversion (OTEC) In Small Islands Developing States (SIDS) by Dr. Al Binger (Visiting Professor, Saga University Institute of Ocean Energy, Saga, Japan. He is Director of the University of the West Indies Centre for Environment and Development, Kingston, Jamaica)
324 http://www.lifeofthelandhawaii.org/Proposed-2009-plant/
325 http://www.lifeofthelandhawaii.org/Proposed-2009-plant/Curtis2.pdf

Japan (2007)

In 2007 seawater desalination in OTEC plants was successfully demonstrated by India's NIOT on the floating barge called the Sagar Shakti

Hawai`i (2007-10)

Henry Curtis posted videos of (1) Dr. Ted Johnson, Director of Renewable Energy Program Development at Lockheed Martin's New Ventures Organization, where one of his areas of responsibility is the development of the Ocean Thermal Energy Conversion (OTEC) business;[329] (2) Dr. Krock (OCEES International), former Chairman of the Department of Ocean Engineering and as the Director of J.K.K. Look Laboratory of Oceanographic Engineering for the University of Hawaii; and founded OCEES, a company seeking to design and build an OTEC system;[330] (3) Dr. David Rezachek is one of Hawaii's foremost energy experts, with a wide and deep knowledge base especially focusing on ocean energy;[331] And (4) Dr. Luis Vega (headed the OTEC project at NELHA), Reb Bellinger (Makai Ocean Engineering, a local company heavily involved in sea water air conditioning and OTEC), and David Robichaux, an energy consultant.[332]

U.S. (2009-2010)

In 2004 NOAA established The Coastal Response Research Center (CRRC) at the University of New Hampshire (UNH). CRRC has been charged with analyzing OTEC. The first workshop (Technical Readiness of OTEC) was held in November, 2009 at the University of New Hampshire. Technical Readiness of OTEC[333]

The second workshop (OTEC: Assessing Potential Physical, Chemical and Biological Impacts and Risks was held in Honolulu (June 22-24, 2010). LOL Executive Director Henry Curtis was the only invited observer to the invitation only Conference. OTEC: Assessing Potential Physical, Chemical and Biological Impacts and Risks[334]

Philippines (2009-2010)

"An ocean power development company based in the United States is planning to invest in the Philippines, a Department of Energy (DOE) source said. The DOE source said Deep Ocean Power Philippines, a unit of California-based Deep Ocean Power, is currently conducting studies on at least 36 sites for possible ocean power sources.

---

[326] http://www.lifeofthelandhawaii.org/Proposed-2009-plant/Rezachek.pdf
[327] http://www.lifeofthelandhawaii.org/Proposed-2009-plant/Bellinger.pdf
[328] http://www.lifeofthelandhawaii.org/Proposed-2009-plant/Krock.pdf
[329] http://www.vimeo.com/12568409
[330] http://www.vimeo.com/12369586
[331] http://www.vimeo.com/12387494
[332] http://www.vimeo.com/12723004
[333] http://www.crrc.unh.edu/workshops/otec_technology_09/otec1_final_report_full.pdf
[334] http://www.crrc.unh.edu/workshops/otec_2/OTECII_effects_withappendix.pdf

These sites are located in Laoag, Zambales, Mindoro, Isabela, Panay, Negros and parts of Mindanao. "They applied for 36 sites covering 21,450 hectares, however the areas are still subject to verification under the prescribed blocking system of the DOE," the source said. ...Deep Ocean will construct a land-based power plant but its pumping station will be located in the deep ocean."[335]

"As a Nevada Corporation, "Our mission is to create Disruptive Innovation in developing countries for power, water, infrastructure and food projects thru an inexaustable resource of renewable energy."[336] Deep Ocean Power Philippines, Inc. (Makati City) & Deep Ocean Power Inc. (Downey, California)

"Deep Ocean Power Philippines Inc. (DOPPI), a joint venture between Filipino and American investors, is expected to build the first ocean power facility in the country in 2012. DOPPI chairman Alberto David told reporters over the weekend that they are going to build two ocean-run power facilities in Panay and Mindoro with initial capacity of 10 to 20 megawatts (MW) each. US-based Deep Ocean Power Inc. vice president Derek Murray said they would like to take advantage of developing renewable energy sources in the Philippines."[337]

"The DoE has already approved the plan of Deep Ocean Power Philippines Inc., joint venture between Filipino and American investors, to build the first ocean power facility in the country in 2012."[338]

---

[335] US-based ocean power development firm eyes RP By Donnabelle L. Gatdula (The Philippine Star) February 13, 2009. http://www.philstar.com/Article.aspx?articleId=439753&publicationSubCategoryId=66

[336] http://circlepad.com/deepoceanpower/Homepage

[337] US-Pinoy group to build 1st ocean power facility in RP By Donnabelle L. Gatdula (The Philippine Star) October 26, 2009. http://www.philstar.com/Article.aspx?articleid=517489

[338] Deep Ocean Power Philippines http://www.deepoceanpowerphilippines.com/news.php

APPENDIX 2: OTEC Final EIS (1981)[339]

"This Environmental Impact Statement (EIS) is prepared in compliance with the National Environmental Policy Act of 1969 (NEPA), as amended, which requires an EIS for each major Federal action that significantly affects the quality of the human environment. This EIS considers the reasonably foreseeable environmental consequences inherent to commercial Ocean Thermal Energy Conversion (OTEC) development by the year 2000 under the legal regime established by the OTEC Act of 1980. Regulatory alternatives for mitigating adverse environmental impacts associated with construction, deployment, and operation of commercial OTEC plants are evaluated, and the preferred regulatory alternative is identified.

The information contained in the EIS is being used to help identify the research needs for an environmental research plan required by the OTEC Act of 1980, and to develop a technical support document that will provide guidance regarding the types of environmental information that might be submitted with an OTEC application."

University of Hawaii at Manoa (May 14, 1981) by Jon Van Dyke, Associate Dean and Professor of Law, Principle Investigator of Sea Grant Project on Pacific Ocean Legal Issues & Sherry Broder, Attorney at Law

"We have reviewed the Draft EIS for OTEC and found it to be informative based on available data. We have the following comments on some of the specific areas. …Comparatively speaking, Hawaii has a lower amount of biocide released into ocean waters because heavy industries are almost non-existent. In some areas, the quality of water is exceptionally clean because of the minimal discharge of products that could degrade it. The EIS should include an analysis of this type of situation. NOAA should require licensee to maintain the already existing quality of water to the extent possible. Just because Hawaii has potential sites with superior water quality, higher quantities of biocide discharge or other types of polluting discharge should not be permitted."

Environmental Center, University of Hawaii at Manoa by Diane C Drigot, Ph.D., Acting Director (May 15, 1981) Reviewers: William Kimmerer, Hawaii Institute of Marine Biology; Jacqueline Miller, Garret Kawamura, and Alexis Cheong Linder, Environmental Center.

"We find the DEIS to be adequate in addressing the potential impacts attributed to commercial OTEC development. …

Determinations of the quantity and type of discharge of the OTEC plants are a desirable part of the EIS content in order to make a well-informed assessment of the participated environmental impacts. Plume studies, other than laboratory or computer modeling, should be done under field conditions. …Warm/cold water discharge characteristics

---

339 Ocean Thermal Energy Conversion: Final Environmental Impact Statement, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Ocean Minerals and Energy (July 1981)

should be specified in greater detail to require information on mode of discharge (i.e., separate or combined), discharge temperature(s), plume characteristics (including depth range and affected area). ...require information on the planned working fluid as well as any other potentially hazardous chemicals (e.g., chlorine) which will be used in the OTEC operation. ...Included in the list of onshore components of the OTEC facility should be chemical on/off loading facilities. This will be a critical component of an OTEC plantship's operations."

APPENDIX 3: OTEC & FISH (National Marine Fisheries Service, 1983)[340]

In 1 hour the world's oceans receive enough solar energy theoretically to meet its annual demand for fuel. ...

At Kahe Point on the western shore of Oahu, the 1,000-m contour is about 3.8 nmi from shore. The minimum DT observed at this site was 20.0 C° whereas the maximum reached 22.8C° (Ocean Data System, Inc. (ODSI) 1977). Studies by Seckel (1955) and Maynard et al. (1975) indicate that a minimum of 914 m will be needed to obtain a Delta T of 19C° during winter when surface temperatures are colder. In summer, the temperature difference between the surface and 914 m ranged to 23.0C°.

The depth of the mixed layer at Kahe Point was 50 m in summer and 90 m in winter (ODSI 1977). The upper water column off Kahe exhibited what appeared to be some seasonal variation in current speed whereas in waters deeper than 350 m, there was no evidence of seasonal trend (Noda and Associates 1982). At 50 m, the monthly maximum current speed ranged from 52.7 cm/sec in August to 77.4 cm/sec in May (Noda 1981). Monthly mean values at this depth varied from 17.5 cm/sec in August to 27.2 cm/sec in March.

Currents are often strong off Kahe but could be highly variable (Bathen 1978). The net drift is rather consistent and moderate to strong toward the south of Maili Point to Barbers Point from August to January when winds are less dominated by the northeast trades. In deep water, net drift is variable toward the shoreline from February to April and directly offshore from May to July.

Waves impinging on the Kahe area may be generated either from earthquakes (tsunami) or wind. An OTEC power transmission cable would require adequate tsunami protection through the coastal zone. Runup or height change during a tsunami at both Kahe and Barbers Point was about 3.6 m during the 1946 tsunami that washed the shores of Oahu (Cox and Mink 1963; Dames & Moore 1970; Armstrong 1973). (pp4-5)

Increases in phytoplankton biomass and assimilation rate can occur only in water layers which receive a minimum illumination of 400 lx (Moiseev 1969). Below this level, photosynthesis and proliferation cease and phytoplankton perish. In the summer compensation depth, has been estimated to be less than 50-100 m in the North and South Pacific about 80-120 m in the equatorial Pacific, and about 100-140 m in the subtropical regions.

Compensation depth can be approximated in field work as the depth at which light is attenuated to 1% of the surface radiation and can be estimated with a bathyphotometer or doubling the depth of the Secchi-disk visibility (Parsons and Takahashi 1973). Below the compensation depth, there is no net photosynthesis. The photic zone was ...145 m a

[340] CHARACTERISTICS OF POTENTIAL OCEAN THERMAL ENERGY CONVERSION (OTEC) SITES IN THE PACIFIC OCEAN (August 1983) RICHARD N. UCHIDA Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu

t Kahe Point, which is characteristic of clear-blue Ocean waters (Noda et al. 1980, 1981b). (pp12)

Differences at Island Sites

Data collected during surveys conducted at Kate Point are useful in examining differences in biological parameters between open ocean (Keahole and DOMES) sites and nearshore island sites. The Kahe Point surveys are particularly useful because not only has the site been selected for an OTEC pilot plant but also because much of the environmental surveys were completed before the construction of Hawaiian Electric's oil-fired generating plant at Kahe Point. Also, the location has been surveyed extensively during the O'OTEC cruises (Noda et el. 1981b; Noda and Associates 1982).

1. Kahe Point

In a study to obtain baseline data from waters off Kahe Point, Noda et al. (1981b) carried out a shipboard measurement program from May 1980 to May 1981. Bimonthly cruises were made to the following two O'OTEC benchmark sites off Kahe Point:

** Site 1, at lat. 2l°19.5'N and long. 158°12.5'W, approximately 4.9 nmi west-southwest of Kahe Point (Figure 13).*

** S i t e 2, about 4.7 mi west-southwest of Maili Point, at lat. 21°23.5N and long. 158°15.5'W.*

Biomass

Based on results of six cruises, Noda et al. (1981b) reported that in the Kahe environment, there is a deep CML [chlorophyll maximum layer] which is characteristic of many other oceanic systems and which represents an important facet of phytoplankton ecology. In time and space, the chlorophyll maximum remained about the same in vertical position (86 m) as well as in concentration (average = 0.27 μg / liter). This layer accounted for 77% of the chlorophyll biomass in the photic zone. About 60-80% of the cells were in the <3 μn size fraction. Pigment levels were low and uniform down to 44 m, and averaged 19.90 + 2.31 mg chlorophyll a/m2 and 18.69 +- 5.34 mg phaeopigments/m2 over the year. Pigments also showed considerable uniformity over time except at both stations in August 1980 and at Station 1 in October 1980.

Primary production

The average annual primary production for the Kahe area was 60.4 ± 15.6 gC/m2/yr, a value similar to those for other subtropical gyre waters

The ratio of productivity to biomass, which is useful as a relative index of specific rates of photosynthesis, showed that the characteristic feature of the Kahe system is persistent nutrient limitation that phytoplankton in the area are growing slowly. Noda et al . also observed a temporal pattern to the P/B ratios which parallel that photosynthesis. In the light saturated layer they found low P/B ratios from May to December and generally higher ratios from January to May, which suggested a relaxation in the degree of nutrient impoverishment.

The results also indicated that photosynthesis in the light-saturated layer accounted for only 30% of the total production. Temporal variability, according to the authors, was due to changes in the activity of populations found in the light-limited layer. There was a highly significant positive correlation between fraction of production taking place below 44 m and that in the total water column

To determine which of the various processes influenced production in the light-limited layer, Noda et al. examined different variables but could not identify any which had a consistent seasonal pattern that would provide an explanation. They did, however, find that the temporal pattern of primary productivity had a general correspondence with local wind patterns, that is, during December-April when productivity was highest, the frequency of northeast, east, and southeast trades was lowest. Primary production was lowest from May to November, slightly higher from December through March, then low once again in May. The coupling between wind activity and ocean circulation, however, remains undelineated. The circulation off Kahe suggests that upwelling occurs during eddy formation, but it is insufficient in strength and duration to significantly affect the sea surface. It is reasonable to assume, however, that the lower regions of the photic zone are affected.

Compensation depth

The calculated depth of the 1% light level off Kake Point ranged from 142 to 150 m and averaged 146 m (Noda et e l . 1981b). The compensation depth at Kahe, therefore, is not dissimilar from the results obtained by Gundersen et al,. (1976), who calculated the photic zone (defined according to the 1% light level) at Station B at 140 m in the Kealaikahiki Channel (between the Islands of Lanai and Kahoolawe at lat . 20°41'N and long. 156°55'W).

Community composition

Throughout the photic zone extending down to 145 m, 65% of the microbial biomass in the Kahe environment is represented by organism in the ≤3 µm size fraction (Noda et al. 1981b). Takahashi and Bienfang3 reported that the vertical distribution of picoplankton is not influenced by sinking, thus reinforcing it s dominance in a nutrient-limited environment. In addition, the picoplankton's potential for ammonium uptake at low levels favors its success in a substrate (light or nutrient) limited system.

Takahashi and Bienfang found that the <3 µm assimilates ammonium at rates 75% faster than those for the large 3-20 µm fraction. Thus, in the CML the picoplankton can take advantage of higher nutrient supply without being subjected to the hazards of sinking and therefore, being transported to light-deficient depths where photosynthesis is absent.

Noda et al. (1981b) suggested that the dominance of picoplankton off Kahe may be related to the prevailing nutrient field. Modest climatic fluctuations in the Kahe area produces thermal stratification which persists thus restricting vertical input from deep nutrient-rich water. This produces an environment driven by regenerated nutrients and results in a condition characterized by numerous, small nutrient inputs, low ambient concentrations, and an importance of reduced forms of nitrogen.

Seasonal variations

Noda et al. (1981b) found considerable uniformity in pigment levels over time at Kahe Point, but there were exceptions particularly when large divergences occurred at both sites during August 1980 and at Site 1 in October 1980. The ATP values were highest in August-January but displayed a relatively even pattern the remainder of the year. Photosynthetic rates showed a consistent upward trend from low values in May-November 1980, increasing levels through March 1981, and slightly lower values to May 1983. Temporal variations were usually significant. Noda et al. concluded that although photosynthetic rates showed a significant increase during the second half of the survey period, the biomass parameters showed little regularity and unlike the photosynthetic rate no significant changes occurred. They reported that it was not clear whether any ecological significance can be attached to temporal variability of the biomass parameter.

Because two scales of spatial variability occurred during the Kahe survey, each was addressed by Noda et al. (1981b). Cast-to-cast differences were examined for small-scale spatial variability arising from the ship's drift during sampling; the average distance between hydrocasts was 0.9 km. Station-to-station differences were termed large-scale spatial variability and represented an average of 9 km on the horizontal scale.

The results clearly indicated that large-scale spatial differences in biomass parameters were not great. Noda et al. noted that although comparison of time-averaged values of the various parameters may indicate station-to-station differences since values at one station may exceed those at the other rather consistently the differences between the means were not significant .

In nearly all the comparisons for photosynthesis, however, Noda et al. found that the Station 2 mean was higher than that for Station 1 and the absolute difference averaged 5.26 mgC/m2/h over the year of the study. This translated into o 47% higher photosynthetic rate at Station 2. Thus, although absolute values of the station-to-station differences were not large in comparison with temporal variations observed earlier, the ability to measure differences between station may prove useful in future monitoring programs which assess the areal extent of impact t o biological productivity resulting from the operation of an OTEC plant at Kahe. Noda et al. concluded that because large-scale spatial differences were not pronounced, small-scale differences were even less important.

Criteria standards for the Kahe environment

From the baseline data collected for the Kahe environment, Noda et al. (1981b) calculated the natural range of phytoplankton density, expressed as the 95% confidence limits for the depth-integrated data (Table 6) . Also, based on the given analytical capability observed temporal and spatial variabilities at Kahe, they used the analysis of variance data to determine criteria for detecting significant environmental changes. They reasoned that the detection of s i g n i f i c a n t differences between two measurements depends on precise measurements of the level below it; for example, analytical precision depends on precise measurements to detect any subsample variation. Table 7 gives the *criteria for detecting significant (P 0.05) differences for each parameter and for each level under examination. (pp18-21)*

Off Kahe, organisms such as ostracods, euphausiids, and copepods like Oncaea spp., Pleuromamma sp., and Lusicutia sp p .migrated vertically, and were found between 25 and 200 m during the day (Noda et al. 1981b). Medusae, gastropod larvae, fish eggs, Foraminifera, and Corycaeidae were non-migrating epipelagic animals, and radiolaria, pelecypod larvae, amphipods , chaetognaths , larvacea, salps, and numerous copepods such as Acrocalenus spp., Paracalanus spp., Clausocalanus spp., Euchaets spp., Haloptilus spp., Candacia spp., Arcatis negligens, and Oithona spp. appeared to have a vertical migration pattern. However, their increased night-time abundance may be indicative of net avoidance in day – time sampling. Their abundance in deep, daytime samples was not notably greater than their night-time abundance which suggests that no upward migration was occurring; however, because of the wide depth ranges used for the study, more detailed observations are needed. (p28)

In waters 6-25 nmi off Kahe Point, micronekton organisms in a 1,200-m water column showed a mean standing stock of 900 organisms and a wet weight of 0.5 kg/ 100 m2 of ocean surface (Maynard et al. 1975). Over half of the number of individuals and t h e i r biomasses were composed mostly of small fishes. At night, there were substantial in abundance of nekton in shallow water as a result of vertical migration. For micronekton determined to be inhabitants of water deeper than 400 m during the day, Maynard et al. found that about 45% migrated upward at night. During daylight hours, about 90% of the mean total micronekton standing stock were in waters deeper than 400 m ([Hawaii.] DPED 1980). (p29)

There are a number of commercially valuable fish species in the Kahe area. The abundance of larval and juvenile tunas were studied by Higgins (1970) at a site about 7 km seaward of Kahe and very close to the proposed offshore OTEC site.

Midwater trawl catches of juvenile tunas were much lower in this area than at another site 56 km offshore. Also, almost all bigeye and yellowfin tunas were in the upper layers and small juvenile skipjack tuna were most abundant in the shallow water whereas large ones tended t o be more abundant i n deep water.

Data from Higgins (1970) and Miller (1979) suggest that an OTEC plant 3 nmi offshore from Kahe Point may be ideally situated with respect to avoiding tuna larvae inshore and tuna juveniles offshore ([Hawaii.] DPED 1980). (pp29-30)

Jones and Ryan (1981) also listed the following species of fishes that were attracted to the platform and pipe during the operation of Mini-OTEC: Spotted triggerfish, Opelu, Rainbow runner, Mahimahi, Pilotfish, Whitetip shark, Kahala, Bigeye scad, Filefish, Rudderfish, Yellow tang, Blenny, Damselfish, Whale shark, Skip jack tuna, Yellowfin tuna, Wahoo ...In a report describing the effects of impingement of marine organisms at Kahe Point as a result of the operation of the existing fossil-fueled electric generation plant, Coles et al. (1987) observed that several commercially important invertebrates and vertebrates were affected. Among the invertebrates were lobster, shrimp, octopus, crab. None, however, were caught in sufficient numbers to merit concern. Among several commercially important species, only the kala, Naso unicornis, was affected in sufficient numbers to warrant attention. Based on extrapolation over 1 year, Coles et al.

estimated that about 1,600 kala would be affected, mostly juveniles, and the projected loss would amount to 9.6 kg/yr. The amount, according t o them, is well below the 7,700 kg caught in 1978 in the State of Hawaii. (pp30-31)

The fishing grounds off ...Kahe Points are high-producing regions in the Hawaiian fisheries not only for inshore reef and bottom fishes but also for pelagic species such as skipjack, yellowfin, and bigeye tunas, blue marlin, striped marlin, mahimahi, and wahoo (Table 19). (p31)

A report which summarized ichthyoplankton population studies conducted in the vicinity of Kahe Point during the mid and late 1970's indicated that some data were nearly site specific for the OTEC site ([Hawaii.] DPED 1980). Leis (1978), who reported on 15 species of larval fish collected about 1.9 mi from the shoreline, found median concentrations of 0-112 larvae/l,000 m3 per species with upper ranges of 7-112 larvae/l,000 m3 per species. He added that 100 fish larvae/1,000 m3 would be a reasonable estimate of the mean fish larvae population at the OTEC site. (p32)

The Hawaii DPED (1980) report al so provided an estimate of the potential impact of an OTEC plant on the larval fish population. Assuming that an OTEC plant would entrain about 13.8 million m3 of surface water per day, DPED estimated that about 1.38 million fish would be impacted per day, based on the population estimate provided by Leis (1978). There is however, a need to expand the data base on such studies so that a critical evaluation could be made on potential impact. This is particularly true of the potential impact on larval tuna populations because of the importance of adult tunas in the Hawaiian fishery. The larva1 tuna population in waters 0.6 mi seaward of Kahe Point can be as high as 441/1,000 m3 or roughly 10-100 times greater than populations found in oceanic waters of the central Pacific (Miller 1979). Miller postulated that there is a relatively deep source of these larvae, which may migrate inshore in response to upwelling of deep cold water and a shoaling of the thermocline shoreward. The Hawaii DPED report concluded that tuna and other larval fish populations, therefore, may be impacted by OTEC-related alterations of the temperature structure of receiving water in the area as well as by primary entrainment. (pp32-33)

Miller et al. (1979) present data on common nearshore marine fish larvae found at Kahe Point. Their data indicate that the inshore and offshore abundance of larvae in winter at Kahe Point was below the mean level (109) for all Oahu sampling sites. In summer, the number of larvae inshore exceeded the summer mean (135) by a considerable margin; however, the offshore total was slightly below the mean. (p33)

Hirota concluded that (1) the neuston layer contains some species in very high abundance but which are rather uncommon in the 1-200 m layer, (2) the larvae of commercially important tunas occur more abundantly in the neuston layer then in the 1-200 m layer, (3) the species in the 1-200 m layer are primarily midwater forms, and (4) very few larval fish occur between 200 and 1,000 m. (p35)

Ichthyoplankton constitute a considerable proportion of the midwater plankton in tropical regions (Vinogradov 1968). In the 500-1,000 m layer, they constitute as much as 20-25% of the total mass of net plankton. In the middle latitudes, however, the picture changes considerable and the fish biomass in the deep layers is higher than in the tropical regions but its proportion in the plankton is considerably lower (p35)

APPENDIX 4: OTEC & FISH (NOAA, 1986)[341]

Phytoplankton

Primary production in Hawaiian and open tropical Pacific waters is low relative to that of Continental Shelf areas in the Pacific ...The variation is associated with input of nutrients to the surface: where water passes over shallow banks, at the edge of eddies which form in the wake of islands ...Investigations of plankton near oceanic islands have repeatedly revealed that taxonomic composition, standing crop, and production change with distance from shore. The intensity of this "island mass" effect and the area influenced are generally greater on the leeward side of the island.

Zooplankton

Although zooplankton have not been studied extensively in ...Hawaii ...The importance of an island effect on zooplankton abundance is evident from studies near Jamaica and Barbados ...Abundance of zooplankton decreases considerably with depth. ...In the mid-Pacific, Hirota (1977) showed the highest concentration in the upper 150m and moderately high concentration between 200 and 900 m. Standing stocks in the upper 200 m varied about 50-90% of that in the upper 1000 m. Off of Kahe Point in Hawaii, Noda et al. (1981a) observed an approximate tenfold difference between surface samples and those from 600-1000 m.

Although diel migration of zooplankton has been observed but not extensively documented in Hawaii ...the phenomenon is general and fairly well known. "Diel vertical movements occur in all planktonic phyla and in most of the smaller taxonomic groups" (Longhurst 1976). In general this consists of a migration from deep water toward near surface layers, where plankton spend the night and then descend again at dawn. The plankters do not necessarily rise all the way to the surface: aggregations tend to occur at the level of the deep chlorophyll maximum, and abundance in the surface water may even decrease during the night as a result of downward migration of surface zooplankters to the chlorophyll maximum layer.

Fisheries

The area near Kahe Point sustains a varied and valuable fishery. In the years from 1976 to 1980, 101 different species were identified in the harvest from the area. Hawaii Division of Aquatic Resources records show that the average annual catch was about 219 metric tons with an annual yield to commercial fishermen of $350,000. ...
Spatial distribution of larvae is quite complicated depending on both the reproductive habits of the fish and water movement in and near the spawning area. Most of the important reef species have pelagic eggs and appear to be spawned at times and locations where the eggs will be quickly moved offshore to areas where predators may be less abundant. This pattern has been substantiated in Hawaii by Leis (1982) who found reef fish eggs were more abundant 3.0km from shore than 0.2 km out, and Miller

[341] THE POTENTIAL IMPACT OF OCEAN THERMAL ENERGY CONVERSION (OTEC) ON FISHERIES (MYERS ET AL, NOAA, 1986)

(1974) who reported larvae of some fish were more abundant 50 km off Oahu than 5km out.

Larval distribution of pelagic species may be much different. Miller et al. (1979) reported tuna larvae were much more abundant near shore and on the leeward rather than wind-ward coast. It appears likely that high surface densities of larvae are produced by wind-driven upwelling of layers of water containing fairly dense larval concentrations. Comparing absolute abundance of larvae between areas is particularly difficult because various investigators use different techniques, including sampling at different depths, and because the samples display considerable variability.

In the mid-Pacific, Hirota (1977) found:

1) that the larvae of commercially important tuna occur more abundantly in the neuston layer than from 1-200 m,

2) the species in the 1-200 m layer are primarily midwater forms, and

3) very few larval fish occur between 200-1000 m.

Of the five sea turtles that have been reported off Hawaii, the green sea turtle is the most abundant. A single green sea turtle has been observed repeatedly on the reef directly off the Kahe Point power station.

In passage through the plant, entrained organisms will be subject to a number of stresses such as temperature and pressure changes, and chemical additions. Upon discharge to the environment, entrained organisms will be redistributed in the water column along with additional organisms entrained into the discharge plume. The artificial upwelling of nutrients and other constituents contained in the deeper, colder waters and their subsequent redistribution may also effect some biological changes.

Attraction/Avoidance

The attraction or avoidance of fish towards objects, light and noise is a known phenomena that is expected to occur with OTEC operations, whether they be open-ocean plant-ships, stationary towers, moored platforms, or land-based plants. For the purpose of this study, Seki (1984) has summarized available information on this topic and related it to OTEC development; the following is a brief synopsis of his findings.

The attraction of fish to free-floating and anchored objects or structures has been studied throughout the world's tropical and sub-tropical waters. The objects with which fish have been observed to associate include drifting seaweed ...and artificial surface or midwater structures, including commercial fish aggregating devices (FAD's) ...Tunas dominate the catch of the pole-and-line, trolling, handline, and purse seine boats fishing around FAD's, as evidenced by some catch data obtained from Kiribati, Western Samoa, Fiji, and Hawaii (Shomura and Matsumoto 1982).

In comparison to floating OTEC structures, the tower and man-made island designs of OTEC plants are expected to function as artificial reefs, duplicating those conditions that cause concentrations of fishes and invertebrates on natural reefs and rough bottom *areas. The effect of tower designs would be similar to that of off-shore oil platforms, which have resulted in an increase in offshore sport fishing in the' immediate area. Numerous studies have described the variety of fish which have been attracted to artificial reefs at various sites. In all studies, the many different species found generally represent similar basic broad behavioral classes, such as the Turner et al. (1969) reef or non reef associates (the former further split into resident or semi resident).*

Four reefs were established at various sites in Hawaii between 1960 and 1973, using primarily car bodies, damaged concrete pipes, and old car tires filled with mortar. The southern boundary of a reef created on one of these sites (Waianae) on the western coast of the Island of Oahu ...Sampling along a fish transect established before the reef construction indicated the presence of 32 different species and a standing crop density of 103 pounds of fish per acre.

The reef was constructed in two sections, one composed of car bodies and the other of damaged concrete pipes. Thirty species of fishes (standing crop estimated at 1,271 pounds/acre) were present at the car body section. This was a tenfold increase over the pre-reef count. The concrete pipe section showed a fivefold increase of 45 fish species and a standing crop estimated at 496 pound/acre.

Although attraction of fish to man-made structures is well documented, questions still arise regarding the relationship between artificial structures and fish production. Mallory (1965) believed that a structure concentrated the fish which constantly migrated in and out, thus serving as an orientation point. This was true for a number of species (primarily the game fishes) associated with flot-sam. Stroud (1965) felt that since the artificial habitat provides food and shelter, reproduction will be enhanced resulting in an increase in production and yield of fish. A third hypothesis ...combines both viewpoints; fish are concentrated by recruitment, and, as the colonization progresses on the structures, a reproducing resident fish community may evolve. Although this may hold true for many of the reef fishes, this hypothesis falls short of accounting for overall fish attraction as evidenced primarily for such species as the deeper water pelagic scombrids and billfishes.

The attraction of various marine organisms to light is a phenomenon that has been used in the harvesting of fish for many years. ...Various species of tuna and squid ...are caught by the use of night lights. How much of an effect the lights from an OTEC facility will have on the tuna is not presently known. As indicated ...every species has a particular optimum light intensity in which its activity is at a maximum. It is probable that the intensity of the artificial light would fall within the thresholds of some species.

Regarding avoidance traits of marine biota to structures and operations in the ocean, published information is virtually nonexistent. Yuen (1981) indicated that the endangered and threatened species would probably avoid the area due to human presence and to the noise emitted from the plant. Among the few studies that address avoidance was one on the negative phototactic behavior of fish. Dragesund (1958) found that herring would sometimes display a shock response. That is, when the light was turned on, the fish would make a sudden upward movement towards the light only to later disperse or school and descend.

Studies on other aspects of avoidance, such as of the physical structures, are nonexistent in published literature. Future studies should be directed in this area.

Impingement

Impingement at coastal power plants has been an ecological problem (loss of a large number of organisms), an operational problem (reduction in cooling water flow), and a cost problem (removal and disposal of organisms). Impingement occurs when organisms too large to pass through the intake screen, are pulled against it, and are unable to escape due to the current velocity. Schooling fishes are especially susceptible, and impingement mortalities may involve millions of individuals.

As a result, data on impingement of fish have been collected from many operating plants …Variation in impingement on intake screens is related, among other things, to season, swimming speeds, intake location, and operating schedules of the power plant. Screen catches at most coastal power plants studied in temperate waters fluctuate markedly with season, due to migrations into and out of intake areas and to changes in water temperature that affect the fishes' ability to swim successfully against intake currents. In tropical areas, where OTEC plants will be located, impingement may be less variable because there is generally less migrational movement of populations and the water temperature is essentially the same the entire year.

The swimming speed of an organism determines whether or not it will escape impingement or entrainment once in the vicinity of an intake. Eggs and larvae of marine fish drift passively in the ocean within the zooplankton community.

Early larval stages utilize swimming only to capture prey, escape predation, or migrate vertically. In general, sustained swimming speeds of fish larvae fall into a range of 2-4 body lengths/second for larvae in advanced development or for juveniles (Blaxter 1969; Bainbridge 1960). ...The fastest burst swimmers are yellowfin tuna, which as adults can swim 27 body lengths/s for 5 seconds ...Although larvae do not have strong sustained swimming ability, they possess impressive darting or burst speeds relative to their size. Blaxter (1969) suggests bursts of 10 body lengths is which, for most larvae (up to 25 mm), would limit their speed to less than the 0.25-0.30 m/s suggested as typical of OTEC plant warm-water intake velocity ...

Swimming ability is a function of morphological shape, stage of development, length, ambient temperature and light, and the duration required for the performance. ...

Knowledge of these factors and the types of species likely to be near the OTEC plant site is necessary to predict the potential of larvae and juveniles to escape intake currents. ...

The design of the water intake structure will greatly affect current velocity. It has been shown that fish are better able to orient to a horizontal flow than a vertical flow. Intake structures placed or capped so that intake flows are in the horizontal plane enable fish to orient to the flow and more effectively avoid the intake (Langford 1983).

Because of the large volume of water required by OTEC plants and the relatively high flow rate at the screens, impingement of organisms on the warm-water intake screens *will assuredly be a visible effect and may, in some cases, be ecologically important. Impingement rates will depend on intake location and velocity. Time of day, behavior characteristics of the populations of organisms associated with the plant site and, to some extent, season of the year, although this will be a relatively minor factor in tropical waters. ...*

Impinged organisms generally fall into the micronekton ...and gelatinous organisms. ...Micronekton are an important intermediate step in the food chain between the zooplankton and commercially important fishes. The significance of large-scale mortalities due to impingement at coastal power plants in temperate waters has not been quantified from field data and there is presently no conclusive evidence of actual population declines in any species due to impingement losses. Attempts have been made to model the effects on populations (see section on Potential Range of Ecological Effects) but there is, in general, a lack of needed data on natural mortality rates.

In general, the data base for tropical-subtropical waters is even more deficient than for temperate waters. Very few quantitative studies have been made in tropical-subtropical waters to systematically collect samples of micronekton. Therefore, it is very difficult to estimate the impingement rate.

Sullivan and Sands (l980), using data from water off Oahu, Hawaii, estimated a daily impingement of 420 kg for the warm-water screen of a 400-MWe OTEC plant, and concluded that this loss is probably insignificant when the replacement ability of the micronekton population in the surrounding region is considered.

Primary Entrainment

Any organism small enough to pass through the intake screens (approximately 1.3 cm; Sands 1980) will be entrained in the seawater flowing through the heat exchangers (primary entrainment). During this period, organisms are subjected to thermal and mechanical stresses as a result of changes in pressure and temperature, shear and acceleration forces, abrasion, and collision with structures. In addition, organisms will be subjected to biocides used to clean the surfaces of the heat exchangers, anti-corrosion agents, and corrosion products. Effects on organisms will be due to a combination of these factors.

The effects of primary entrainment at conventional power plant shave been extensively studied and a number of reviews have been reported (e.g.. Schubel and Marcy 1978). There is general agreement that while a great many species of organisms cannot survive passage through the cooling water system, there is a wide range of tolerance among species, and plant design and operating characteristics are critical factors. Mechanical damage is probably the major single factor contributing to primary entrainment mortality. The importance of thermal and chemical stress will vary depending on thermal exposure, biocide treatments, and corrosion rates.

Entrainment effects associated with OTEC will no doubt be one of the most important factors to consider with respect to fisheries. Because of the low thermal efficiency of OTEC plants the amount of water needed is extremely large ... for the total combined warm and cold water flow ...as compared to an average ...for condensing water for a *nuclear plant. Because of this large water requirement, the number of organisms subject to entrainment will be large.*

Temperature

Organisms entrained in conventional power plants are subjected to rapid increases in temperature as they pass through power plant condensers. The near instantaneous temperature changes may range from less than 6°C to in more than 19°C, and the exposure time to these elevated temperatures may range from several minutes to an hour (including time in the discharge canal) depending on the plant design.

Laboratory research on the larvae of four species of temperate subtropical marine fish has shown that their survival following entrainment in a once-through cooling water system will depend on the increase in condenser water temperature over ambient water temperature and the length of exposure. ...

Unlike conventional power plants where organisms experience only an increase in temperature as they pass through the condensers, organisms entrained in OTEC plants will experience both increases and decreases in temperature. Organisms entrained in the warm water will pass through the evaporator, where the temperature will be decreased by 2-3°C, while organisms entrained in the cold water will pass through the condenser, where temperature will be increased 2-3°C. Additionally, organisms will be subject to larger temperature changes upon mixing of the two effluents (if practiced) and/or discharge to the environment. For instance, a mixed discharge would effect a temperature drop of about10°C for the warm-water organisms and a 10°C increase for any cold-water organisms. Entrained organisms ...are distribution in the water column when discharged with effluent waters. This redistribution could also expose organisms to a different temperature regime. No literature was found on cold shock in fish for the temperature range that are expected for the OTEC discharge.

Cold shock literature is limited to describing effects of rapidly reduced temperatures during the cooler months to new temperatures at or near the low lethal temperatures, which produce death by the formation of ice in the tissues or induce primary (respiratory) or secondary (nerve blockage) chill comas. All reported fish kills or experimental cold shocks involved species in temperate climates. ... A general prediction of the effect of cold shock cannot be made to a number of species. Further, knowledge of thermal requirements of the adults of species may not be sufficient to predict those of egg and larval forms. In Brett's (1956) review, he states that " . . the thermal requirements in the very early stages are more exacting than in the adult." For eggs and larvae of stenothermal species, reduced temperatures, although not actually "cold," will retard development and may cause abnormalities. Harada et al. (1978) found that no yellowfin tuna larvae developed normally in temperatures below 20°C.

Pressure

Rapid change in hydrostatic pressure is one of the stresses which organisms are subjected during entrainment. This pressure change may be either negative (vacuums within the pump) or positive, and the magnitude of the change is dependent on design. It *has been suggested that rapid changes in pressure that occur in power plant cooling water pumps may be potentially damaging to entrained fish (Marcy et al. 1980). Although much research has been conducted on the effect of pressure change on fish, very little of it has any direct relevance to the relatively small pressure changes (1-5 atmospheres; 1 atmosphere change equivalent to a 10-m depth change) to which fish are subjected in power plant cooling systems.*

Much less entrainment of organisms is expected in the cold water intake of an OTEC plant, but any entrained organisms will be ex-posed to a pressure change of 70-100 atmospheres depending on depth of the intake pipe.

Entrained fish larvae possessing a swim bladder would be very vulnerable to rapid changes in pressure of this magnitude. ...

Chemical Additions

Due to the low thermodynamic efficiencies available through the OTEC system, the heat transfer rate at the heat exchanger surfaces will be critical. The inhibition of biofouling due to microorganisms must thus be an integral aspect of OTEC operations. As in coastal power plants, current thought here supports the need for intermittent chlorination to keep biofouling to a sufficiently low level. ...There is concern over the use of chlorine because of its toxicity. It has been shown that added chlorine can seriously affect the growth and survival of entrained organisms, although there are species-to-species variations and certain synergistic effects with temperature and trace metals.

The biocide concern is amplified in an OTEC operation because of the large volumes of water involved, i.e., the achievement of a certain concentration for biocidal effectiveness will require the application of large quantities of biocide. Although the required dose of chlorine will be somewhat site-specific, recent studies indicate that concentrations of total residual chlorine ...is well below the new source performance standards (NSPS) requirement for chlorine discharges from steam electric generating stations, the standards which would most likely apply to OTEC discharges (Myers and Ditmars 1985). ...

There is also a potential for synergistic reactions of chlorine with trace metals and ammonia leaks. Recent studies (Venkataramiah et al.1981a,b) on marine fishes and zooplankton have shown that the toxicity of ammonia and chlorine varies with habitat of the species and with duration of exposure. Within the same species ...smaller fish were more sensitive than larger fish. This work confirms past research on other species and provides further evidence that exposure to chlorine in marine waters, while not well understood, may present a serious problem and should receive additional study.

Because of the large surface areas required for OTEC heat ex-changers ...heat exchangers are considered one of the principal sources of trace metal release. Myers and Ditmars (1985) have used the results of DOE-supported corrosion tests (Tipton 1980) to make worst-case estimates of trace metal concentrations in OTEC discharges ...With the possible exception of copper, these estimates suggest that the release of trace metals from heat exchanger surfaces would not pose significant concern. ...With the exception of catastrophic accidents, any leaks of working fluids will be diluted by the large volumetric flow of seawater through the plant, to the point that problems should not *arise. For instance, with the Ocean Thermal Corporation OTEC design for Kahe Point, it is predicted that normal leaking of ammonia could result in an increase ...above the ambient level ...in the mixed discharge (Ocean Thermal Corporation 1983).Upon reaction with the seawater, only about 5 % of this increase would remain as un-ionized ammonia, the principal toxic form. The concentration of un-ionized ammonia in the discharge would then be ...well below a reported minimum-risk level.*

Secondary Entrainment

Secondary entrainment refers to the capture of organisms in discharge waters (effluent plume) as a result of turbulent mixing or behavioral responses. The rate at which organisms are entrained in this manner will depend on the discharge flow rate, the near-field dilution, and the average population density along the near-field trajectory of the plume (Paddock and Ditmars1983). Most of the same stresses encountered in primary entrainment will also be encountered in secondary entrainment, the difference being that the magnitude of the stress will, in general, be much less.

Determining the effects on fisheries organisms of secondary entrainment will be even more difficult than for primary entrainment and results from previous power plant studies are limited in their usefulness. ...Large variation in hatching success suggested that the unknown hatching inhibitor in the mater fluctuated during plant operation. It is possible that trace metals in the effluent caused the variation, since previous work by Rosenthal and Alder dice (1976) showed reduced hatching in herring eggs exposed to trace metals. The effects of small changes in water temperature have been shown by Peters and Angelovic (1973) to be an important factor in controlling fish feeding and growth. Small changes in temperature (either increases or decreases) in the discharge plume may, therefore, have an effect on larval fish growth, but this will be very dependent on the depth at which the discharge occurs and the total area that is impacted.

Ocean Water Mixing

An OTEC plant's displacement of large quantities of deep ocean water can cause an upwelling effect that may disturb the natural temperature structure, salinity gradient and levels of dissolved oxygen, nutrients, and trace metals in the surface waters. Artificial upwelling is not a characteristic of conventional power plants; therefore, there is little direct analogy to the OTEC situation. However, some studies that have been made on nutrient distribution and changes in trace metal levels may be of some use in predicting upwelling effects.

In general, it is thought that the pumping of large amounts of deep nutrient-rich Ocean water to the surface layer may have positive effects if the same type of biostimulation occurs near OTEC plants as occurs near areas of natural upwelling.
However, whether upwelling will be harmful or beneficial to local ecosystems will depend on many factors as discussed in the section Impacts on Fishery Food Chains.

The concentration of trace metals in surface water may increase due to upwelling of metal-rich deep water or the formation of corrosion products. The impact of these increases will depend in large part on the amount and chemical form of the metals involved. The free ion activity, not the total metal concentration, determines biological *availability and effect. Increases in the bioavailability of micronutrients, e.g., iron, manganese, and copper, could increase production of the algae community. Similarly, toxicity could result from high availability of metals, such as copper, zinc, or cadmium, which could be detrimental to biological production.*

If the trace metal complement of the effluent water is harmful, the potential biostimulatory effect of upwelled nutrients may either not occur or be unnoticeable. The trace metal complement mill changes with time through a variety of processes, and a bloom may be merely delayed.

With current information it is not possible to predict what effect the altered trace metal regime will have on the utilization of up welled macronutrients, nor is it clear whether the effects will differ with location.

The Potential Range of Ecological Effects Resulting From OTEC Operations

Marine ecosystem impacts which may result from OTEC operations can be described only in very general terms. This section attempts to estimate the upper and lower bounds of these effects for a 40-MWe shore based plant with the effluent plume coming to equilibrium near the bottom of the mixed layer (see Effluent Discharge section). Impacts which we consider include impingement, primary and secondary entrainment, and nutrient enrichment.

This or any estimate of impacts is limited by the environmental data available and by an incomplete understanding of the amounts and types of ecological compensation which may occur. Also, evaluating the importance of projected effects will be particularly difficult and dependent upon resource and system boundaries.

Impingement-Impingement rates will depend on volume and speed of the intake waters and the abundance of animals larger than the mesh size of the intake screen and their ability to avoid the intake. An animal's ability to avoid the intake depends on (1) rheotactic behavior, (2) visual perception in low light environments, and (3) swimming speed.

Swimming speed depends on (a) species limitations (form or hydrodynamics), (b) temperature, and (c) physical condition. Physical condition depends on (i) nutritional state, and (ii) presence of disease or injury. While neither abundance nor avoidance capability is well documented, reasonable estimates are possible.

Fish, in general, can swim about 3-6 body lengths per second and will avoid intakes which are visible and in a horizontal flow field (Hocus and Dinger 1980). With estimated intake velocities of 0.25 to 0.30 m/s (see Seawater Systems section), it is unlikely that fish over 10 cm in length will be impinged, and many smaller ones could probably avoid the screens. The minimum length of fish impinged will be several times the screen mesh size. Thus, most impinged animals will be in a size range probably narrower than from 3 to 10 cm.

While there are no measurements of the absolute abundance of animals susceptible to impingement by an OTEC plant, trawl surveys conducted near Hawaii (Maynard et al. 1975) ...may be used to provide estimates of impingement rate.

While catch efficiencies of the trawls are not known, we assume the fishes' susceptibility to capture by net is about the same as by impingement. Although the nets were pulled several times faster than plant intake velocities, most animals caught where of the same small size (<10 cm) which is most susceptible to entrainment or impingement. By adjusting the reported trawl catches for items identified as undersized or soft-bodied (entrainable rather than impingeable) and oversized (those which can probably avoid an intake), we can estimate expected impingement. In both areas surveyed, fishes were the most abundant group, with crustaceans and cephalopods also present.

In Hawaii surface-waters, a combined catch of all three groups was 0.2 mg/m3 during the day and 5.4 in g/m3 at night. ...In these samples, there appeared to be few animals which were large enough to escape intake velocities. In Hawaii the net was pulled faster than in Puerto Rico ...and larger animals were collected. Adjusting the nocturnal catch in Hawaii for those fish weighing more than 10 g (those most likely to be able to avoid impingement) results in estimates of the biomass of animals which will be impinged at night (4.6 mg/m3). The average impingeable biomass over a 24-hour period is 2.4 mg/m3. Similar calculations with data from deeper water result in an estimate of impingeable biomass at the cold water intake of ...4.2 mg/m3 in Hawaii. ...

A 40-MWe plant ...would probably impinge 20-35 kg live weight daily from the surface water and another 40-65 kg at the cold water intake, roughly in accord (being an order of magnitude less) with the impingement estimated by Sullivan and Sands (1980) for a 400-MWe OTEC plant in similar waters (see Impingement section). These estimates of impingeable biomass are based on the assumption that larger organisms can detect and avoid the intake screens.

We are unaware of any measures of the concentration of larger organisms which could be used to estimate impingement rates on a screen which they could not detect; thus, our estimates can serve only as a lower bound. Higher rates are possible, but we have no means of estimating them.

Primary Entrainment of Plankton

Plankton entrainment rates are a function of plankton density and the rate of water intake. While the intake rate can be predicted and information on average density of various planktonic groups is available, their vertical stratification is, in many cases, not clearly documented. Those motile organisms which aggregate at particular depths may be entrained at rates vastly different than predicted from their average density in the mixed layer. Phytoplankton biomass is approximately the same in Hawaii and the Caribbean. ...

Judging from chlorophyll-a concentration at discrete depths, there is no consistent pattern in the vertical distribution of phytoplankton in the upper 50 m near Hawaii and Puerto Rico (Sands 1980). Thus, average concentrations can be used to estimate phytoplankton entrainment. However, it should be recognized that while mean abundances in Hawaii and the Caribbean are similar, individual measurements showed considerable variation, so the rate of entrainment of phytoplankton may also vary widely over time. To be conservative in estimating the range, extreme lower and upper *bounds are assumed to be 0.05 mg/m3 and 0.25 mg/m3. Daily phytoplankton entrainment by a 40-MWe plant, again with surface and deep-water intake rates each in the range of 120-200m/s, will probably be between 0.5 kg chlorophyll-a (0.05 mg chlorophyll-a m3 and 120 m/s) and 4.3 kg (0.25 mg chloropyll-am3 and 200 m/s). Assuming a factor of 100 for relating chlorophyll-a to organic carbon (Holm-Hansen 1969), we estimate that the organic carbon of phytoplankton entrained will be in the range 50 to 430 kg C/d. If the chlorophyll-a concentration is 0.1mg/m3, a figure frequently used to describe subtropical oceanic water, then phytoplankton entrainment will be in the range 100 to170 kg C/d.*

The zooplankton biomass which is subject to entrainment by an OTEC plant consists of two major fractions: macro plankton caught in conventional nets (200 pm or larger mesh) and microplankton small enough to pass through such nets. The larger animals in surface waters have been studied enough that their density is fairly well known. In Hawaiian water the mean dry weight biomass in the upper 200 m was 4.9 mg/m3 and 3.3 mg/m3 in two different sets of cruises (Noda et al. 1981b, from Uchida 1983). ...Converting these dry weights to near surface zooplankton carbon ...yields estimates of 1.3 mg C/m3 in Hawaii.

Macrozooplankton abundance at cold-water intake depths has not been studied as thoroughly as at the surface. The concentration clearly decreases with depth and will probably be less than 0.24 mg C/m3. The 0.24 mg C/m3 average estimated from four studies is probably inflated because many of the samples were taken during the day when plankton abundance is greater than the 24-houraverage and because we chose the highest of the conversion factors reported for estimating dry weight.

The smaller zooplankton, i.e., microzooplankton, have received little study so estimates of their density are not very precise. ...A study in Hawaii (Gundersen et al. 1976) showed an average biomass of 0.7 mg C/m3. ...We calculate the microzooplankton biomass averaged 2.3mg C/m3 in the eastern tropical Pacific and 1.2 mg C/m3 in the California current. From these estimates it appears that microzooplankton abundance is approximately the same as the average macro-zooplankton density in Hawaii.

This similarity in biomass of these vastly different sized animals has also been noted by Sheldon et al. (1977). With little information indicating the factors responsible for differences intensity of microplankton, a more precise estimate of abundance in surface water is not possible. With micro- and macro zooplankton densities in the mixed layer each averaging about 1 mg C/m3, the warm water intake of a40-MWe plant will entrain between IO and 17 kg C/d in each of the zooplankton size categories. For the lack of evidence that microplankton are abundant at such depths, we assumed that entrainment at the cold water pipe will be limited to macro plankton. If deeper water macro plankton are present at a density of 0.2 mg C/m3, then entrainment will probably range from 2 to 4 kg C/d.

Secondary Entrainment

Turbulent mixing will result in a rapid dilution of the effluent water through the entrainment of ambient water (see Effluent Discharge section). As a result, there is a potential for impact on the plankton present in the ambient water as they become entrained into the discharge plume. While it is difficult to predict the scale of impact from *this secondary entrainment, the potential effect is considerable. This impact will depend on the abundance of organisms in the dilution water, their sensitivity to the altered water quality, and the amount of water involved.*

Secondary entrainment will occur over a narrow depth range. Because of the desire to avoid recirculation of effluent back into the warm-water intake, the discharge location may be below 30m. Based on the density of the effluent relative to the density and density gradient of ambient waters near the discharge, the plume will come to equilibrium near the bottom of the mixed layer. Thus, it appears that the dilution water and therefore secondary entrainment of organisms will generally be from depths between 30 and80 m.

However, some recent modeling investigations (Wang 1984) indicate that there may also be an induced upwelling from beneath the plume which would entrain some water from below the mixed layer (see Regional Influence section).

Several characteristics of the effluent (e.g., reduced water temperatures, the presence of a biocide, and a super saturation of nitrogen gas) may adversely affect secondarily entrained organisms. Assuming a mixed discharge, we estimate that the temperature of the effluent at the point of discharge could be as low as 15°C. While many of the organisms which could be secondarily entrained engage in vertical migrations which expose them to a wide range of temperatures, others, including some of the ichthyoplankton, are not accustomed to such low temperatures, even thermally tolerant. Temperate organisms may be immobilized or killed by sudden exposure to cold temperature (Hoss et al. 1974; Bradley 1978; Stauf-fer 1980). The probability of mortality is greatest when the animals are living near their lower lethal limit.

While most of the important tropical organisms have not been studied for thermal effects, it seems likely that many of those found in surface waters are stenothermal (e.g.. tuna larvae) and may be impacted by temperature changes during secondary entrainment. While biocides will probably be introduced only intermittently and at low concentrations, it is reasonable to assume that if the biocide is concentrated enough to kill fouling organisms it may also affect the more sensitive animals which are secondarily entrained. Prediction of biocide impacts from current information is difficult because most research has involved temperate organisms.

Conducting additional research on biocide effects will be difficult because likely effluent concentrations are near the limit of detectability. Whatever biocide effects occur will be greatest in the zone of initial dilution where their concentration is greatest and thermal impacts are largest. Furthermore, previous research has shown that thermal and chlorine effects are synergistic (Hoss et al. 1977).

There is also a possibility that temperature or chlorine effects may interact with effects from gas super saturation. When saturated cold water is brought to the surface and warmed, it will be supersaturated with nitrogen, a condition which has caused fish mortality at other types of power plants. With all the uncertainty surrounding the effects of water quality on secondarily entrained organisms, any prediction of effects is largely subjective. Until additional information is collected, it is assumed that cold shock effects will be insignificant for short-term temperature drops of less than 2°C, even in combinations with biocide concentrations and nitrogen super saturation 20% that at the *point of discharge. If surface and deep water intake rates are equal, the total discharge rate will be twice the surface intake rate.*

Assuming the temperature of the mixed layer to be constant, the amount of dilution water required to reduce the temperature difference to 2°C would be 8 times the surface intake rate (a 5:1 dilution being needed to decrease the difference between effluent temperature and ambient temperature to 2°C). With the further assumption that the concentration of biota in the depth interval of 30 to 80 m is the same as used in estimating primary entrainment mortality, an upper limit on secondary entrainment mortality may then be about 8 times that lost to surface primary entrainment.

If cold shock rather than exposure to biocides, trace metals, or pressure changes is the major factor involved in the harmful effect of secondary entrainment, then many species may suffer only slightly, the most vulnerable being non-migratory animals. This, unfortunately, includes many fish larvae.

Impacts on Fishery Food Chains

Increased fish production can occur through either more primary production or shorter food chains, either of which could result from upwelling of nutrient-rich deep water. Primary production changes will in large part be due to the reaction of algae to nutrient and trace metal characteristics of the effluent plume. If these characteristics stimulate algal growth, fast growing diatoms will in all likelihood account for most of the production (Sunda and Huntsman 1983). If these diatoms are larger chain forming species they can probably be utilized directly by macrozooplankton. This could result in a shorter food chain than would occur if small algae were eaten by microzooplankton which were then eaten by macro zooplankton. Removal of one trophic step could increase fish production 5 to 10 times in the receiving waters.

In general, complex food webs, which occur in potential OTEC areas, are resilient so that most changes have little impact on ecosystem function. Minor changes in the food web, however, may drastically alter our acceptance of the fish produced. For example, blooms of the dinoflagellates which cause red tide or ciguatera can make the fish inedible. Unfortunately, the factors responsible for blooms of these algae are not well enough understood to allow precise estimates of OTEC influence on them. Based on the theory that most red tide outbreaks are associated with terrestrial runoff, they would not be expected as a consequence of OTEC operations. It is possible that minimizing disturbances of the benthic substrate (Bagnios 1981) during construction or operation of an OTEC plant will reduce the likelihood of ciguatera.

The indirect predatory effect of a 40-MWe OTEC plant on carbon or energy flow through the fishery food web is predicted to be minimal. Based on estimates of primary and secondary entrainment and impingement of various organisms ...the number of trophic transfers between the various trophic levels and fishery harvest, ...and an assumed trophic transfer efficiency of 15%, calculations were made of equivalent harvestable stock which would be lost due to OTEC operation. If all the entrained or impinged biomass were removed from the system, then 1.8 to 3.1 fewer kg of carbon would be available as fish harvest each day.

Based on a carbon-to-live-weight ratio of l:10 , about 18 to 31 kg of fishery harvest would be lost daily. This probably overestimates actual loss because it is likely that many of the organisms killed will be eaten and thus not be lost from the food web. Our projection that food chain effects will not significantly impact the fishery does not address direct effects on the harvested species.

Many of the fishes are currently being harvested at levels equal to or greater than the Maximum Sustainable Yield (MSY). If such assessment of harvest levels is accurate, then those stocks may not be able to compensate for the individuals lost through entrainment or impingement, and yield will be reduced.

Unfortunately, we do not know the fine-scale temporal and spatial distribution of the early life stages of the major species, and thus are unable to predict the number which may be impacted by OTEC operation. In addition, our knowledge of the survival of these early stages is too incomplete to predict the amount of impact on the resource.

Potential Impact on Fisheries

Defining in detail what constitutes significant adverse impact on fisheries is very subjective. Effects which reduce commercial and recreational fisheries harvest would likely be considered adverse. On the other hand, if the plant were to serve as a fish aggregating phenomenon, harvest efficiency may be increased and the overall effect considered beneficial. However, this potential beneficial effect would have to be weighed against the overall negative effect that aggregation (see Attraction/Avoidance section) may have on entrainment and impingement. In predicting impacts of conventional power plant operations on fish population levels, scientists have relied on life cycle models which focus on those components of the life cycle which are susceptible to power plant effects at the appropriate stages. Simple models take a gross view of the life cycle, examine the environment in which the species exist, and incorporate details of the plant operations and effects. More complex models account for increased temporal resolution, more detailed environmental variation, and knowledge of behavioral responses to changes in the environment.

With OTEC, adverse impacts cannot be examined with any degree of confidence because what information is available on fish eggs and larvae at potential sites is not sufficiently precise. Furthermore, effects from operations of conventional power plants can hardly be extrapolated to that of an OTEC plant because of the unprecedented volume of water the latter is expected to pump and the redistribution of water properties that will occur. However, in the absence of data which can be used as input into a life cycle model, a crude evaluation of OTEC-related impacts on fisheries has been made by Matsumoto (1984) for the purpose of this study, based on a review of the combined effects of impingement, direct entrainment, and biocide usage to fish. Matsumoto (1984) concluded that an assumption of total mortality of all fish eggs, larvae and juveniles, directly entrained is not unreasonable.

Because the eggs and larvae of most fishes caught commercially off Kahe Point are buoyant and tend to reside near or at the surface, the degree of secondary entrainment of fish eggs and larvae will be very dependent on the discharge depth of the effluent. Little is known regarding the effects of secondary entrainment; however, Matsumoto (1984) believes the effects would be minimal for deep (e.g., 100 m) discharges. More *information is needed, however, on the micro-distribution of fish eggs and larvae to judge whether such a conclusion would be justified for shallow discharges where the degree of secondary entrainment may be 10 to 20 times (worst case) that of direct entrainment on the warm water side.*

If 100% mortality is assumed for both direct and secondary entrainment, one must then ask what effect this will have on fisheries. Off Kahe Point, the principal fisheries that would be affected by OTEC operations include six pelagic and two demersal fish groups representing 98% by weight of the area's total annual production. The pelagic forms include tunas (mainly skipjack and yellowfin tuna), billfishes (Pacific blue and striped marlin), mahimahi, wahoo, bonefish, and jacks (principally scads), where the demersal forms include goatfishes (six species) and snappers (eight species). Based on density values of tuna and billfish larvae at depths near the warm water intake and discharge points, and warm and coldwater intake rates of 160 m/s. ...Assuming total mortality during entrainment, it was estimated 13.7 million skip-jack and 5.5 million yellowfin larvae will be killed each spawning season. To be more realistic, these mortality figures must be adjusted for natural mortality which is estimated at 93% for skipjack and 91 % for yellowfin. This would result in estimates of OTEC-induced mortality of 1.0 million and 0.5 million, respectively. Any effects of secondary entrainment would add to these figures; however, Matsumoto suspects that the effects of secondary entrainment would be minimal.

The OTEC plant is also expected to function as a fish aggregating device and attract fish from adjacent areas. Any increase of large aggregations of fishes, such as tunas, mahimahi, mackerels, and carangids, will eventually result in concentrated spawnings around the plant, subjecting more than the usual amounts of eggs and larvae to entrainment effects. The impact on fisheries will be largely through the recruitment process. Through recruitment, the impact on pelagic species, particularly tunas, is not expected to be noticeable because most of them are migrants from the eastern Pacific fishery, the northwestern Pacific, and from equatorial waters. The effects of recruitment on bottom and reef-associated fishes would most likely be felt in areas further downstream from the plant site, if the prevailing currents carry the eggs and larvae along the coast and out into open ocean. The full impact of the damages caused by the plant may not be apparent at the plant site. Direct effects could occur, however, in the demersal fishery.

For the Ocean Thermal Corporation OTEC design for Kahe Point, Oahu ...warm effluent from the Hawaiian Electric conventional power plant at Kahe Point is used as a supplementary heat source, and sand particles which are contained in this effluent (McCain 1977; Coles 1980) will eventually be discharged over the escarpment and build up over a period of time, blanketing the rocky bottom near the discharge point. The effect would be to force fishes such as snappers to relocate to other areas. The net effect to the fishery should be negligible, however, since demersal species comprise only a small portion (1.3%) of the total fish production off Kahe Point. ...

MEASURES TO REDUCE POTENTIAL EFFECTS TO FISHERIES

From the previous chapter and background reports, one can conclude that there will remain some level of uncertainty regarding the potential risk to fisheries due to construction and operation of an OTEC plant until a full-scale OTEC operation can be *monitored for some period of time. However, certain aspects of an OTEC operation warrant enough concern to examine measures that would minimize the risk to fisheries of early plant operations.*

First, from the viewpoint of general environmental risk, proper siting is the single most effective means to minimize the potential for environmental damage. The avoidance of areas of high biological productivity and others of special biological importance (e.g., critical habitats, spawning grounds, coral reefs) is desirable. However, the flexibility in choice of location may be limited in many of the islands that have a suitable thermal resource.

For instance, as noted by Uchida (1983), there are a number of sites in Hawaiian waters that satisfy criteria for both near shore floating and shore-based OTEC power plants. However, on the island of Oahu, only the area along the Waianae coast from Barbers Point to Kaena Point was concluded to meet certain criteria for OTEC siting (Shupe1982). Along or offshore of this part of the Oahu coast are major coral formations and important commercial and recreational fisheries. Once the location has been tentatively chosen preliminary oceanographic information will have to be collected to identify initial engineering flexibility. This will include information on the thermal resource, waves and tides, currents, and extreme oceanographic events. ...

Cold Water Intake

Generally, reviews by Hoses and Peters (1983) and Uchida (1983) reveal that the direct environmental implications of the deep water intake of cold water are small. The depths involved are below the euphotic zone, estimated to be in the range of 100-150 m in sub-tropical waters of the Caribbean and the Pacific. As a consequence, the entrainment of phytoplankton by the cold water pipe (CWP) is not a concern.

The information on zooplankton distributions indicated that the CWP will entrain certain zooplankton. It is also apparent that the deeper the placement of the CWP intake, the fewer the number of zooplankton that will be entrained. If the CWP intake could be placed beneath the zone within which certain zooplankton undergo die migrations (see Zooplankton section), this would also help to minimize entrainment.

However, the extension of the CWP to depths deeper than necessary to achieve the needed AT would be very ex-pensive, since this is one area where present technology is being advanced. This could also totally upset the financial aspects of a plant since the CWP construction and deployment costs will comprise a major percentage of the total construction and deployment costs. It might be argued that the cost of extending the CWP to deeper depths to achieve less entrainment of zooplankton would be offset by a decrease in seawater volume requirements, and thus pumping requirements, if a sufficiently greater AT was obtained. Although such trade-offs will have to be examined on a site-specific basis, such factors tend to balance out when consideration is given to other factors such as the increase in pipe frictional losses. Any extension of the CWP is going to be expensive.

Furthermore, although deep zooplankton play a role in the food web and thus fisheries, it is not a well defined role as yet. Therefore, the true benefit of trying to avoid deep zooplankton entrainment cannot be quantified with the present state of knowledge. As *noted by Hoses et al. (1983) and in the section on Eggs and Larvae of Important Species, little information is available on the vertical distribution of fish eggs and larvae in the Caribbean and Pacific. However, it appears that they are most abundant in the upper 25 in, particularly at night. Although Miller (1979) suggests therein be a deep source of certain larvae in waters near shore Kahe Point, few larvae are found below 200 m. The relative lack of information on fish larvae suggests that additional information should be gathered at specific OTEC sites when a design is contemplated.*

The most significant environmental implication of the CWP in-take would appear to be related to the intake in these deep waters of nutrients and other natural chemical constituents, which are generally present in greater concentrations here than in surface waters (NOAA 198 la). Since the potential environmental impact does not relate to the intake as much as to the discharge of these constituents back to the ocean near the surface, this topic is taken up under discharges (see Discharge Location and Configuration).

To conclude this section, it is suggested that for most situations the placement and configuration of the CWP will be driven by economic considerations. However, the lack of flexibility in design does not seem to imply any significant disadvantage in terms of potential environmental impact and risk to fisheries.

Warm Water Intake

As discussed under Biological Interaction with the Environment, the warm water intake will have significant interaction with the biological environment, entraining or impinging phytoplankton, zooplankton, ichthyoplankton, and fish. Generally (see Phytoplankton), the concentration of phytoplankton increases near tropical and subtropical islands due both to the upwelling of nutrients from depths as well as a greater input of nutrients from the land mass. Also, in both the Caribbean and Pacific areas under discussion, the levels of maximum phytoplankton biomass tend to be near the 100-m level, near the bottom of the mixed layer. For instance, for waters off Keahole Point, Hawaii, Noda et al. (1980) reported that the subsurface chlorophyll maximum occurred between 64 and 94 m. Chlorophyll-a levels tended to be relatively constant in the top 40 m or so of the water column. In general, they increase below this level to the levels found at the chlorophyll maximum and then quickly decrease to very low values, with the lowest values occurring beneath the euphotic zone. As noted by Uchida (1983) for six cruises in the Kahe Point environment, Noda et al. (1981a) observed that the chlorophyll maximum remained relatively constant in its vertical position at 86 m as well as in its concentration. Furthermore, this layer accounted for 77% of the chorophyll biomass in the photic zone.

The discussion in the section Impacts on Fishery Food Chains suggests that the predatory effect on harvestable fish stock caused by any food chain effect of the entrainment of phytoplankton is not a concern. However, where the design flexibility exists, it is probably prudent to avoid the direct entrainment of phytoplankton to the extent practicable. In light of the information on phytoplankton distributions, this would suggest that the warm water intake of an OTEC plant should probably be located in shallow water (i.e., 0-40 m). The secondary entrainment of phytoplankton is a separate issue and is discussed under the next section.

As discussed in the Zooplankton section, the abundance of zooplankton tends to be greatest near the level of the chlorophyll maximum, particularly at night when many zooplankters migrate from both deeper and shallower waters to this level. Thus, the avoidance of zooplankton to the extent practicable also suggests relatively shallow warm-water intake depths. However, as in thecae of phytoplankton, the effect on fish stocks due to the predation of zooplankton by an OTEC plant of 40-MWe capacity is not expected to be significant (see Impacts on Fishery Fond Chains). Like phytoplankton zooplankton also exhibit an island mass effect with Concentrations higher at near shore locations (see Zooplankton section). ...

The only conclusion which can be drawn from observations of larval fish (see Eggs and Larvae section) is that the actual distributions may be quite complex. The implication is that the spatial, temporal and species distribution of larval fish should be determined before engineering flexibility in the location of the warm water in-take is considered. From the standpoint of impingement and entrainment of adult fish, the warm-water intake velocity is a critical factor with lower velocities being more desirable (see Impingement section).

The general guideline regarding velocities for conventional power plant intakes is to keep the velocity below 15 cm/s so as to allow fish to escape the screen wells (U.S. Environmental Protection Agency 1973). Although the effectiveness of velocity caps (covers used to create horizontal velocity fields for a vertical intake) to reduce fish entrainment is not universally accepted, EPA recommend their use for offshore, submerged intakes; the principle is that fish tend to avoid horizontal velocity fields more so than vertical ones (see Impingement section).

<u>Discharge Location and Configuration</u>

The discharge of effluent waters from an OTEC operation has important implications for both the operation of the plant and its environmental effect. It is of great importance that discharge waters not recirculate to the warm water intake and thereby reduce the effective thermal resource of the plant. However, for most situations the negative buoyancy of the discharge plume and the initial dilutions achieved (see Effluent Discharge section) should assure that recirculation is not a problem.

It is also of great importance that a discharge scheme be chosen so as to minimize the potential effects to fisheries and other biological resources. As discussed, the initial and, to a certain extent, subsequent fates of the effluent plume will be very dependent upon the density of the discharge, the configuration of the discharge outlet, the vertical ambient density distribution, and the presence of currents. ...For the Kahe Point case considered, the upper 50 m were fairly mixed so that there was little stratification in density. The calculations showed that there would be little impedance to the sinking of effluent plumes, whether mixed or separate, until a depth of 50-100 m was reached. Discharges at 100 m did not stray too far from that depth because of the stronger stratification there. Calculated dilutions were in the range of 4-7. ...

Although the examples offered are limited, they do provide an indication as to how the level of neutral buoyancy (where the density of the plume equals that of the ambient waters) and dilutions are affected by the type of discharge. For a given situation, larger differences in density between the discharge and receiving waters will involve longer *trajectories and higher dilutions before a neutral buoyancy is achieved. This may be desirable if dilution and removal of certain constituents (e.g., chlorine) from the immediate environment is desired. However, it might be undesirable if the redistribution of organisms is a concern, or if the utilization of nutrients from the cold water is possible and desired. Long trajectories and high dilutions also result in larger secondary entrainment of the organisms which could have an effect many times that of primary entrainment.*

This brief treatment of discharge schemes provides only a glimpse of the discharge possibilities and how they might be used to advantage. The presence of currents, occurrence of coastal upwelling, and placement of the plant will greatly influence the final schemes chosen. Also if the plant is land-based, an artificial island, or a shelf sitter, the presence of the seabed may influence the selection. For example, a mixed effluent discharged to shallow waters will probably hit the seabed before it reaches its level of neutral buoyancy. This would affect the rate of subsequent dilution and also cause impact to benthic biological resources in the area, such as corals.

It is obvious that the discharge scheme, more so than either of the intakes, will have to be tine-tuned to the environmental conditions at a site. ...

For the most part, the normal release of working fluids and metals from heat exchanger and other surfaces is not expected to be a problem (see Chemical Additions section). Given that a biocide such as chlorine may be a necessary evil for an OTEC operation, a certain amount of engineering flexibility can still be utilized to reduce the degree or scale of potential effects. All of the previously discussed options are definite candidates (i.e., plant location and intake discharge schemes). For instance, achieving a high dilution and a level of neutral buoyancy below the euphotic zone may be very desirable to limit the exposure of biota to the biocide. This would require the identification of a certain optimal discharge scheme. In addition, certain dosing schemes can be used.

Flexibility in biocide dosing might involve applying the biocide to different power modules at different times and mixing the dosed module effluent with other module effluents to create some degree of pre-dilution. For instance, if a 40-MWe OTEC plant was composed of four 10-MWe modules and the condenser and evaporator could be dosed separately, a certain dose to one of the evaporator units and subsequent mixing with the total warm and cold water discharge would produce a dilution of 8 to 1 prior to discharge. In other words, a free residual chlorine level of 0.05 pg/g in the effluent of the evaporator or unit in question, would be diluted to 0.006 pg/g before discharge to the environment. Initial dilutions of 5 to 10 could further reduce these concentrations to 0.0012 and 0.0006 pg/g respectively.

<u>RESEARCH PRIORITIES</u>

The preceding sections have presented information and inferences regarding the potential effects of OTEC operations on fisheries. The discussions have primarily relied upon information on power plant effects in temperate waters and the limited biological information available for tropical waters.

Although such an assessment provides valuable insights regarding the effects of early small-scale OTEC development, a more thorough assessment will eventually be needed.

To do so will require much additional research of both generic and site-specific types as defined below. However, although further research is needed, the preceding sections also allude to areas where additional information is either not needed or deemed to be unimportant. Specifically, the assessments in the Biological Interactions section of the predatory effect of an OTEC plant on phytoplankton and zooplankton (with the exception of ichthyoplankton) would suggest that the effect is so minimal as to not warrant further investigation of this topic.

As emphasized below, additional information on the eggs and larvae of fish is direly needed.

Investigations of Fish Distribution

There is almost no quantitative information available on the distribution of the early life stages (eggs to juveniles) of fish in tropical waters. Both spatial and temporal information of this type is needed and should be given high priority, in order to determine the potential numbers of fish that will be subjected to impingement and primary and secondary entrainment. An understanding of the distribution of fish in the water column may allow plant modifications to be made that will help decrease the environmental impact of OTEC operations. Studies on the Effects of Entrainment Primary and secondary entrainment effects associated with OTEC are potentially important because of the extremely large volumes of water involved. Unlike conventional power plants where organisms experience an increase in temperature as they pass-through the condensers, larval fish entrained in an OTEC plant will be subjected to a decrease in temperature of about 2°C upon passage through the evaporators. Additionally, in the case of a mixed discharge, organisms entrained in the warm water intake will be further subjected to a decrease in temperature of about 10°C when the warm and cold waters are mixed.

Depending on where this discharge is made, secondary entrainment may expose additional organisms to some temperature decreases. Since we found no reported work on the effects of cold shock on the young of tropical fish, research on this subject was initiated by the National Marine Fisheries Service. This research is examining the effects of cold shock (using realistic decreases in temperature) that could occur as a result of entrainment. In the future, factors such as the addition of biocides and increased levels of trace metals in the water should be examined in conjunction with the temperature studies.

Biostimulation/Inhibition

The OTEC plants are unique in their utilization of cold water from the deep ocean. This use of large amounts of deep ocean water creates a potential for changes in the upper part of the water column similar to those caused by natural upwelling. The increased nutrient load of cold, deep ocean waters may have stimulating, inhibiting, or no effects on the productivity of marine fisheries. Although some experiments have described the effect of mixing deep water with surface waters at potential OTEC sites (e.g., Quinby-Hunt 1979; Szyper et al. 1984), further work is needed. This research should look at nutrient and trace metal distributions of waters from different depths and test their ability to affect primary production and species composition. This type of research can be completed in a relatively short time, and the results must then be combined with the *effects of natural nutrient fluxes to determine the ecological significance of potential changes in primary production.*

Early Life History Studies

It appears that the major direct impacts of OTEC operations on fish will be on the early stages in their life history. In order to evaluate OTEC impacts on these stages, we need more information on their abundance, distribution, migration, and growth and mortality rates. Generic information on tropical species is lacking and general principles may be applicable to many species. Such information should be collected, starting with some of the major recreational and commercial species. The duration for this type of research is in years, but specific parts can be completed in less time.

Dynamics of Fishery Populations

The research priorities outlined above are directed at establishing the effects of OTEC operations on the biological community which supports and includes harvested fishery populations. Such research should indicate whether effects may be positive or negative and supply information needed to predict the number and life stage offish directly impacted. In order to evaluate any such effects as they relate to commercial or recreational fisheries, additional information is needed.

For example, while some information is available on many of the fisheries, much more is needed, including:

1) Stock structure (i.e., the number and geographic distribution of the stocks);

2) Stock assessment over time, which depends upon age distribution of the stocks, size at age, and age-specific fecundity,

3) Accurate catch and effort statistics, and

4) Increased information about the factors affecting recruitment, including development of models to predict compensation for mortality at various early life stages.

Although parts of this research area can be performed over short time scales, the topic as a whole will require years to address adequately.

Ciguatera

Independent of other impacts, fisheries could be severely impacted if the fish present were inedible due to ciguatera fish poisoning, which occurs in many tropical waters. Current information is inadequate to predict or prevent such an occurrence, and additional information is needed, including a description of the environmental factors responsible for blooms of the toxin-producing algae, methods of easily detecting contaminated fish, and methods of mitigation.

Construction Effects

Further research is also needed to properly assess the effects from disturbances to the environment (including the fisheries) by actual construction of the OTEC facility. Any dredging in open seas will generate turbidity and sedimentation, not only in the immediate area of construction but also in adjacent areas. Sediment in the dredging plume will settle out of the water column, covering and perhaps killing some benthic life, including, possibly, coral communities. Dredging has also been found to be correlated with outbreaks of ciguatera poisoning. Thus, in addition to the information needed on ciguatera, there is a need to gather data on effects of sediment son coral reef ecosystems as well as on the downstream extent of the dredging plume.

CONCLUSIONS

This report examines the potential impact to fisheries due to the operation of ocean thermal energy conversion (OTEC) plants. The effort is primarily a synthesis of existing information that has pertinence to the topic, and an extrapolation to conditions brought about by OTEC operations. The intent was to gain a perspective of the potential risk to fisheries, to identify practicable measures that would reduce the potential for problems, and to suggest research areas where significant uncertainties exist, uncertainties that under certain conditions might impede the commercial development of OTEC.

The report focused on two regions where U.S.OTEC interests might lie: the Caribbean, in the Pacific.

It also focused on near-shore operation of OTEC as compared to open ocean application; the rationale here is that the near shore area is considered to be the more ecologically sensitive as well as more likely to see OTEC development in the near term. Additionally, the report has contained itself primarily to those factors of concern that would be associated with the normal operating conditions of an OTEC plant: the impingement and direct entrainment of biota, the secondary entrainment of biota, the redistribution of ocean water properties, and the addition of biocides and other chemical constituents.

These concerns are highlighted by the relatively large volume of water that will be pumped through OTEC plants. Fish impingement rates caused by these flows will depend on the abundance of fish which are larger than the mesh size of an OTEC intake screen and on the ability of the fish to avoid the intake. Although this avoidance ability will also depend on a number of factors, it can be increased through the use or creation of horizontal intake flow fields. It can also be increased by keeping the flow speeds as low as practicable.

It is estimated that a 40-MWe Hawaiian or Puerto Rican OTEC plant would impinge about 20-35 kg of organisms daily, due to the warm water intake, and another 40-65 kg at the cold water intake. It is estimated that the effect on a fishery of such impingement rates will be negligible compared to other pressures on a fishery; however, the use of the above mitigating measures and attempts to locate intakes away from areas of high biological activity are recommended. Organisms, including fish eggs and larvae, that are caught up in the intake flows and not impinged, will be entrained, travel through the plant, and then be discharged. Although the combined effect of the various stresses that *these entrained organisms would undergo is difficult to quantify with accuracy, it is considered prudent to assume 100% mortality until better knowledge is available.*

Additionally, entrainment mortality will be added to by the secondary entrainment of organisms. This entrainment is due to a discharge plume that, in falling or rising to find its level of neutral buoyancy, entrains surrounding water and biota as it is diluted. With typical dilution ratios expected to be in the range of 5:1 to 10:1, the level of secondary entrainment may be quite high.

However, until further information is gathered, assessments of the associated mortality are very subjective. It is concluded that cold shock to biota may be the main concern with secondary entrainment arid that organisms may only suffer slightly. However, the most vulnerable of the organisms will be the non-migratory species; and these, un-fortunately, include many larvae. OTEC plants have the potential of influencing the food chains leading to fish in several ways. Increased fish production can occur through either more primary production or shorter food chains, either of which could result from the "pumped upwelling" of nutrient-rich deep water. On the other hand, minor changes in food webs may drastically alter our acceptance of the fish produced.

*For example, blooms of the dinoflagellates which cause red tides or ciguatera can make the fish inedible. Although more information is needed on such processes, red tide outbreaks are not expected and the minimization of benthic disturbances during OTEC construction and operation will reduce the likelihood of ciguatera outbreaks.
In trying to examine impacts to fisheries due to mortalities associated with OTEC operations, one key problem is the lack of detailed information on the spatial and temporal distribution of fish eggs and larvae, the natural mortality of most fish, and the range of natural variability associated with the various life stages of fish. This results in a low degree of confidence in anything beyond rather subjective conclusion. However, even these conclusions are valuable until further information is gained. Design measures that might be taken to reduce the potential risk to fisheries relate to the location of the plant, location and configuration of the intakes and discharges, and the mode of introducing biocides to the system.*

From the viewpoint of general environmental risk, proper siting is the single most effective means to minimize the potential for environmental damage. Here, the avoidance of areas of high biological productivity and of others of special importance (e.g., critical habitats, spawning grounds, coral reefs) is desirable. For most situations the placement and configuration of the coldwater pipe will be constrained purely by economic considerations. However, the perceived lack of flexibility does not seem to imply any significant disadvantage in terms of potential environmental impact and risk to fisheries. Regarding the warm water intake, it is felt that more information is needed on the microscale distribution of fish eggs and larvae. However, in general, it is believed that warm water intakes placed below the surface, where many fish eggs rend to concentrate, and above the chlorophyll maximum maybe most desirable. This suggests a placement between about 10 and40 m.

Additionally, if there was some flexibility over the location of the plant, particularly its warm water intake, a plant located further offshore might imply a lower environmental and fishery risk on qualitative grounds, other factors being equal.

The placement and configuration of discharges will be a very site-specific consideration. Mixed vs. separate, and deep vs. shallow, discharges can achieve different dilutions and levels of neutral buoyancy. Different permutations have implications regarding the utilization of cold water nutrients, the potential for recirculation into the warm water intake, the degree of secondary entrainment, the amount of cold shock, and the concentration of biocides.

Brief treatment of the possibilities suggests that in deeper water the discharge of a mixed effluent near the surface would offer a number of advantages. First, the cost of the discharge structure is minimized.

Second, the plume, because of the density addition provided by the mixed cold water, would probably sink deep enough to avoid problem of recirculation into the warm water intake.

Third, sufficient dilution would be imparted to minimize potential problems with biocides and other trace constituents. Also, the mixed discharge would minimize the degree of cold shock to organisms secondarily entrained. However, with the discharge near the surface, there may be some impact associated with the entrainment of ambient water and organisms into the discharge plume.

The presence of currents, occurrences of coastal upwelling, and placement of the plant will also influence the final discharge scheme chosen for a particular plant. For instance, for a land-based or very near shore plant, the effluent from a near surface discharge will probably hit the seabed and roll down it before the level of neutral buoyancy is reached. Depending upon a number of factors, e.g., benthic resources, this might necessitate a deep discharge.

In general, it is not believed that the effect of the corrosion products of metals will be a problem with OTEC. However, the addition of chlorine as an antifouling over long time periods does create smile concern. Although more information is needed on the chemistry and long-term effects of chlorine, this concern is lessened through the achievement of high dilutions of the biocide and/or a level of neutral buoyancy near the bottom of the euphotic zone. Certain dosing schemes can be utilized to achieve predilections that, combined with the initial dilution process would result in much lower levels of biocides in the environment.

In conclusion, the potential risk to fisheries of OTEC operations is not judged to be so great as to not proceed with the early development of OTEC. Due to the lack of a suitable precedent, however, there will remain some level of uncertainty regarding these initial conclusions until a pilot plant operation can be monitored for some period of time. In the meantime, further research on fisheries should be undertaken to assure an acceptable level of risk regarding the larger commercial OTEC deployments.

APPENDIX 5: WAIANAE COMMUNITY RESPONSE TO KAHE OTEC (1983-86)[342]

OTEC is a solar energy technology based on the heat engine principle. ...

In September, as provided under PL 96-310, the DOE announced a Program Opportunity Notice (PON) for the design, construction, deployment, and operation of a closed-cycle OTEC pilot plant.

According to the PON, the DOE would consider a jointly financed venture with a private developer. Prospective contractors were to submit joint financing proposals and the DOE would select the most qualified and financially advantageous project. The joint DOE/private sector project was to proceed in six phases:

Phase I: Conceptual design, February 1982 to June 1983;

Phase II: Preliminary design, September 1983 to November 1984 (last completed phase due to budget cuts);

Phase III: Detail design;

Phase IV: Construction, deployment, and acceptance testing;

Phase V: Joint operational testing; and,

Phase VI: Transfer of ownership.

A major requirement was that the plant produce a minimum power output of 40 megawatts (MW) so that additional information leading to a full scale plant of about 100-400 MW could be obtained. Nine respondents to the PON were received with three proposed for Hawaii:

1. Ocean Thermal Corporation
2. General Electric/Brown and Root
3. SOLARAMCO

In February, 1982, the DOE decided on two contractors: General Electric and Ocean Thermal Corporation. Both proposed facilities were to be sited off Kahe Point, Oahu, with the generated electricity to be transferred by cable to the nearby HECO Kahe Point power grid.

The GE proposal was to locate its plant on a fixed steel platform approximately 1.6 km offshore in water approximately 100 m deep. The working fluid was to be Freon.

---

[342] Ocean Thermal Energy Conversion at Kahe Point: An Attempt at Community Dialogue (November 1986) by Brian Takeda, Department of Urban and Regional Planning, University of Hawaii. Program on Conflict Resolution (PCR), Matsunaga Institute for Peace, University of Hawai`i at Manoa. Prepared for the Hawaii Natural Energy Institute (HNEI) and the State of Hawaii Department of Planning and Economic Development (DPED). Working Paper Series: 1987-03

The OTC proposal was in initially to locate a concrete, land based structure on an artificial island approximately 180 m offshore, in water approximately 9 m deep. A causeway built of rubble was to connect the plant to shore. The working fluid was to be ammonia.

During Phase I: Conceptual Design, OTC determined that plant costs could be lowered by moving the plant to 550 m offshore in 15 m of water. The land-based concept was abandoned in favor of locating the containment structure directly on the sea floor with the rubble causeway to be replaced by a concrete trestle (Office of Technology Assessment: 1984).

The GE proposal was also modified. Because of the forces of wave action, structural modifications to the heat exchangers were necessary. This consequently changed the selection of working fluid from freon to ammonia.

By mid-1983 the DOE, having reviewed the results of Phase I by both GE and OTC, decided to fund only the OTC contract for Phase II: Preliminary Design.

According to the design studies, OTC's pilot plant would be approximately 113 m long, 72 m wide, and with a roof extending 14 m above mean sea level (OTC:1984:2-2). In other words, the structure would be roughly the size of a football field.

By July 1983, the DOE also decided that additional funding would not continue beyond the results of Phase II. According to a review by the Office of Technology Assessment (OTA), Phase II work was to commence around September 1983, last approximately 18 months, and end in February 1985.

Since 1984, however, additional DOE funding has not been forthcoming although the State of Hawaii had already provided almost $2 million for environmental studies. ...

Under the PON proposal, the DOE was to jointly finance the OTEC pilot project. During this time, however, there was an on-going shift in federal policy toward energy research and development relating to solar energy (OTA:1984:2).

Sometime in late 1982 or early 1983, OTC was notified that the federal share of funding would not continue beyond Phase II: Preliminary Design. If OTC was to complete the project it must do so with funds acquired from private investors. In January, 1983, the State OPED had issued a pamphlet entitled, "State of Hawaii Public Sector, OTEC Program, 1980-1985." The pamphlet stated the OPED had a lead role in assessing impact and public information. OTC, however, decided the OPED would not have to be consulted at that time.

Initial Contact with Waianae Neighborhood Board #24

In late 1983, OTC subcontractors, represented by Lloyd Jones, Advanced Projects Manager for Hawaiian Dredging and Construction (HOC), and John Knox and Berna Cabacungan representing SMS Research (later changed to Community Resources, Inc.), initially contacted the Waianae Neighborhood Board #24 (WNB). ...

Lionel Oki, an attorney who served on the WNB, was invited to serve as a CAC member. Oki eventually accepted. "He would help keep us (the developers) honest," said Knox who was concerned that the community perceive the CAC as representative.

Following the discussion period Knox and Cabacungan selected 12 regular and 6 alternate members for the OTEC CAC. The Fina1 criteria used in making the selection included:

1. Adequate representation of the different potentially affected community areas from Ewa to Waianae;

2. Adequate representation of different potentially affected interests such as fisherman, surfers, boaters, businessmen, divers, and canoe paddlers;

3. A history of previous community involvement and leadership; and,

4. A willingness to keep an open mind on the use of a community dialog process to determine how OTC and the CAC can best make decisions about the project.

In retrospect, some CAC members saw OTEC as inevitable. Since the project was coming, the community should try to get whatever it could out of it (Landis:1986). Other CAC members felt that if OTC could not generate some kind of major consensus from all of the potentially affected communities, then there might be a long drawn out battle.

During the permitting process, when public hearings were to be held, the community could prolong the process by making claims that the project was not safe, that the impact on the surrounding marine life had not adequately been considered, or any number of related questions (Lapilio:l986). The strength of the CAC for those who took this position was that the potential to defeat the project could be used as leverage in the bargaining process.

Another concern was whether or not the CAC could represent multiple community interests. From January 4 to approximately June 27, 1984, the CAC met regularly once each week for about 2 hours per meeting. At one of the meetings Bob Hoffman, a CAC member commented, "We were not appointed to represent the community. I was asked to represent the scuba diver's concerns. We are not representing the community (CAC Meeting:2/29/84). At the same meeting another member reiterated Hoffman's concern, "If we say we want fishing on the pier (trestle), it doesn't mean the entire neighborhood wants fishing on the pier. So, at an early stage (February) at least some of the CAC members felt their role was not to represent the community, but rather specific interests.

In retrospect, Knox commented that the CAC was to act as a model of diffusion, taking the content of the CAC meetings back to the wider communities. It was hoped the CAC members would discuss whatever issues developed with their respective interest groups and would in turn ensure representation of those interests at the meetings.

Interestingly, while the developer representatives could identify the role the CAC would play, the members in the CAC had difficulty understanding their role as a group. The members were saying:

1. The strength or power of the CAC could either be in the power to stop the project or, OTC's interpretation, that the CAC could make suggestions which OTC could then carry out; and,

2. The CAC did not represent the Leeward Coast communities but rather specific interests in those communities (fisherman, surfers, etc.).

Another member, who was concerned about potentia1 blasting and safety considerations involved in the use of ammonia and chlorine, saw the issue as much more elementary. If certain questions regarding plant safety could not be answered, then it made no sense to discuss benefits OTC might offer (Ross:1986).

Despite the different interests and views, the CAC meetings continued as planned. By April, the following major issues had emerged:

1. The necessity of a concrete trestle to connect the OTEC facility with the HECO Kahe power station;

2. The effects from construction and blasting and the possibility of ciguatera (fish poisoning);

3. Safety considerations involved in the use of hazardous chemicals, especially ammonia and chlorine;

4. The effects of the cold and warm water pipes on juvenile fish fry and planktonic organisms on which fish fry and other ocean animals feed; and,

5. The development of the Waianae coastline. ...

Because the OTEC facility was to be constructed on an open reef, a certain amount of dredging and blasting might become necessary. ...

Between January 4, 1984 and April 3, 1984, the CAC had met with the developer approximately 11 times (WNB #24 Meeting Minutes: January 4, 1984 through April 3, 1984). As far as CAC members were concerned, many questions regarding the use of ammonia remained unanswered. ...

One feature of OTEC is the use of warm surface and cold deep ocean water. The collection pipes used to obtain this water also ingest planktonic organisms, juvenile fish fry, and fish eggs. The amount is difficult to estimate. After passage through the heat exchanger, the organisms would probably be damaged. This issue soon became one of extreme concern. A flyer, published by community members who were not part of the CAC, stated:

"...Just the warm water intake pipe for OTEC alone will kill nearly 1000 pounds of fish eggs and small fish ... according to a recent OTEC Environmental Assessment. The report says that more than 10.000 adult fish per day or over three and a half million adult fish per year will be sucked into the OTEC pipes and be killed. Millions more fish eggs and keiki (fry) fish will be sucked into the 24-foot diameter cold water intake pipe each year. If built here at Kahe. OTEC would act like a giant ocean vacuum cleaner

sucking up fish eggs, fish keiki and adult fish for 24 hours a day, for 30 years" (Talk Story: Na Opio Aloha Aina: 1984).

How the Na Opio Aloha Aina, a group concerned with Waianae's future, came into possession of these data from the Environmental Assessment is unclear. According to Jones and Knox, however, many people in the community went out of their way to tell them that the Na Opio Aloha Aina was representative of an extremist view and not that of the wider community. The Na Opio Aloha Aina, it should be noted, tends to find most forms of commercial development proposed for the rural Leeward Coast objectionable. ...

Adding to the growing mistrust was a proposed House Resolution which not only supported OTEC but stated that the trestle would be a design feature (see Appendix E: HR 193 for details). Members of the Waianae Neighborhood Board, the CAC, and the wider community were made aware of this resolution on May 1, 1984. The CAC/WNB had earlier been informed by OTC that the project had not yet been finalized and that options were still open. The CAC/WNB assumed that this meant the need for the trestle was still negotiable and, more importantly, that No-OTEC II was a possibility. For the community and CAC members, who were frustrated with the progress of the meetings, the House Resolution only served to complicate matters. ...

Over the course of the meetings anti-development sentiments, which earlier had been restrained, became more prominent. The issue of ocean mining was raised. Ocean mining was of particular interest since there was a fear that not only would it add to development, but that it might eventually come to Waianae, resulting in pollution and degradation of the ocean. ...

The Phase II ICC meeting on August 10, 1984, involved a community forum. The purpose was to clarify issues which had arisen at the past four information meetings. Only one developer representative, Cabacungan, was in attendance.

The content of the final informational meeting included a series of presentations from various guest speakers. The WNB desired these speakers because of their non-affiliation with OTC, and because they represented an independent expert point of view. Simply put, they were not supportive of OTEC. The speakers included Sherwood Maynard, Director of the Marine Option Program, Sea Grant College Program, University of Hawaii, George Fuller, a biologist with the National Marine Fisheries Service, and Eric Enos of the Waianae Land Use Concerns Committee represented a range of views. The meeting was not emotionally charged as were some of the previous sessions.

When Cabacungan rose to speak, she could only repeat what had been said before, that OTC still wished to continue the dialog and hoped that some solution could still be worked out. Besides this meeting, two events would further dampen OTC's interests in continuing the discussions. First, only a few days earlier (August 7, 1984) the WNB had come to a decision regarding OTEC:

"Due to the experimenta1 nature of OTEC with its unknown and unanswerable risk factors, the Neighborhood Board does not support the proposed build an OTEC plant at Kahe Point, Oahu." ...

The statement of non-support was certainly damaging to OTC's efforts, but it was the second event which, according to Jones, was the nail in the coffin. The price of oil was beginning to drop from its benchmark price. ...Furthermore, only a few days earlier a forecast appeared in the Wall Street Journal, predicting oil prices as low as $15 per barrel by 1985 (Wall Street Journal:8/2/84).

The price of oil was important to OTC since it reflected the price HECO would offer for the electricity OTC generated. Under the 1978 Public Utility Regulatory Policies Act (PURPA), utilities such as HECO are obligated to purchase electricity from small scale producers at the same price they would pay for their highest cost alternative (Talbot:1983:41). For HECO the highest cost alternative was oil. Thus, while oil prices remained high OTC could be assured that energy prices per kilowatt hour might make construction of OTEC a financially feasible venture. However, as oil prices dropped the project became less and less feasible. According to Jones, if oil remained at the $25 to $30 level, OTEC would still have been possible.

The OTEC project, however, has not been totally terminated. It is most likely on hold until an increase in oil prices or a major technological breakthrough once again makes OTEC financially feasible. Since the August 10 meeting 1ittle effort to communicate with the community has taken place. ...

Rock-Based Ocean Thermal Energy Conversion (ROTEC)

Late in 1984 a Norwegian consortium composed of four engineering and construction firms began investigating the possibility of ROTEC in Hawaii. The concept calls for a below ocean floor OTEC power plant utilizing carbon dioxide as the working fluid. The preliminary studies have indicated the sub-ocean rock strata around areas such as Kahe Point are too porous for ROTEC. Plans for further exploration are pending.

The Pacific International Center for High Technology Research (PICHTR)

Another recent event has been a pledge from the Government of Japan to contribute $1 million per year for eight years towards the establishment of the PICHTR. Recognizing Hawaii as a center for OTEC research (NELH at Ke-ahole Point), the Japanese wish to concentrate on the open-cycle rather than the closed-cycle approach. According to the Japanese, the open-cycle is viewed as a potential "integrated resource" which can be a source of fresh drinking water, electricity, air conditioning, and aquaculture products (Honolulu Advertiser:5/18/86). ...

The Community Perspective

From the communities' perspective OTEC was seen as having significant environmental and aesthetic impacts on "rural" Waianae. Those who fished as part of a subsistence lifestyle were wary of any threat to their livelihood.

APPENDIX 6: OCEAN ENERGY DEVELOPMENT GUIDELINES (2007)

In the summer of 2007 Hawaiian Electric Company hosted a few meetings on ocean energy. After the first meeting HECO proposed that the message be: go away. The preface of the Final Report was written by Life of the Land's Assistant Executive Director Kat Brady. The rest of the Report was written by four individuals including Life of the Land's Executive Director Henry Curtis. The Ocean Energy Development Guidelines[343] (July 2007) was approved by all the people present accept those who represented agencies and couldn't take a position within the group.

Ocean Energy Development Guidelines Preface:

E Komo Mai

(Welcome),

Mahalo for considering Hawai`i as a site for your ocean energy project.

As island people we are acutely aware of climate change and its impacts, as well as our responsibility to be good global citizens by reducing our carbon emissions and footprint. Our people realize that to do this we must aggressively increase our use of local resources, such as our surrounding ocean, to produce energy. Our legislature just passed, and the Governor signed Act 234 – Hawai`i's first bill regulating greenhouse gases.

There are several things about Hawai`i that differentiate us from any other place on the planet.

- Our values of āloha `āina (love of the land), mālama `āina (to care for and nurture the land), and mālama ke kai (to care for the ocean) are based in Hawaiian culture
- Native Hawaiian rights are protected under the Hawai`i State Constitution
- Our natural resources are protected under the Hawai`i State Constitution
- All beaches in Hawai`i are public – meaning everyone has equal access
- All submerged lands are held in trust for the people of Hawai`i
- Native Hawaiians are the indigenous people of these islands
- Our two official languages are Hawaiian and English
- We are the most isolated archipelago on the planet
- We are the most oil dependent state in the nation

A broad cross-section of our O`ahu community was convened to create a tool to help you better understand our communities, our relationship with the ocean, and the kinds of issues that are of interest to our people relating to ocean energy.

We hope that you find our efforts helpful!

---

343 http://hawaii.gov/dcca/dca/web_references/other_sites/ocean-energy-development-guidelines-final-word.pdf

APPENDIX 7: TECHNICAL READINESS OF OTEC (NOAA 2009)

Due, in part, to increased interest by the U.S. Navy and the issuance of several recent contracts to industry to increase research and development on OTEC components, NOAA's Office of Ocean and Coastal Resource Management (OCRM), in cooperation with the Coastal Response Research Center (CRRC), held the first in a series of workshops focused on OTEC.

The first workshop, discussed in this report, sought to gather information on the technical readiness of OTEC and evaluate advancements to the technology since the last major attempt, OTEC-1 in 1980.

In order to provide the workshop participants with common assumptions for the design of an OTEC facility, the Organizing Committee (OC) limited discussion to a floating, closed-cycle, moored OTEC facility producing electricity transmitted to shore via an undersea cable. ...

The first OTEC facility constructed was likely to be ≤ 10 MWe, however, commercially successful OTEC facilities would likely be ≥ 100 MWe, and are the expressed goal of the OTEC industry. The OC selected closed-cycled for evaluation at this workshop, as they believed the first ≥ 100 MWe OTEC facilities will use a closed-cycle design due to its greater efficiency. The discussions at the workshop were limited to electrical generation.

The technical feasibility of additional applications for OTEC (i.e., potable water, seawater air-conditioning) were not discussed. While an operational OTEC facility will contain many components, the OC decided to limit discussion to seven components: (1) platforms; (2) platform mooring system; (3) platform/pipe interface; (4) heat exchangers; (5) pumps and turbines; (6) power cable; and (7) cold water pipe.
Discussion was limited to these components because they were viewed as critical and a potentially limiting technical factor to the success of OTEC. It should be made clear that this report is a qualitative analysis of the state of the technology, and is meant to inform NOAA OCRM.

This report is not an exhaustive engineering analysis, nor is it an independent appraisal of the technology. This report does not take into account economic, environmental and social impacts and/or constraints, and is not part of the decision and permitting process for OTEC by OCRM in the United States.

A. Platforms

State-of-the-Art Technologies

Changes in offshore platforms have primarily been driven by the petroleum industry. Since the 1980's, there has been improved meteorological and oceanographic data gathering methods, which has led to more reliable and weather-resistant platform designs. In addition, improved analytical tools allow for optimized and cost-effective platform construction.

The group identified three platform designs as being most feasible for OTEC application: semi-submersible, spar, and ship shape (mono hull). All three have been validated in *other industries (e.g., offshore oil, windfarms) and there are no significant additional manufacturing, operating, or deployment challenges associated with their use in an OTEC application.*

Semi-submersible platforms have standard offshore rig fabrication procedures. There are fewer qualified manufacturing facilities for spar platforms than semisubmersible and mono hull. Monohull manufacturing uses a Floating, Production, Storage, and Off-loading Unit (FPSO) for construction. Spar platforms present the most difficulties for installation because they require deepwater work. Spars are also more difficult to operate than the other two platform types.

Operation and maintenance (O&M) procedures for these platforms are well-established, and typically include maintenance of machinery and removal of biological growth on the submerged sections. Relocating platforms can present some difficulties especially with the spar configuration. Spar platforms need to be disassembled and reassembled for relocation. However, the spar configuration is most favorable for the cold water pipe attachment because there is less motion at the joint.

Decommissioning of platforms is regularly performed in other industries and should not cause significant challenges for OTEC facilities. Overall, the life cycle of a platform for an OTEC facility is straightforward and has well-established procedures.

Challenges, Risks, and Cost Drivers

There are few challenges associated with using currently available platform technology for OTEC application. The following table compares risks associated with the three platform configurations.

Table 1.

Platform Type	***Motion/survivability risk***	***Arrangement difficulty***	***Cost***	***Technical Readiness***
Semisubmersible	*Small*	*Medium*	*Medium*	*High*
Spar	*Small*	*High*	*Medium-High*	*Medium*
Ship shape/ monohull	*Medium*	*Low*	*Low*	*High*

The major cost driver for platforms is size and adaptability to OTEC application. Platforms need to house a significant amount of equipment for an OTEC application, and larger platforms significantly increase the cost and difficulty of fabrication and deployment.

Research and Development

Because platforms are well established, the majority of research and development goals are efficiency and cost related. Development of simpler, lower cost manufacturing and deployment techniques will reduce overall OTEC costs and improve the economic feasibility of the plant. Because OTEC platform technology is transferred from other industries, standards must be developed for platforms specific to OTEC facilities.

B. Platform Mooring

State-of-the-Art Technologies

The most important advancement from 1980 to the present is the significant progress made in deep water moorings in sand and rock bottoms. In 1980, the depth limit was ~305 m, but within the past 10 years advancements in synthetic materials has allowed numerous moorings at depths up to 3,000 m. Advancements in software have allowed precise models to be created that facilitate optimization of platform mooring systems, and the widespread use of GPS and underwater acoustic systems (e.g., SONAR) allows precise placement of mooring components.

Assuming that an OTEC platform is not significantly different than platforms currently in use in the offshore oil industry, mooring technology is mature and has been demonstrated in more challenging and demanding environments. The key driver will be optimization to make it economically viable in the environment in which it is deployed. The group reported that appropriate mooring technology exists for numerous vessel sizes, loads and bottom types, however it is very site specific and the mooring system would need to be custom designed using existing components (anchors, pilings). Mooring lines for all components currently exist for depths to 3,000 m. Electrical conductor can be embedded into mooring line in order to combine the mooring and power cable, however this presents a new set of issues and design challenges that may not be economically viable. Equipment currently exists to deploy mooring systems, however it may need to be modified based on location and economics. Software models exist for mooring systems, however they would need to be modified to address the intricacies of an OTEC plant (i.e., Does fluid flow in pipeline have a significant impact on the model?). Increasing availability of GPS coupled high resolution SONAR has provided a more detailed view of the seafloor and allows precise placement of moorings.

Design, fabrication, and construction of the platform mooring components(anchors, mooring lines, hardware/terminations, integrity monitoring instrumentation)were identified as either commercially available off-the-shelf, or requiring minimal customization. The amount of customization and difficulty may increase with increasing platform size, weight, bottom slope and exotic seafloor characteristics. Mobilization and deployment of mooring components were identified as simple without significant challenges, however some minor modification to equipment may be required. Monitoring component performance during installation and use was also identified as relatively simple with few challenges and high reliability.

Operation of the platform mooring is not complex and very reliable; existing technology is suitable. Maintenance of the platform mooring system is technically simple, with the primary focus on mitigating the impact of marine fouling on equipment and periodic replacement/repair of integrity monitoring instrumentation.

Decommissioning of the platform mooring as a system was identified as technically feasible and routine, however, labor intensive and expensive.

Challenges, Risks, and Cost Drivers

One of the most important challenges with the platform mooring is preventing marine fouling of the mooring line and hardware. Excessive fouling may impact the integrity of the mooring lines, and increase drag resulting in higher loading. Most platform moorings are near shore, while OTEC platforms are likely to be in very deepwater and are exposed to high sea conditions, which may present design challenges. Another significant challenge will be the requirement to disconnect and recover the moorings in case of extreme storms.

Mobilization and deployment were identified as the riskiest part of the platform mooring life cycle. Potential issues include: inability to deploy effectively and safely, significant delay in startup, additional costs, or complete system failure.

Cost drivers include need for spare components, site conditions, weather, water depth, installation complexity, material costs, performance requirements, installation risk and insurance, labor costs, permitting and regulations, removal and decommissioning costs and requirements. Cost savings could be realized through mooring optimization (single point vs. multipoint), coordination and optimization of platform design, less stringent motion and survivability requirements, citing, mitigating high cost factors, and the ability to self-install.

Research and Development Needs

The Platform Mooring group identified several research topics, including: Adaptation of codes and standards to reflect OTEC systems, mooring systems on high slope bottoms, techniques requiring minimal equipment for mooring and power cable installation, optimized anchoring systems for volcanic rock, and new paradigms and designs relevant to OTEC needs.

C. Platform/Pipe Interface

State-of-the-Art Technologies

One of the most significant advances since 1980 is experience working in open ocean deep water environments and advanced modeling technology. Sensor and modeling technology has matured and now gives a better understanding of sustained loading, allowing optimized designs. Advances in materials science have produced lighter, stronger, and more durable materials that can be incorporated into the platform/pipe interface, allowing larger pipes to be used. Several experimental OTEC plants have been constructed since 1980, and while most either failed or were shut down for various reasons, numerous lessons have been learned from those experiences, including important design considerations and failure points related to the pipe/platform interface.

The pipe/platform interface group concluded that the technology to create an interface suitable for a ≥ 100 MWe facility (~ 10 m diameter CWP) is not currently available, but experience with smaller 1 m diameter pipes has demonstrated that the technologies are *viable. There are generally three accepted platform pipe interface designs: a flex pipe attached to a surface buoy, a fixed interface, and an interface with a gimbal. The off-shore oil industry routinely handles multiple risers up to 1 m diameter at substantial depths (> 305 m), and the technology used can likely be adapted to OTEC and scaled to larger diameters.*

Design, fabrication and construction of a platform/pipe interface for a ≥ 100 MWe facility will require significant testing and modeling, and may require two to four years before it is ready for installation. Fixed and gimbaled interfaces are easier to design and manufacture, while flex interfaces are more complex and more difficult to design and manufacture. Construction of the interface is not technically challenging, and could be completed rapidly, however, mobilization and deployment is difficult and has been the failure point in several OTEC projects. The effort required and probability of success of mobilization and deployment depends greatly upon the type and size of the cold water pipe, platform type, and interface. While some experience exists for smaller pipes, larger interfaces (> 1 m CWP) will require custom installation and it is unclear what special requirements or problems may occur. Vertical build interfaces are easier to deploy than horizontal. Horizontal build interfaces are difficult for fixed and gimbaled interfaces. The ability to detach the CWP adds complexity and cost to the interface.

Operation and maintenance of the interface is relatively simple for a fixed interface, but substantially more involved for gimbaled and flex interfaces. The gimbaled interface requires periodic lubrication and cleaning, while the flex interface requires frequent repair as it has several connection and fatigue points.

The fixed interface has the highest scalability followed by the gimbaled. The flex interface is probably not feasible for ≥ 100 MWe facilities due to the size of the coldwater pipe. Current design and deployment technologies are likely scalable to ≥ 100MWe, however the group noted that a interface for a ≤ 10 MWe facility should be successfully fabricated and deployed prior to attempting anything larger, as unforeseen difficulties may arise with increasing pipe size.

Challenges, Risks, and Cost Drivers

There are numerous challenges with the platform/pipe interface. The most significant is the lack of experience with interfaces holding pipes larger than 1 m diameter. A significant amount of design, fabrication, and modeling will be required to develop an interface for a ≥ 100 MWe OTEC facility. The biggest challenge will be to design an interface that is able to couple and decouple the CWP, and withstand the forces of an open ocean environment and storm events.

Risks associated with the platform/pipe interface include complete failure, resulting in loss of the pipe and significant production delays, as well as partial failure, resulting in degraded performance due to leakage. If the interface fails, it will be difficult and expensive to repair in situ, especially if the pipe is lost.

Cost drivers include: choice of materials, and the design and fabrication process for not only the interface, but also the cold water pipe and the platform. Local climate, currents and wave patterns will dictate the design loading and will have a significant impact on *cost. Tradeoffs between relative motion of the CWP vs. the platform and complexity of the system will also impact costs, as well the ability to couple/decouple the CWP.*

Research and Development Needs

The research and development needs include: modeling of failure modes, expanded remote monitoring, low cost buoyancy, OTEC system modeling, deep oceanographic data collection, data mining, and processing, supply chain integration, and improvement in composite materials.

The CWP and pipe/platform interface groups are closely linked and present some difficulties in design and installation. Because the platform/pipe interface for a hanging CWP has only been demonstrated for ≤ 1 m diameter pipes, the scalability is unclear and there are significant unknowns. Research should focus on increasing the size of the platform/pipe interface to accommodate pipes used in ≥ 100 MWe facilities. The conditions of the open ocean and deep-sea currents cause numerous stresses on the CWP and interface, and until significantly larger sizes of these components are built and used successfully, they will remain the biggest hurdle to successful ≥ 100 MWe OTEC facilities.

D. Heat Exchangers

State-of-the-Art Technologies

Heat exchangers (HX) have improved in many ways since the 1980s driven primarily by other industries (e.g., aerospace, power plant, petroleum, cryogenic, liquefied natural gas (LNG), geothermal). Typical 1980 HX designs were plain tube, shell and tube, and plate and frame. Stainless steel was typically used. The open cycle and hybrid cycle OTEC facility concepts were developed in the 1980s, but HXs for these applications were not designed or validated. Today HX have an improved heat transfer coefficients mainly due to the use of new and modified materials. Titanium is more cost effective today, plastics have been developed for HX use, and aluminum-alloying techniques have improved. Surface enhancements have been developed (e.g., roughing). Fabrication practices have also improved: extrusion, aluminum brazing, welding techniques, quality control, instrumentation, and coating processes. More of the HX fabrication process is automated and, therefore, has improved capacity for large HXs.

HXs have been validated for closed cycle applications and designed for hybrid cycle application. Direct contact condensers are currently operational for geothermal applications. Flash evaporators have been demonstrated and mixed working fluid cycle HXs have been developed. This discussion focuses on heat exchangers for a closed cycle OTEC facility. The most appropriate working fluids for OTEC are propylene and ammonia, with an emphasis on the latter due to its thermodynamic properties and extensive experience with similar applications. Shell and tube, plate and frame, and aluminum plate-fin are the three HX types most suited and ready for OTEC.

The group discussed the life cycle of three different types of HXs that could be used for an OTEC facility: shell and tube, plate and frame and aluminum plate-fin. The timeframe for commercial manufacturing for OTEC use for all three of these HX types is two to three years.

Shell and tube HXs are typically constructed of titanium, carbon steel, stainless steel, copper-nickel, or aluminum. Complexity and cost of HX installation would vary with platform design; an HX integrated into the platform would likely need to be done while the platform is being constructed. The size of these HXs is important because of the limited space on an OTEC platform. The manifold design for shell and tube HXs depends on the platform configuration. The largest shell and tube HX currently available would result in 5 MWe (net OTEC power), however, they can be installed in modules, creating greater net power output. Manufacturing of shell and tube HXs is relatively labor intensive, but integrating them into the OTEC facility is low cost compared to the alternatives. The HX is constructed on shore and then floated to the OTEC facility. There are some issues with transportation due to the large size of shell and tube HXs; special equipment is needed.

O&M of shell and tube HX is easy and there are performance data to validate performance. These HXs degrade slowly and need few repairs. They are replaced once they surpass their service life, usually limited by material degradation (e.g., corrosion, pitting). It is necessary to monitor the HX for leaks. Some of this monitoring is visual, and therefore, there needs to be space for personnel to inspect HXs. There are detectors in the exhaust water to detect ammonia (i.e., the working fluid). Chlorination is necessary to decrease biofouling in the "warm" (i.e. evaporators) water portion of the HX. There are well-established guidelines for personnel safety when handling shell and tube HXs. These O&M processes and guidelines/codes come from other industries using shell and tube HXs (e.g., process industry, refrigeration industry, power plants). American Society of Mechanical Engineers (ASME) developed most of these codes. Shell and tube HXs can be easily scaled to ≥100 MWe facilities with a modular design. Decommissioning these HXs is labor intensive and there are environmental risks associated with the release of the working fluid. However, there are existing industry standards for decommissioning. There is salvage value in the metals and ammonia as both can be recycled.

Plate and frame HXs are constructed of stainless steel or titanium. Manufacturing is easy because it consists of a completely automated welding process. One complicating factors is there the large plate size of plate and frame HXs needed for OTEC facilities. Installation of the HXs into the OTEC facility is difficult because of the complex piping system and expensive valving required. Each individual plate and frame HX is transported to the OTEC site. Plate and frame HXs are less flexible than shell and tube for OTEC because they require more ventilation. However, the plate and frame HXs are less expensive than the shell and tube. With the necessary piping and manifolding system, the costs of the two types of HXs are equivalent.

Many of the O&M processes for plate and frame HXs are the same as the shell and tube HX. However, there are some added difficulties. Plate and frame HXs cannot be submerged because gaskets are not fully welded and have to be dry. The HXs can be repaired by replacing the individual plates. Personnel safety is similar to that of shell and tube HXs, but also includes confined space entry. Plate and frame HXs have limited scalability. To scale up to a ≥ 100 MWe, the number and size of plates required would greatly increase. Decommissioning plate and frame HXs has the same procedures and issues as shell and tube.

Aluminum plate fin HXs are fabricated with brazed aluminum and mostly used in the cryogenic and LNG industries. They have a modular design similar to shell and tube, but with lower power output per module. Due, in part, to surface area to volume ratio constraints, each module has an effective upper thermodynamic limit of approximately 2MWe, requiring the use of multiple modules for plants ≥ 2 MWe. Aluminum plate fin have a lower integration cost because the brazed aluminum units can be assembled onsite. The units can fit inside a standard shipping container, presenting fewer transportation issues.

O&M for aluminum plate fin HXs is similar to that of shell and tube and plate and frame. O&M practices unique to plate fin HXs include: monitoring for aluminum corrosion and the need for offsite repair. Plate fin HXs are scalable because of their modular design. There is data validating performance for aluminum plate fin HXs; the Department of Energy (DOE) has test data for these HXs. Decommissioning practices for plate fin are the same as the other two HXs.

Challenges, Risks, and Cost Drivers

There are risks associated with working fluids leaking from the HXs because of potential environmental damage, and the negative impact on turbine efficiency. There needs to be more data collected on biofouling of HXs. The biggest challenge is the limited economic incentive for HX manufacturers to optimize HX design/fabrication for OTEC facilities. The temperature difference between the "warm" and "cold" water (□T) is relatively small compared to other applications for HXs. The challenge is to design an HX that can handle large flows, have a high heat transfer coefficient, and be easily integrated into an OTEC facility.

Research and Development Needs

Research and development on HXs for OTEC application aims to improve heat transfer without incurring a large pressure drop. Improvements to HX design will increase the cost effectiveness of the entire OTEC plant. Research areas include: materials, enhanced surface, and fabrication techniques. Many of these areas have already been the subject of much research but OTEC requires further improvements and validation. Surface enhancements will increase surface area, turbulence and mixing, thereby increasing the heat transfer capacity. Research into materials includes greater extraction processes, qualification of aluminum alloys for the lifetime of an OTEC plant, and the use of plastics.

E. Pumps and Turbines

State-of-the-Art Technologies

Compared to other components of the OTEC facility, pump and turbine technology is the most advanced with respect to technical readiness. There have not been any revolutionary breakthroughs in the design of pumps and turbines in the past 30 years, however, there have been some changes since the 1980s that have improved performance including use of lightweight and lower friction materials. Electronic monitoring is now available that can examine the health and status of pumps and turbines, helping to decrease O&M costs.

The petroleum industry has more than 30 years of experience with pumps and turbines in harsh environments, such as offshore facilities. Axial flow turbines are able to support large MWe production and these units are commercially available. Toshiba(Tokyo, Japan), GE Rotoflow (Fairfield, CT), Mitsubishi (Cypress, California), ElliottTurbo machinery (Jeannette, PA) and Hitachi (Tokyo, Japan) manufacture suitable turbines. For a 10 MWe facility, two radial flow turbines each rated at 7-8 MW gross power could be used. Increasing the number of turbines improves reliability and net power production. This is relatively easy to do because of the modular design used in OTEC facilities.

Cold and warm water pumps for an OTEC facility would be axial flow impeller design mounted on the platform. These pumps are highly efficient (87-92%), and are commercially available from numerous vendors. A 100 MWe facility would require pumps capable of moving approximately 200 m3/s of cold water and 400 m3/s of coldwater (Vega L. , 1995). Multiple-pump solutions of this size are available off-the-shelf, and could integrate into a ≥100 MWe OTEC facility. The OTEC working fluid pumping system would require feed pumps and recycle pumps. For the ≥ 100 MWe facility, 8 working fluid pumps and 8 recycle pumps would be required. These pumps are commercially available and have a relatively low cost, however, they require significant maintenance. There is a large design database available for these pumps.

Turbines for OTEC applications are commercially available. Materials suitable for these turbines include steel, carbon steel and chromium. Large turbines are a challenge, however, this can be mitigated by using a modular design. There are well-established manufacturing practices for 5-10 MWe turbines (e.g., forging, machining, and casting).Turbines are very adaptable to a platform environment and could easily be integrated in to an OTEC system. Ammonia turbines are reliable, but there is little data in their use at this scale. There are some manufacturers of ammonia turbines; mainly for the refrigeration industry. There is an 18-24 month lead-time for delivery of these turbines.

O&M procedures for turbines of this sort are well established and do not to present any extra difficulties. Routine inspection is required along with periodic repair. There are few unique safety concerns for personnel working on turbines on OTEC facilities; however, it is important to note that a leak of the working fluid (e.g., ammonia) may present safety issues. Some of the monitoring can be done using electronic sensors without disrupting plant performance and avoiding potential risk to personnel. The pumps and turbines would likely last the life of the OTEC plant (30 years).

Turbines would likely be installed in modular fashion for a ≥ 100 MWe OTEC facility. They should be reliable because they are a very well established technology that is already in use in similar conditions and because it is relatively easy to provide redundancy. Typically twice the number of turbines needed are installed. This redundancy allows for regular maintenance without compromising the plant performance. Decommissioning the turbines is straightforward and protocols and procedures exist. 85-90% of the materials can be recycled.

Pumps for OTEC application are also available with a 12-18 month lead-time. The maximum impeller diameter for a pump is ~2.1 m. There is a range of design *configurations available from multiple vendors. Similar to OTEC turbines, the pumping system would use n+1 redundancy. The main materials used in pump fabrication are carbon steel, stainless steel, copper, and insulating material.*

Access to pumps on an OTEC platform can complicate and increase the cost of O&M because in some designs they are submerged. It is critical to have spare working fluid pumps available at the facility. The overall performance of the plant relies heavily on proper operation of pumps and turbines. Pumps are scalable to a ≥ 100 MWe OTEC facility because they can be installed modularly. Pumps are also highly reliable.

Challenges, Risks, and Cost Drivers

Turbines have very low operational risks, however, if they do fail OTEC performance is greatly hindered. It is important to have spare parts readily available to maintain turbines and pumps. There is a risk of foreign objects damaging the turbine blades. Electronic monitoring must be able to detect any potential internal damage. Cost drivers are turbine and pump efficiency. Currently, turbines and pumps are ~ 80-90% efficient. Improving efficiency will result in higher net power output of the OTEC facility.

Research and Development Needs

There are few R&D needs for pumps and turbines for OTEC application because they are commercially available. Any improvements will decrease the cost and allow the plant to operate more efficiently. The main research area is condition-based maintenance: remote sensing for turbine and pump performance. Other research areas are associated with open cycle OTEC facilities that operate at much lower pressure than closed cycle systems. This presents unique challenges for pump and turbine design. R&D is needed to improve lower pressure turbine and pumps.

F. Power Cable

State-of-the-Art Technologies

One of the biggest advances since 1980 in power cables is associated with production and installation of high voltage undersea cables. There are currently 10 sea crossing alternating current (AC) cables ranging from 90 kV – 500 kV, and 20 direct current (DC) cables up to 500 kV in use; the majority has been installed within the last 10years. The increase in offshore wind farms has led to a better understanding of cable dynamics, and connections up to 50 kV are common. Significant progress has been made in understanding cable dynamics, primarily driven by needs of the offshore oil drilling and wind farm community, which use similar sized cables. Platform-cable connections are now standard and routine up to 50 kV.

The group concluded that the technology to create power cables systems (cable, splicing, terminations) suitable for use with OTEC facilities exists, however there are several limitations. The most notable is that while cables are available up to 500 kV, there is a larger selection at lower voltages (< 100 kV) and OTEC plants design may be limited by power cable availability. Cables under 20 miles long are likely to be AC and use single phase > 69 kV, or three phase < 69 kV. Cables longer than 20 miles are likely to be DC in order to reduce transmission losses. DC cables are currently available up to500 kV, *however have the disadvantage of requiring conversion between AC and DC on both ends, resulting in significant energy loss. Codes and standards exist for cable construction, including Institute of Electrical and Electronic Engineers (IEEE),International Electrotechnical Commission (IEC), and American Petroleum Institute(API). To protect the cable during installation and throughout its 30 year expected lifespan, it will likely have steel armoring, adding a significant amount of weight and strain.*

For cables less than 500 kV, design and fabrication were identified as either commercially available off the shelf, or requiring minimal customization. For cables greater than 500 kV, no commercial product exists and significant effort would be required to design and manufacture an appropriate cable. For OTEC facilities larger than10 MWe, design and fabrication of the cable termination on the platform side will require a custom design and be the most technically challenging part of the power cable system. Mobilization and deployment of the cable is difficult, but well understood. The depth, seafloor characteristics, weight of cable, and required route will affect the difficulty and cost of mobilization and deployment.

Operation and maintenance of the cable is routine and well understood. Maintenance of the power cable system includes periodic marine growth removal, full cable inspection, and annual maintenance of substations using divers and ROVs, where appropriate. In the event damage to the cable is discovered, repair is possible in shallow water, but very difficult in deep (> 500 feet) water, and may require replacement of the cable.

The power cable system will be difficult to scale to a 100 MWe OTEC facility due to capacity limitations and ability to design and fabricate a platform-side termination interface. A 10 MWe plant is unlikely to use the same cable type and design as a 100MWe plant, and a completely new design will likely be required. Power cable design is also affected by the mooring system; individual mooring types may require significantly different power cable systems.

Challenges, Risks, and Cost Drivers

One area identified by the group as a challenge is the cable termination interface on the platform side. While standard for ≤ 10 MWe plants, the larger and heavier power cables required by ≥ 100 MWe OTEC plants will increase fatigue, bending and the stress and strain on the cable and the cable-platform interface and pose significant technological and engineering challenges. Further analysis and modeling is needed, however, the group noted that software already exists to complete this analysis. In addition, the extreme depths at which the cables will be located may present challenges with respect to hydrostatic pressure, and additional testing and modeling may be required. Cost drivers include size and type of cable required, design sea conditions, seafloor characteristics, cost of materials, exchange rate, and required cable routing.

Research and Development Needs

The primary research need identified by the group was development of a dynamic cable for an OTEC facility > 10 MWe that can withstand repetitive bending and have more dielectric capabilities. Lighter armoring and conductor materials are needed to reduce weight, which will also reduce the stress and strains on the cable.

G. Cold Water Pipe

State-of-the-Art Technologies

In the 1980s, materials considered for CWP construction included E-glass/vinyl ester, steel, and/or concrete, and typically had a synthetic foam core sandwich design. Currently, CWP materials include: R-glass/vinyl ester, fiberglass, and carbon fiber composite. The design has improved; proprietary designs have been developed including the hollow pultruded core sandwich. Fabrication of the CWP will likely include vacuum assisted resin transfer molding (VARTM) and large protrusion processes. VARTM allows sandwich core manufacturing and/or stepwise manufacturing. The large protrusion process allows hollow core manufacturing which helps mitigate pressure issues at depths in the water column. There have also been improvements in computational tools and structural monitoring of CWPs (e.g., cameras, sensors, robotic devices).

The design, construction, and deployment of a CWP for a ≤ 10 MWe facility is fairly well understood, however has only been successfully completed at ≤ 1 MW (e.g.,OTEC-1). The fabrication methods required for construction of a ≤ 10 MWe CWP (~ 7 m diameter) are currently available, and can likely be scaled to construct a pipe suitable fora ≥100 MWe facility (~ 10 m diameter). The CWP can be deployed in situ with astepwise fabrication or as one whole pipe. The latter would be fabricated on shore and towed to the platform. Both of these methods have been developed and validated for a CWPs suitable for a ≤ 10 MWe plant (~ 7 m), however have only been successfully demonstrated on a much smaller scale (< 2 m diameter). Construction and deployment of a CWP for a ≥ 100 MWe CWP have not been attempted.

Studies have shown that biofouling on the interior and exterior of the CWP will not significantly impact the performance of the OTEC plant (C.B. Panchal, 1984).Smooth interior surfaces of the CWP achieved by coatings and additives mitigate biofouling. The CWP is designed to last the lifetime of the facility, and with current engineering knowledge and methods may approach 30 years. Fiber optics will be used to monitor CWP performance and detect any damage. Fiber optics is a well-understood technology that is regularly used in the offshore oil industry. The offshore oil industry also has experience in repairing structures at depth. There are existing monitoring methods to analyze ageing, saturation, and fatigue.

Emergency preparedness is a key issue for the CWP of an OTEC facility. The design may include the ability to detach the CWP from the platform prior to a large storm event in order to prevent damage and/or loss. This significantly complicates the design of the platform/pipe interface and is likely to increase complexity and cost. The CWP from OTEC-1 was successfully recovered and re-used from a depth of 1,371 m in 1982, and suggests that recovery and decommissioning (i.e., disposal or recycling) of the CWP will use established procedures used previously in OTEC, as well as the oil industry, and should not present any significant technological challenges.

Challenges, Risks, and Cost Drivers

The challenges and risks associated with a ≤ 10 MWe CWP are fairly well understood. Transportation, deployment, and decoupling of a single piece pipe is difficult, and would *require towing it from shore. Conversely, segmented pipes, while easier to deploy, risk failure at the many joints required. The CWP is vulnerable to severe storm events that may exceed design limits, cause damage and/or failure. The increased CWP size required for a ≥ 100 MWe facility introduces some challenges, primarily due to lack of experience with pipes in that size class. While previous OTEC pilot and experimental plants have successfully constructed and deployed CWPs, there is little experience with a CWP larger than 2 m.*

The major cost drivers for the CWP are the materials used in fabrication and the deployment techniques. Deployment of the CWP is equipment and labor intensive, and will be greatly affected by labor, fuel and equipment costs.

Research and Development Needs

CWP research and development on CWPs for both ≤ 10 MWe and ≥ 100 MWe facilities should address material and equipment cost effectiveness. Research on alternative designs (e.g. flexible CWP) should be conducted. A full demonstration of large CWP (i.e., suitable for ≥ 100 MWe) production, delivery, and installation is needed. In addition, there must be a minimum of a one year operational record of CWP at a ≤ 10MWe facility prior to scaling up to a ≥ 100 MWe facility.

The CWP and its interface with the platform are the most complex components on the OTEC plant. The CWP is unique to OTEC facilities, and nothing on the same size scale has been attempted in oceanic environments. There are numerous risks associated with these technologies. Many of these risks should be studied further with the goal of validating the CWP and interface design.

VI. RESEARCH AND DEVELOPMENT NEEDS

At the conclusion of the workshop, the groups reconvened and developed the following general list of research and development needs to improve the technical readiness of OTEC.

<u>Heat Exchanger</u>

** Enhanced heat transfer through an increase in surface area, turbulence, mixing without pressure drop validated performance*
** Advancement in materials (aluminum alloys, plastics, low cost titanium)*
** Improved fabrication techniques (bonding, brazing, welding, extrusion, etc.)*

<u>Power Cable</u>

** Development of dynamic cable greater than 30 MWe*
** Development of a platform-cable interface that can withstand repetitive bending and have better dielectric capabilities.*
** Lightweight armoring and conductor*

<u>Cold Water Pipe</u>

** Improve cost effectiveness of materials/equipment*

** Full demonstration of pipe production, delivery and installation*

Pumps and Turbines

** Low pressure steam for open cycle*
** Lower cost of compressors for maintaining vacuum (centrifugal)*
** Condition-based maintenance sensing and turbine performance optimization*
** Condition-based maintenance sensing for pumps*

Platform Moorings

** Investigate/be flexible to new paradigms and designs relevant to OTEC needs*
** Optimization of platform moorings for OTEC needs*
** Investigate effective anchoring systems in volcanic rock*
** Investigate techniques that require minimal equipment for mooring & power cable installation*
** Investigate effective mooring systems on high slope bottoms*
** Adapt codes and standards to reflect OTEC systems*

Platform/Pipe Interface

** Develop low cost buoyancy*
** Analytical simulation specific to OTEC*
** Find and adapt existing technologies and analysis tools to structural analysis and simulation*
** Better modeling of failure modes*

Platform

** Low cost manufacturing techniques (i.e., innovation, quality control)*
** Developing OTEC standards based on cost/risk*

General

** Large scale testing of subsystems*
** Trade off studies need to be performed relative to the location of water production (onshore vs. offshore, water production)*
** Compile standards from other industries and adapt to OTEC*

VII. CONCLUSION

It should be made clear that this report is a qualitative analysis of the state of the technology, and is meant to inform NOAA OCRM. This report is not an exhaustive engineering analysis, nor is it an independent appraisal of the technology. This report does not take into account economic, environmental and social impacts and/or constraints, and is not part of the decision and permitting process for OTEC by OCRM in the United States.

The qualitative analysis of the technical readiness of OTEC by experts at this workshop suggest that a < 10 MWe floating, closed-cycle OTEC facility is technically feasible using *current design, manufacturing, deployment techniques and materials. The technical readiness and scalability to a > 100 MWe facility is less clear. Workshop participants concluded that existing platform, platform mooring, pumps and turbines, and heat exchanger technologies are generally scalable using modular designs (several smaller units to achieve the total capacity needed), however, the power cable, cold water pipe and the platform/pipe interface present fabrication and deployment challenges for ≥100 MWe facilities, and further research, modeling and testing is required. The experience gained during the construction, deployment and operation of a ≤ 10 MWe facility will greatly aid the understanding of the challenges associated with a ≥ 100 MWe facility, and is a necessary step in the commercialization and development of OTEC.*

APPENDIX 8: OTEC: ASSESSING POTENTIAL PHYSICAL, CHEMICAL, AND BIOLOGICAL IMPACTS AND RISKS (NOAA 2010)

OTEC BACKGROUND

OTEC is unique in that very large flows of water are required to efficiently operate. It is estimated that 3-5 m3/sec of warm surface water and a roughly equivalent amount of cold water from the deep ocean are required for each MWe of power generated (Myers et al., 1986). Therefore, for a small commercial sized facility (i.e., 40 MWe), this requires flows of 120 – 500 m3/sec (i.e., between 2 and 11 billion gallons per day).
In July 1981, NOAA issued the Final Environmental Impact Statement (EIS) for commercial OTEC licensing. Based on information available at the time, potential impacts were divided into three categories: major effects, minor effects and potential effects from accidents. ...

In 1986, NOAA's National Marine Fisheries Service (NMFS) built upon the 1981EIS and developed a report entitled "The Potential Impact of Ocean Thermal Energy Conversion (OTEC) on Fisheries" (Myers et al., 1986). This report attempted to quantify the impact of an OTEC facility to marine biota, and estimated losses due to entrainment (i.e., entering the system through an intake) and impingement (i.e., held against a surface by water flow). The report concluded that:

"The potential risk to fisheries of OTEC operations is not judged to be so great as to not proceed with the early development of OTEC. Due to the lack of a suitable precedent, there will remain some level of uncertainty regarding these initial conclusions until a pilot plant operation can be monitored for some period of time. In the meantime, further research on fisheries should be undertaken to assure an acceptable level of risk regarding the larger commercial OTEC deployments" (Myers et al, 1986).

While the NOAA NMFS report provides an overview of the types of impacts that could be expected, it did little to quantify the magnitude of the impact, as the estimates generated were speculative and relied on now outdated techniques and methods.
An example of this is the entrainment and impingement estimates, which were generated using an average composite of biomass in the Hawaii region. This technique ignored the ability of the facility to act as a fish attractant, thus increasing the concentration of organisms subject to entrainment and impingement. Some impacts may be minimized or mitigated through changes in operational or design parameters. However, the feasibility of design modifications due to environmental concerns needs to be weighed against the efficiency of energy production.

Mitigation measures that result in substantial reductions in the efficiency of an OTEC facility could cause a project to be economically unviable, and thus cancelled. While the easiest to identify impacts may be direct (i.e., biota directly killed through entrainment or impingement), cumulative and secondary ecosystem impacts may be much more of a concern and are much more difficult to assess. Cumulative and secondary ecosystem impacts will likely require careful long-term monitoring to distinguish effects, and may be impossible to fully evaluate due to ecosystem complexity.

C. Regulatory Considerations

The construction, installation and operation of an OTEC facility in U.S. waters will need to comply with many state and federal regulations.

Under the Ocean Thermal Energy Conversion Act (OTECA), an OTEC facility developer must obtain necessary authorizations from NOAA and the U.S. Coast Guard (USCG) in order to construct and operate an OTEC facility. Apart from the USCG authorization, all other federal license and permit requirements are incorporated into the NOAA OTECA license. In addition to federal authorization, OTECA also provides approval authority to those states whose waters are adjacent to federal waters for which an OTEC facility has been proposed.

States also have authority under the Coastal Zone Management Act to review OTECA licenses. Regulatory drivers include both direct and indirect impacts to biota and water quality, as well as food-chain and ecosystem impacts. Although a regulation does not directly require protection of smaller organisms (i.e., prey species), if the absence of these organisms impacts protected species, then they must protected as well.

Some of the federal regulations applicable to the construction, installation and operation of an OTEC facility identified at this workshop include:

Clean Water Act (CWA): The requirements of the Clean Water Act apply to several aspects of an OTEC facility, including any changes to the chemical and thermal composition of the discharge plume, cold and warm water intakes, as well as installation of the mooring and transmission lines on the seabed.

Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA): The Magnuson-Stevens Act requires review of any federal authorization for an activity that may adversely affect “essential fish habitat” which includes "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.”

Endangered Species Act (ESA): The Endangered Species Act regulates any activity affecting threatened and endangered plants and animals and the habitats and ecosystems in which they are found. The law requires federal agencies, in consultation with the U.S. Fish and Wildlife Service and/or the NOAA Fisheries Service, to ensure that actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat of such species. The law prohibits any action that causes a "taking" of any listed species of endangered fish or wildlife. Several species listed in the ESA inhabit the region surrounding Hawaii where the first OTEC facility is likely to be built, including numerous species of whales and sea turtles, as well as the Hawaiian Monk Seal.

Marine Mammal Protection Act (MMPA): The Marine Mammal Protection Act establishes requirements to prevent marine mammal species and population stocks from declining beyond the point where they cease to be significant functioning elements of ecosystems of which they are a part. Any aspect of an OTEC facility which harms or influences the behavior of a marine mammal will be regulated under the MMPA.

Migratory Bird Treaty Act (MBTA): The Migratory Bird Treaty Act protects migratory birds and establishes Federal responsibilities for the protection of nearly all species of birds, their eggs and nests. The MBTA makes it illegal for people to "take" migratory birds, their eggs, feathers or nests. Take is defined in the MBTA to include by any means or in any manner, any attempt at hunting, pursuing, wounding, killing, possessing or transporting any migratory bird, nest, egg, or part thereof. A migratory bird is any species or family of birds that live, reproduce or migrate within or across international borders at some point during their annual life cycle. Migratory birds may use an OTEC facility as a resting point during migration, requiring the facility to comply with the MBTA.

National Environmental Policy Act (NEPA): The National Environmental Policy Act requires federal agencies to incorporate environmental values into the decision making process through consideration of the short and long term environmental impacts of any decision. OTECA requires that an environmental impact statement be developed for each license. Greatly complicating this requirement is the statutory timeframe established under OTECA for reviewing license applications of 356 days. In order to complete a defensible NEPA analysis within the OTECA timeframe, it will be imperative that license applicants conduct thorough baseline assessments prior to the submission of a license application. Additional federal and regulations apply to OTEC facilities beyond those discussed above and the discussions at the workshop.

III. WORKSHOP PURPOSE AND SCOPE

This workshop was preceded by a workshop in 2009 (CRRC, 2010) which focused on the technical readiness of OTEC given advancements since the mid-1980s. The technical readiness workshop found that there have been significant advancements in the design and fabrication of the OTEC components and subsystems since the 1980's. The report concluded that construction, installation, and operation of a demonstration (i.e., ≤ 10 MWe) closed-cycle OTEC facility is technically feasible. Experience gained from a demonstration system would greatly aid in the understanding of the challenges associated with a larger commercial facility.

Despite being technically feasible, the extent of design and operational changes required to limit environmental impacts remain unclear. Compounding that uncertainty is the lack of knowledge of the impacts and risks of OTEC. The type and magnitude of potential impacts are largely unknown and must be reasonably ascertained prior to the commitments to design, construct and authorize an OTEC facility.

As a next step in establishing the regulatory feasibility OTEC, a second workshop washed to develop a better understanding of impacts and risks of construction, installation and operation of an OTEC facility, as well as to identify the baseline and monitoring requirements to assess potential impacts.

When evaluating environmental impacts, it is important to consider the scale and overall effect of the impact (i.e., an impact may be devastating to a local population, but inconsequential to the species or ecosystem). Workshop participants were not given specific guidance or limitations on scale or greater effects of the impact, however, most participants focused on localized impacts with some consideration for ecosystem-level impacts.

In order to provide the workshop participants with common design assumptions, the workshop Organizing Committee (OC) limited discussion to a floating, closed-cycle, moored OTEC facility producing electricity transmitted to shore via an undersea cable, with both demonstration (e.g., 5 MWe) and commercial scale (e.g., 100 MWe) facilities being considered.

Discussions at the workshop were limited to electrical generation, and did not include any co-generation of potable water or liquid fuels. ...This report is a qualitative analysis of the potential environmental impacts, monitoring and baseline assumptions, and is meant to inform NOAA OCRM, regulatory agencies and stakeholders. This report is not an exhaustive ecological analysis, nor does it claim to identify every potential environmental impact associated with OTEC. The workshop participants expressed their individual opinions and ideas during the sessions; this report is not the participants' consensus advice to NOAA, but does summarize information gained by NOAA as a result of the workshop. This report does not consider economic, military, technical and social impacts and/or constraints, and is not part of the decision and permitting process for an OTEC facility within U.S. waters.

IV. WORKSHOP ORGANIZATION AND STRUCTURE

The workshop, held in Honolulu, Hawaii on June 22 – 24th, 2010, consisted of plenary sessions where invited speakers discussed their experiences with OTEC and gave their opinions on the state of the technology and potential environmental impacts. Participants for this workshop were selected from a variety of fields and expertise, and included members from State and Federal government, academia, industry, and nongovernment organizations with expertise in policy, engineering, biology, ecology, and oceanography.

Five breakout groups discussed potential impacts from key OTEC sources, including:
1) warm water intake;
2) cold water intake;
3) discharge (including biocides and working fluid leaks);
4) physical presence, construction, and accidents; and
5) noise and electromagnetic fields. ...

V. BREAKOUT GROUP REPORTS

A. Warm Water Intake

The warm water intake group examined the potential physical, chemical and biological impacts from the warm water intake system. The warm water intake system consists of the warm water intake pipe, intake screening, and any component with which warm water comes into contact with. The warm water intake is likely to be in relatively shallow water in an effort to capture the warmest water while at the same time avoiding surface disturbances such as wind and waves. Due to its relatively shallow depth, the principal impacts from the warm water intake system are likely to be entrainment and impingement.

Entrainment, when an organism or particle passes through screening or filters and enters the warm water intake system, mostly affects small organisms that lack *adequate mobility to escape the intake current. Classes of biota likely to become entrained in the warm water intake include: phytoplankton, zooplankton (including microzooplankton, meroplankton (e.g., larvae), icthyoplankton and possibly macrozooplankton), as well as small fish. Once entrained, the biota may be subjected to mechanical and shear stresses from the intake pumps, periodic chemical stresses from the application of anti-fouling biocides, and temperature stress. The impact due to entrainment will vary with the intake screen mesh size, intake velocity and flow rate, survivability characteristics of organisms, and biological community composition and abundance in the region. For the warm-water intake discussions, it was assumed that there would be a low survival rate for organisms entrained.*

Impingement, when an organism is held against a surface by water flow or becomes stuck within a structure, is more likely to affect larger organisms. Classes of biota likely to become impinged against the warm water intake screening include macrozooplankton, cnidarians, small fish, and larger weak or sick fish. Healthy juvenile and adult sea turtles are unlikely to become entrained or impinged in the warm water intake, however, it is possible that sick or weakened individuals could. The magnitude, size and type of impinged organism would depend on the screen mesh size and design, intake velocity and flow, community composition and abundance of biota present in the area.

If the magnitude of the direct effect (e.g., injury or death due to impingement, entrainment) is large enough, there are likely to also be indirect impacts, such as changes in the food web and behavior (i.e., shifting from predation to scavenging). The warm water intake system may also potentially impact diel migrations of micronekton, and may alter their local distribution and abundance. This will have a direct impact on the micronekton and their primary predators. The group concluded that 100% mortality of impinged or entrained organisms is likely.

Baseline Assessments, Monitoring Strategies and Modeling Methods

Some baseline physical, chemical and biological data for the past 30 years exists for the waters surrounding Hawaii (i.e., Hawaii Ocean Time Series (HOT), National Energy Laboratory of Hawaii Authority (NELHA)), and fisheries data, and can be used for initial assessments, however, additional monitoring will be required using current methods and technology to confirm the validity of the historical data. Monitoring strategies will depend upon likelihood and magnitude of the potential impact, with frequent, high resolution monitoring of high priority groups (i.e., endangered species), and infrequent monitoring of groups unlikely to be impacted. As a starting point, plankton should be sampled at least monthly and analyzed for abundance and community composition using visual identification or advanced molecular techniques. Monitoring strategies and modeling should be tailored to ensure that impacts from the warm water intake are fully understood. Biological modeling should be included in the assessment of impacts, and models such as Ecopath with Ecosim, adult equivalent loss (AEL), empirical transport model (ETM), fecundity hindcast (FH), and modification of other existing power plant models should be considered to accurately estimate the impacts to biota from an OTEC warm water intake.

Assessment of OTEC Impacts and Risk

In order to determine the impact of the warm water intake, multiple technologies are required. To assess micronekton and ichthyoplankton impacts, a multiple opening and closing net environmental sensing system (MOCNESS) should be used. These sampling devices are deployed by boat and contain multiple openings at varying depths in order to sample the water column. The use of an acoustic Doppler current profiler (ADCP) can determine particle movement at multiple depths, and would allow continuous assessment of micronekton. Numerous remote sensing technologies exist, including video plankton recording, satellite imaging, and ocean observing systems (OOS) that may allow monitoring of plankton and some nekton. The Natural Energy Laboratory of Hawaii Authority (NELHA) and Kahe power plant both operate pipes similar in size to the pipe required for a 10 MWe OTEC warm water pipe, and examination of entrainment and impingement from these facilities, as well as additional biomass sampling, would provide a better understanding of the sampling requirements and likely impacts due to entrainment and impingement. Advanced molecular techniques (e.g., molecular biology, metagenetics) should be used to characterize plankton and microbial species and their relative abundance relative to a baseline. Table 6 summarizes likelihood, significance, and regulatory implications of potential impacts resulting from the warm water intake system.

Additional Research and Data Gaps

In order to better understand the potential impacts of the warm water intake system, interdisciplinary research is required. Data gaps include: general biota stock structure; early life history studies; quantitative spatial (including water column) and temporal data on abundance and distribution of all biota; mortality of larval and juvenile fish; factors affecting recruitment and compensation for mortality; and effects of coldwater shock once discharged on biota at the OTEC-relevant temperature ranges. Research requirements are similar for entrainment and impingement, and include: updating site-specific baseline ecosystem studies, quantification of biota entering the system compared to the total available resource, analysis of larval abundance and distribution, mortality resulting from the warm water intake system, update of existing stock assessments based upon larval mortality, quantification of swimming speed of both fish and micronekton to assess entrainment and impingement potential.

Mitigation of Impacts

In order to reduce potential physical, chemical and biological impacts of the warm water intake system, it is important to design the warm water intake to reduce the likelihood of entrainment and impingement. For larger organisms like fish, this can be done by increasing the size of the pipe opening to reduce intake velocities, however, the preferred method of minimizing entrainment and impingement for all species is through careful selection of intake depth, mesh size, and location. The group concluded that intake mesh size and design is likely to be plant-specific, and could be tailored to minimize biological impacts. Minimizing lighting on the facility would reduce attraction and should be considered. Deterrent strategies, such as high intensity strobe lights and sound should be considered to repel sensitive species (i.e., juvenile and adult fish). The practicality of these methods will need to be carefully evaluated since some of these mitigation *methods could reduce the efficiency of the OTEC facility. Decreased intake velocity and changes tithe depth may substantially reduce efficiency of energy production.*

B. Cold Water Intake

The cold water intake group examined the potential physical, chemical and biological impacts of the cold water intake system. Like the warm water intake, entrainment and impingement are likely to be the primary impacts from the cold water intake system. However, due to the depth of the cold water pipe intake (e.g., 1000 m) the biomass concentration is anticipated to be less than at the warm water intake. Mesopelagic microzooplankton would likely be entrained, however, not enough is known about deepwater ecosystems to determine if this would include meroplankton or ichthyoplankton. Entrained organisms would be subject to extreme pressure changes on the order of 100atmospheres (1,422 PSI), mechanical and shear stress from the intake pumps and water flow, as well as extreme temperature changes. Impingement of organisms in the coldwater intake is likely to be limited to macrozooplankton and small fish. However, because it is anticipated the debris screens would be located on the surface (to aid in cleaning)rather than at the deep water intake, mortality is most likely to be caused by extreme pressure changes associated with entrainment prior to impingement. A low survival rate is anticipated. The large volume of seawater transported by the cold water intake system ultimately released either via a cold water return or mixed return at a much shallower depth. This disruption in vertical stratification could disrupt the community composition and ecological functions, possibly resulting in disruptions to the local food web.

Subsea currents and associated shearing forces will cause the cold water pipe to oscillate on the order of one pipe diameter. This will create noise and vibration, which may impact organisms. The magnitude and nature of this impact is unknown. These oscillations, caused by fluid movement around the pipe, are also likely to shed vortices, which also create an unknown impact.

The ocean is not homogeneous, and some locations will be more sensitive than others. Site selection will affect the type and magnitude of the impact. For example, submarine canyons, while potentially thermodynamically ideal for placement of the coldwater intake, contain organisms endemic to that environment and may be unable to survive if disruptions (i.e., change in currents, temperature, chemical characteristics)occur. The distance between the bottom of the cold water pipe and the seafloor will also be a consideration in the site selection. Impacts resulting from material selection and pipe cleaning may also occur, however, these cannot be predicted without further design and maintenance information.

Baseline Assessments, Monitoring Strategies and Modeling Methods

In order to develop an acceptable baseline, a mooring sampling system could be used to sample at the depth of the intake. Sampling would need to occur at least monthly for one year, however, this will likely collect too little data (i.e., under sample). Baseline sampling should occur at day and night to capture diurnal movements, and should be conducted in permanent sampling grids so that once the OTEC facility begins operation, long term impacts can be assessed. Intensive, multi-depth hourly trawls should be considered for periods of up to 5 days to capture vertical movements. Climate *patterns(e.g., El Niño, La Niña) should also be considered when developing monitoring strategies.*

While studies exist that characterize organisms present at the depth of the coldwater intake, these studies used methods that are now considered obsolete with the advent of advanced molecular techniques. In addition, there is some evidence that conditions have changed since the publication of many of these studies, and their findings may differ from current conditions. While these studies can be used for an initial baseline, further sampling and analysis are needed to validate these results prior to their use in any models.

The cold water intake should be closely monitored for impingement, and water in the intake should be sampled frequently (> 2/day) and analyzed using molecular methods to gain a better understanding of what species and quantity of organisms are being entrained.

Assessment of OTEC Impacts and Risks

In order to assess the impact of the cold water intake and risk to species in the region, the type and abundance of organisms present must be known. To assess the micronekton and ichthyoplankton at depth, a MOCNESS sampling device should be used. Remote sensing using passive acoustic arrays, hyper spectral satellite monitoring, cameras placed at the intake, and autonomous underwater vehicles (AUVs) can be used to monitor larger organisms in the region. The 1986 NOAA NMFS report relied on visual identification of plankton and microorganisms to determine impacts. Detection capabilities have advanced considerably since then and now allow positive identification using molecular techniques. Abundance and community composition should be analyzed with these techniques to provide the best possible data. Continual monitoring of the seawater being transported by the cold water pipe is desirable for demonstration plants, as grab and composite samples may not adequately define the impacts. Bioluminescent system monitors or photomultiplier tubes can also be used to detect organisms in the region, however, cannot be the sole method of detection as they only target organisms with bioluminescent properties. Optical particle counters can be considered for continuous monitoring, however, additional analysis is required, as particle counters cannot easily distinguish between inorganic and organic particles.

In order to gain a better understanding of localized changes to seawater chemistry, water in the vicinity of the cold water pipe intake should be analyzed for numerous constituents, including: nitrogen (e.g., nitrate, nitrite, ammonia); phosphorous, phosphate, silica, pH, and dissolved gasses. Significant changes in the source water may indicate shifts in subsea currents and stratification. …

Additional Research and Data Gaps

The majority of data gaps associated with impacts to the cold water pipe focus on the presence and abundance of species at the depth of the intake. Additional research is needed to quantify mesopelagic biota, and gain a better understanding of their behavior. Once the organisms present at depth are characterized and their role in the ecosystem and food web better understood, improved models of the impact the cold water pipe system will be possible. Research should also investigate the fate of entrained *organisms. Further investigation of foraging patterns of endangered species in the region should be considered, as well as archival tagging and acoustic monitoring to better understand their presence at these depths.*

Mitigation of Impacts

The best way to mitigate potential impacts of the cold water intake system without affecting operational efficiency is to prevent the impacts from occurring through careful site selection. Locations that have deep water corals, submarine canyons, high abundance of prey communities, and locations with high currents should be avoided. To minimize impacts, the intake should have a vertical orientation and at a depth which optimizes the reduction of impacts to organisms.

C. Discharge

The discharge group examined the potential physical, chemical and biological impacts of the discharge from the OTEC facility, including biocides and working fluid leaks. After water from the cold water and warm water pipes has passed through heat exchangers and heat has been extracted, the water is returned to the ocean via discharge pipes. Discharge configurations may include individual cold and warm water return pipes, or a combined return where the cold and warm water are mixed and returned above the thermocline. If a combined discharge is selected, the temperature and salinity of the water released would be an average of the cold and warm water discharge. This water would sink to a depth of comparable density, which will vary with location. This may result in localized changes to the temperature and currents, in addition to the plume-induced currents. The discharge pipe will be at a depth below the warm water intake in order to ensure the effluent discharge is not re-circulated into the warm water intake which would reduce the overall efficiency of the facility.

The depth of discharge is crucial and will affect the magnitude and extent of impacts. Organisms that survive the entrainment process may ultimately die if they are released at an unsuitable depth. Organisms in the vicinity of the discharge may be entrained in this plume (i.e., secondary entrainment). The cold water discharge will contain dissolved gasses and nutrients transported from the deep. If released close to the surface, the change in pressure will cause release of some of the gasses, and will likely change the chemistry of the surrounding water. Dissolved carbonates in the discharge may change the pH in the local receiving water, potentially inhibiting the shell production of foraminifera and veliger larvae. Some concern has been expressed over dissolved carbonates released in the form of CO2 into the atmosphere in this process and thus increasing global carbon dioxide emissions. While possible, the magnitude of the release would depend upon the depth and density of the discharge.

Nutrients in the discharge may enhance primary productivity, decrease dissolved oxygen levels, or cause toxic algal blooms (i.e., similar to coastal upwelling). Dead organisms in the discharge plume may act as food source, attracting fish to the vicinity of the plume. The discharge water may also contain particulates and dissolved constituents from erosion and corrosion of facility components, living or dead entrained organisms, biocide from anti-fouling treatment, nutrients, and potentially small working fluid releases from normal operations. The discharge may contain low concentrations of contaminants, however this will vary with the age, design, construction material, and *maintenance of the facility, as well as the overall quality of ocean water in the region (i.e., turbid water will result in greater erosion). The toxicity of these contaminants will vary with concentration, exposure, bioavailability and bioaccumulation potential. The toxicity, water chemistry, and secondary entrainment impacts addressed above apply to separate and combined discharges. Biological impacts associated with the plume will might include: acute or chronic toxicity; behavioral changes; reduced fecundity; attraction or repulsion from the OTEC facility; and changes to the local ecosystem structure.*

Baseline Assessments, Monitoring Strategies and Modeling Methods

Monitoring frequency will be dependent on the variability in the data collected, and is difficult to predict without further site-specific information. However, monitoring should be continuous during construction and installation, as well as the first year of operation for the demonstration plant. The region should be monitored for an additional 3– 5 years thereafter to ensure there are no significant changes in the chemical or physical characteristics of the water column. While 20 years of Hawaii Ocean Time series (HOT) data exists, it was collected monthly and not necessarily at locations under consideration for OTEC, and therefore, is not suitable as a sole source of baseline data and information. The baseline should be measured at specific sites surrounding the proposed OTEC facility location and continue after operation of the demonstration plant commences to better capture any changes. The sampling design for monitoring and assessment should be statistically robust and use the best available and practical technologies. For anticipated discharge flows, there are research plume models (e.g., Makai OTEC plume model) that can predict the fate and transport of the discharge plume. Model development must include spatial and temporal components and include multiple constituents (e.g., temperature, nutrients, dissolved oxygen, salinity).

Assessment of OTEC Impacts and Risks

The assessment of impacts and risks from the discharge pipe are dependent upon accurate measurements of the physical and chemical characteristics of seawater, as well as direct measurements of the biological impacts in the region. Direct measurement of the biological impacts can be accomplished through various monitoring technologies including optical plankton counters, fluorometers, and collection of samples via AUVs, gliders, ships and stationary mooring sampling devices. Assessment of chemical and physical impacts can be made via frequent sampling and analysis of seawater collected with buoyant drifters. Sensors used should be equipped to monitor: nitrate, including other surrogates, hydroacoustics to measure changes in transition layers, in situ ultravioletsensors (ISUS), acoustic receivers on gliders, and dissolved inorganic carbon (DIC) and optical characteristics. Temperature changes can be measured using remote loggers, conductivity, temperature and depth (CTD) systems, and gliders. Direct impacts to biota due to changes in the chemical and physical characteristics of the seawater can be measured through chronic and acute bioassays. Table 8 summarizes the likelihood, significance, and regulatory implications of potential impacts resulting from the discharge from an OTEC facility.

Additional Research and Data Gaps

Additional research is needed to validate plume models, specifically using inert tracers to model plume fate and behavior. This will provide a better understanding of the fate and behavior of chemical and physical constituents of the plume, and how they may impact the region. In order to better understand the impact to the microbial and nanoplankton communities, advanced microbial and molecular techniques should be used to characterize the communities present at the discharge depth. In addition, an in-depth characterization of the biological community should be conducted at intake and discharge depths.

Mitigation of Impacts

Potential impacts can be mitigated by reducing the effect of the discharge through greater dilution or elimination of the causative agents. Dilution can be increased through changes in depth of the pipe, addition of diffusers, enhanced mixing (e.g., creation of turbulent mixing), or use of multiple pipes. Elimination of the impact can also be accomplished through minimizing: biocide use, temperature changes in plume, release of working fluids, and selection of construction materials that reduce the release of toxic compounds. From an environmental standpoint, a mixed discharge is preferable because it results in a plume that is closer in temperature to the receiving water, minimizing temperature effects in the region surrounding the discharge plume.

D. Physical Presence, Construction, and Accidents

The physical presence, construction, and accidents group examined the potential physical, chemical and biological impacts associated with the physical presence, construction, and accidents associated with an OTEC facility. Construction impacts will vary with: location and design of the facility, extent of construction that takes place at sea, type and installation method of the power cable, and type of mooring selected. The platform will likely be built at a shore-based facility and towed to the site. The cold water pipe may be constructed on land and towed to the site, or constructed/ manufactured onsite. The most disruptive aspects of installation are likely to be the placement of anchors, moorings and power cables. The installation and presence of these components may require blasting, drilling and excavation of the seafloor, and could disrupt benthic and pelagic communities, including deep corals and crustaceans, vertebrate fish, marine mammals, sea birds, sea turtles, invertebrates, and microbial communities. In particular, the installation and presence of the power cable will: increase suspended sediment, disturb or destroy coastal resources and coral reefs, as well as alter the behavior of invertebrate and vertebrate in the region. The installation of these components will disrupt habitat heterogeneity, and may have secondary long-term impacts to the ecosystem. Construction, installation and vessel traffic activities are likely to generate noise, and may disrupt movement and communication of fish, marine mammals and reptiles (e.g., whales, dolphins, sea turtles) in the area. Platform lighting may disrupt the normal behavioral patterns of sea birds, turtles, marine mammals, plankton, squid and fish in the region. Noise and EMF generated during construction and operation of an OTEC facility are addressed in Section E, Noise and EMF.

The physical presence of the platform will most likely serve as a fish attraction device (FAD). This may increase the number of impinged and entrained organisms, and could *change local migratory patterns. Accidental release of chemicals, while unlikely, has the possibility of disrupting all life within the plume and in the region surrounding the facility. Direct toxicity, chemical oxidation, and indirect toxicity (i.e., drop in pH increases certain metals, causing toxic effects) can potentially result from a chemical release.*

When examining potential impacts due to physical presence, construction and accidents, it is important to take into consideration the size of the system (i.e., the physical size of a 100 MWe plant is much larger than a demonstration 10 MWe facility). Different size plants will likely have significantly different impacts. The component type will also play a significant role in the type of impact (i.e., a drilled mooring could be disruptive to the benthos, but all mooring/anchors can potentially impact deep sea corals and other biota). Table 9 summarizes likelihood, significance, and regulatory implications of potential impacts resulting from physical presence, construction and accidents.

Baseline Assessments, Monitoring Strategies and Modeling Methods

The baseline assessment may be seasonally dependent, and sampling should take this into consideration. Benthic site surveys should be conducted pre and post-construction to evaluate the impact to the seafloor and the biota that inhabit it. Pre-construction surveys can also be used to avoid particularly sensitive habitats (e.g., deep water corals). Water column assessments should vary in temporal and spatial scales, and should continue for a minimum of three years. Assessments should include sampling via trawl nets, collection and reporting of downed birds to the U.S. Fish and Wildlife Service, as well as multiple surveys to monitor changes in distribution, habitat use, frequency and abundance of marine mammals.

Assessment of OTEC Impacts and Risks

Technology and methods to assess the impact and risk of the physical presence and construction of an OTEC facility should include remote sensing (submersibles, multibeam side scan sonar, ROV, AUV), satellite telemetry of tagged biota, and visual and genetic surveys to identify any potential shifts in community composition. Many impacts are likely to be similar to those observed during construction and installation of oil platforms and offshore windfarms, and techniques and methods used to monitor impacts could be used to assess impacts and risk at an OTEC facility.

E. Noise and Electromagnetic Fields

The noise and electromagnetic fields group examined the potential physical, chemical and biological impacts associated with the production of noise and electromagnetic fields associated with an OTEC facility. The generation of noise and electromagnetic fields (EMF) are of concern due to the large number of marine organisms that regularly use acoustics (e.g., dolphins, whales, fish) and electromagnetic fields (e.g., sharks, turtles) for communication, detection of prey/predators, and navigation.

There are likely to be impacts associated with noise and electromagnetic fields, however, the magnitude and extent of the impact is not known and will likely depend on many factors. Sources of construction-related noise are likely to include: deployment of moorings, anchors and the power cable; deployment of the cold water pipe; and associated boat traffic. Sources of operational noise include turbines, pumps, discharge *turbulence, cable strum (both mooring and power cable), cold water pipe vibration, boat traffic, and frictional noise from water movements. To date, very little direct measurements of the noise associated with OTEC facilities exist. The impact of noise will vary with receptor and exposure (i.e., magnitude, temporal, spatial, spectral), and will most likely manifest themselves as a physiological or behavioral impacts. Physiological impacts could include: hearing damage and loss (e.g., permanent threshold shift (PTS); temporary threshold shift (TTS)) and, in some species, could lead to death through inability to complete basic biological functions (e.g., echolocation for prey detection in dolphins). Behavioral changes may include local or widespread changes in movement (e.g., attractant, deterrent), communication difficulty due to masking, and changes in feeding and breeding habits (e.g., larval recruitment). If these behavioral changes persist, an ecosystem level impact may occur, potentially resulting in localized changes to community structure and food web dynamics.*

Electromagnetic field generation is likely limited to the power cable, with the section that is suspended between the seafloor and the platform most likely to cause impacts. The receptivity and sensitivity to EMF is unknown for many species. Sensitive species (i.e., sea turtles, sharks) are most likely to be impacted, and if exposed, are likely to exhibit changes in behavior, including attraction and avoidance.

Baseline Assessments, Monitoring Strategies and Modeling Methods

A baseline assessment of ambient noise can be determined prior to construction with stationary monitoring equipment. Monitoring should continue throughout the construction, installation and operational phase using the same equipment and locations to facilitate comparison. Autonomous broadband acoustic recorders coupled with validated acoustic propagation models can be used to determine the range of impact. Pre- and post monitoring of species abundance, behavior and distribution will be required to validate models and laboratory tests.

Assessment of OTEC Impacts and Risk

Sound and EMF are relatively easy to monitor and model using acoustic and EMF monitoring equipment positioned on stationary buoys, however effort is required to filter out extraneous sounds. Impacts to biota from noise and EMF are more difficult to quantify, and frequent monitoring for behavioral changes and physiological damage would-be required during construction and operation to ensure the impact to the biota is understood. Changes to behavior and physiological damage for smaller species can be assessed in the lab or aquaculture cage studies, while tagging and telemetry using passive acoustic monitoring devices can be used for larger organisms. Table 10 summarizes likelihood, significance, and regulatory implications of potential impacts resulting from acoustics and EMF.

Additional Research and Data Gaps

In order to better understand the magnitude and type of impact likely to occur, additional research is needed to better understand the tolerance thresholds of marine organisms for sound and electromagnetic fields. While some animals have been widely studied, little is known about the response to sound and electromagnetic fields by the majority of biota that exist in the open ocean. In addition, further research is needed to *understand the role sound has on larval recruitment, and if OTEC-related sounds will impact it.*

Mitigation of Impacts

The most effective way to prevent or limit noise and EMF impacts is to reduce exposure. This can be accomplished through careful site selection to avoid sensitive species, or through a reduction in the sound or EMF generated. Little can be done to reduce the impact of sound once it is generated, and mitigation efforts should focus on reducing the amount generated, or shifting it to a frequency that is less harmful. Acoustic deterrent devices can be used to repel animals from the area, however, this will increase the overall level of noise and may have unintended impacts on other species. EMF size and strength can be reduced through shielding. This can be accomplished on the seafloor by burying the cable. Shielding is more difficult on the riser section of the power cable(i.e., from the seafloor to the OTEC facility). Shielding is typically heavy, and current platform-power cable connections may not be able to support the additional weight.

VI. BASELINE ASSESSMENTS, MONITORING STRATEGIES AND MODELING METHODS

On the final day of the workshop, the participants were divided into four groups: Fisheries and Corals (Table 11 – 13); Marine Mammals (Table 14 – 16); Oceanography (Table 17 – 19); and Plankton (Table 20 – 22). Each group was asked to identify: 1) baseline data needed and minimum baseline duration; 2) monitoring strategies and methods; and 3) modeling strategies and methods. Each group was asked to fill out the following tables. All groups assumed a minimum baseline duration of 1 year; deviations from this are noted and justified in the tables. The 1 year timeframe was chosen as a starting point, not an acceptable minimum, and should not be relied upon as such. Sampling frequency and specific methods were not addressed, and will need to be addressed in a fully developed monitoring plan at a later time.

VII. CONCLUSIONS

The 1981 EIS and 1986 NMFS report identified numerous potential impacts related to the construction and operation of an OTEC facility in Hawaiian waters. The participants of this workshop concurred with these potential impacts, and were able to expand the list based upon 25+ years of knowledge and experience gained in similar fields. The results of this workshop show that physical, chemical and biological impacts of an OTEC plant in Hawaiian waters are likely to occur during the installation and operation of an OTEC facility. However, due to a lack of appropriate field data, the magnitude and extent of these impacts are not known. In order to gain a better understanding of the risk installation and operation of an OTEC facility represents, a baseline consisting of a minimum of one year of data is required prior to construction and installation.

While in some cases one year may be sufficient, unusual weather, currents, high sample variability and other factors may require longer baseline sampling, and in many circumstances, a longer baseline may be desired in order to capture multi-year variability and annual variations. Baseline and monitoring data collected should include the abundance and community composition of large and small biota, as well as well as the physical and chemical characteristics of seawater in the region. Examples of *parameters that should be monitored include, but are not limited to: temperature; salinity; dissolved oxygen; pH; trace metals; and abundance, diversity, and behavioral changes to plankton, fish, marine mammals, turtles, and other biota. Sampling frequency during this baseline should be constituent specific, and follow a sampling plan designed to adequately capture natural variations and cycles. It is worth repeating that this report is not an exhaustive ecological analysis, nor does it claim to identify every potential environmental impact associated with OTEC or provide a detailed baseline and monitoring sampling plan.*

An environmental baseline assessment must be conducted prior to the project installation. Once construction, installation and operation of the facility commences, baseline parameters should be monitored for deviations to provide information on how the facility is impacting the local environment. Once likely impacts are established, steps can be taken to ameliorate these impacts through careful site selection, modifications to the facility, or changes to facility size or scope. Secondary and indirect impacts are not likely to be immediately evident, and long-term monitoring, possibly for the life of the facility, may be required. These impacts have the potential to play a large role in ecosystem-level impacts of an OTEC facility, and further research is needed to quantify the risk involved and develop better methods of detection.

APPENDIX 9: ADVANCES IN HAWAII'S OCEAN ENERGY RD&D (2009)[344]

Hawaii's ocean thermal resources are well documented as the state's Natural Energy Laboratory of Hawaii Authority (NELHA), located at Keahole Point on the island of Hawaii, was one of the world's premier sites for OTEC research from the mid-1970s into the 1990s.

With annual warm surface waters typically in excess of 25° C (77° F) and deep, coldwater available less than 1.6 km (1 mile) offshore providing the rule-of-thumb 20ºC temperature differential, Hawaii is an ideal site for OTEC research, development and commercial deployment. …

On November 18, 2008, during a trip to Asia by Hawaii Governor Linda Lingle, a partnership was launched between Taiwan Industrial Technology Research Institute (ITRI), a non-profit government sponsored research institution, and Lockheed Martin Corporation which will involve the development of a10 MW OTEC pilot plant. ITRI has agreed to join in a feasibility study and will collaborate in the initial pilot plant, to be located in Hawaii. The aim of the agreement is to strengthen mutual understanding and bilateral cooperation in the area of ocean thermal energy conversion.

Lockheed Martin Corporation has developed and studied OTEC technology for over 30 years. Much of the R&D was performed at NELHA, located on the Kona coast of the island of Hawaii. Lockheed's Hawaii projects included the mini-OTEC barge which was the first closed-cycle, at-sea OTEC plant to generate net electricity. Mini-OTEC was deployed off NELHA in 1979.

Lockheed's plans for a 10 MW pilot and discussions with the Hawaiian Electric Company (HECO) were already underway at the time of the agreement with ITRI. Lockheed Martin intends to employ low-cost composite materials and new construction and welding techniques to reduce the capital costs of an OTEC plant.
Their aluminum heat exchanger concept builds upon the lessons learned from earlier USDOE-funded research. Heat exchanger technology is critical, as heat exchangers are expected to command over half of the capital construction costs of a 100 MW OTEC plant.

They envision using a standard semi-submersible center hull platform, as utilized in the offshore oil and gas industries. Deep water platform technology is mature, with approximately 100 floating production platforms built and installed in water depths up to 2400m (7800 ft).

Lockheed Martin has been awarded a cooperative agreement contract with USDOE, with a maximum value of $1.2 million, to demonstrate innovative technologies which will enable ocean thermal energy power generation. Under the terms of the cooperative agreement, which will support the Hawaii pilot plant, Lockheed Martin will demonstrate a cold water pipe fabrication approach using modern fibreglass technology and recent low-cost composite material manufacturing methods at prototype and pilot plant scales.

---

[344] By A.T. Gill (Energy Analyst, State of Hawaii Department of Business, Economic Development and Tourism) and Richard E. Rocheleau (Director, University of Hawaii at Manoa, Hawaii Natural Energy Institute)

Lockheed's offices based in Manassas, Virginia, will lead the OTEC effort, while fabrication work will be performed at the company's Advanced Technology Center in Sunnyvale, California.

OCEES International, Inc. has also proposed a 1MW OTEC facility at NELHA. The U.S. Department of the Navy has awarded an OTEC feasibility study for its base in Guam to Makai Ocean Engineering, a Honolulu-based firm with extensive experience in deep water pipelines. ...

Sea Solar Power, a Baltimore, Maryland company, has submitted a proposal to HECO for a 100 MWOTEC facility on a platform 6.4 km (4 mi) off the southwestern point of Oahu.

The proposed Sea Solar and Lockheed projects were both mentioned in the agreement between HECO and the State of Hawaii, signed on October 20, 2008, to implement aspects of the Hawaii Clean Energy Initiative.

APPENDIX 10: ALTERNATIVES TO THE COLD WATER PIPE

Desert-ocean thermal energy conversion[345]

"The west coast of South Africa and Namibia has an abundant supply of cold surface and near-surface water lying adjacent to the coastline due to the dynamical oceanographic process known as 'upwelling.' This readily available supply of cold water overcomes problems surrounding cold water pipe technology in conventional OTEC systems. If a means can be found to create a positive temperature differential of greater than 18°C with this source water then thermal energy conversion will be possible. It is proposed that the pre-requisite gradient can be obtained by an input of heat from a combination of incoming solar radiation, the hot desert surface and local wind energy.

In operational terms, the best way to achieve this differential is to heat a sufficient volume-per-unit-time of the incoming source water. This modification provides a significant departure from conventional OTEC schemes and has been provisionally named `Des- OTEC'.

The west coast of South Africa and Namibia is home to the Benguela Upwelling System, one of five major coastal upwelling areas in the world ocean. Others are located off the coasts of Peru and Chile, California, N.W. Africa and seasonally off the coast of Somalia. They are all characterised by strong equatorward winds which drive an offshore movement of surface water (through Ekman transport) resulting in the upwelling of cold, nutrient-rich deep water into a broad zone adjacent to the coast. Des-OTEC would be applicable to any of these upwelling systems.

The Benguela therefore has a perennial reservoir of coastal water between 7°C and 12°C. This water is readily available for pumping to a landbased, closed-cycle OTEC plant, however, before the system can operate successfully, it is necessary to acquire a source of heat 18°C or more than the coldwater source. A variety of solar collectors, heat ponds etc. are being considered to obtain this. This heat source can then be used to evaporate the working fluid.

The coastline of the Benguela Upwelling System is mainly of the desert type, especially in its mid and northern sections. There are high rates of incident solar radiation (up to 1200 W.m-2) and elevated sand-surface temperatures (c. 60°C). It is the initial design criterion that this untapped heat source be used to increase the water temperature at a sufficient rate for use in the closed-cycle evaporator.

Incident and back solar radiation may be sufficient to obtain the necessary temperature gradient, however, supplementary energy is available from the substantial wind energy available in the coastal belt. The southerly and south-easterly wind (25 – 40 knots) could be harnessed using available technology to provide subsidiary energy to help with pumping, heating, or potentially, as an independent source of power. …

Des-OTEC provides a conceptual modification to existing OTEC systems by circumventing the need for an ambient temperature gradient in the water column and

[345] http://www.erc.uct.ac.za/emnews/EMN-08-03.pdf

removing the constraints imposed by cold water pipe technology. It is envisaged that small-scale, locally orientated electricity supply schemes would greatly benefit the towns and settlements along the west coast of South Africa and Namibia and the coasts of other upwelling areas. The electric power generated by such schemes can be used for domestic or small-scale industrial supply. Alternatively, it can be used to run desalination plants supplying fresh water for drinking or agriculture. The water pumped ashore as part of Des-OTEC is rich in plant nutrients and would be suitable for local aquaculture projects."

Dr Howard Waldron, Department of Oceanography, University of Cape Town & David Petrie, Energy Management News Volume 14 Number 1, March 2008, published quarterly by the Energy Research Centre (ERC) of the University of Cape Town.

APPENDIX 11: OCEAN ENVIRONMENTS

Mostly from Wikipedia

Ocean Layers

Epipelagic (sunlit) (Photic zone). From the surface (MSL) down to around 200 m (650 ft).This is the illuminated zone at the surface of the sea where there is enough light for photosynthesis. Nearly all primary production in the ocean occurs here. Consequently, plants and animals are largely concentrated in this zone. Examples of organisms living in this zone are plankton, floating seaweed, jellyfish, tuna, many sharks, and dolphins. This zone includes the **neuston** layer which is the air–water interface and includes the upper few millimeters of the water column. About 90% of all marine life lives in the photic zone.

Mesopelagic (twilight). From 200 m down to around 1,000 m (3,300 ft).The name for this zone stems from Greek word meaning middle. Although some light penetrates this second layer, it is insufficient for photosynthesis. At about 500 m the water also becomes depleted of oxygen. Still, life copes, with gills that are more efficient or by minimizing movement. Examples of animals that live here are: swordfish, squid, wolffish and some species of cuttlefish. Many organisms that live in this zone are bioluminescent. Some creatures living in the mesopelagic zone will rise to the epipelagic zone at night in order to feed.

Bathypelagic (midnight). From 1,000 m down to around 4,000 m (13,000 ft).The name stems from the Greek word meaning deep. At this depth the ocean is pitch black, apart from occasional bioluminescent organisms, such as lanternfish. There is no living plant-life. Most animals living here survive by consuming the detritus falling from the zones above, which is known as "marine snow", or, like the marine hatchetfish, by preying on other inhabitants of this zone. Other examples of this zone's inhabitants are giant squid, smaller squids & dumbo octopodes. The giant squid is hunted here by deep-diving sperm whales.

Abyssopelagic (lower midnight) extends from 4,000 m down to above the ocean floor. The name is derived from the Greek word abyss, meaning bottomless (a holdover from the times when the deep ocean was believed to be bottomless). Very few creatures are sufficiently adapted to survive in the cold temperatures and incredible pressures found at this depth. Among the species found in this zone are several species of squid; echinoderms including the basket star, swimming cucumber, and the sea pig; and marine arthropods including the sea spider. Many of the species living at these depths have evolved to be transparent and eyeless as a result of the total lack of light in this zone.

Hadopelagic is the deep water in ocean trenches. The name is derived from the Greek word Hades, the classical Greek underworld. This zone is mostly unknown, and very few species are known to live here (in the open areas). However, many organisms live in hydrothermal vents in this and other zones.

Ocean Zones

Pelagic Zone: Any water in the sea that is not close to the bottom or near to the shore is in the pelagic zone. The word pelagic comes from the Greek word meaning "open sea." The pelagic zone can be thought of in terms of an imaginary cylinder or water column that goes from the surface of the sea almost to the bottom.

The pelagic zone occupies 1,370 million cubic kilometres (330 million cubic miles) and has a vertical range up to 11 kilometres (6.8 miles). Fish that live in the pelagic zone are called pelagic fish. Pelagic life decreases with increasing depth. It is affected by light levels, pressure, temperature, salinity, the supply of dissolved oxygen and nutrients, and the submarine topography. In deep water, the pelagic zone is sometimes called the open-ocean zone and can be contrasted with water that is near the coast or on the continental shelf.

The **benthic zone** is the ecological region at the very bottom of the sea. It includes the sediment surface and some sub-surface layers. Marine organisms living in this zone, such as clams and crabs, are called benthos.

The **demersal zone** is just above the benthic zone. It can be significantly affected by the seabed and the life that lives there. Fish that live in the demersal zone are called demersal fish. Demersal fish can be divided into benthic fish, which are denser than water so they can rest on the bottom, and benthopelagic fish, which swim in the water column just above the bottom. Demersal fish are also known as bottom feeders and groundfish.

Biota

Crustaceans form a very large group of arthropods, usually treated as a subphylum, which includes such familiar animals as crabs, lobsters, crayfish, shrimp, krill and barnacles. The 50,000 described species range in size from Stygotantulus stocki at 0.1 mm (0.004 in), to the Japanese spider crab with a leg span of up to 12.5 ft (3.8 m) and a mass of 44 lb (20 kg). Like other arthropods, crustaceans have an exoskeleton, which they moult to grow. They are distinguished from other groups of arthropods, such as insects, myriapods and chelicerates by the possession of biramous (two-parted) limbs, and by the nauplius form of the larvae. Most crustaceans are free-living aquatic animals, but some are terrestrial (e.g. woodlice), some are parasitic (e.g. fish lice, tongue worms) and some are sessile (e.g. barnacles).

Arthropods are characterized by their jointed limbs and cuticles. They have over a million described species, making up more than 80% of all described living animal species, and are one of only two animal groups that are very successful in dry environments – the other being the amniotes. They range in size from microscopic plankton up to forms a few meters long.

Cephalopoda (Greek meaning “head-feet"). These exclusively marine animals are characterized by bilateral body symmetry, a prominent head, and a set of arms or tentacles (muscular hydrostats) modified from the primitive molluscan foot. Fishermen sometimes call them inkfish, referring to their common ability to squirt ink. Coleoidea includes octopuses, squid, and cuttlefish; and Nautiloidea, represented by Nautilus and Allonautilus.

Plankton: organisms that float or drift within the water

Macroplankton are 200-2,000 micrometers in size.

Microplankton (also called net plankton) is composed of organisms between 0.05 and 1 mm (0.002 and 0.04 inch) in size

Zooplankton from the Greek words meaning "animal wanderer or drifter"

Nekton: organisms that swim (powerfully) in the water

Benthos: organisms on the bottom of a body of water

Neuston refers to organisms that float on the top of water (epineuston) or live right under the surface (hyponeuston). Neustons include flying fish, beetles, protozoans, bacteria, spiders and water striders.

Phytoplankton are the autotrophic component of the plankton community. The name comes from the Greek words meaning "plant", and "wanderer" or "drifter". Most phytoplankton are too small to be individually seen with the unaided eye. However, when present in high enough numbers, they may appear as a green discoloration of the water due to the presence of chlorophyll within their cells (although the actual color may vary with the species of phytoplankton present due to varying levels of chlorophyll or the presence of accessory pigments.).

Phytoplankton obtain energy through the process of photosynthesis and must therefore live in the well-lit surface layer (termed the euphotic zone) of an ocean, sea, lake, or other body of water. Phytoplankton account for half of all photosynthetic activity on Earth, thus phytoplankton are responsible for much of the oxygen present in the Earth's atmosphere – half of the total amount produced by all plant life. Their cumulative energy fixation in carbon compounds (primary production) is the basis for the vast majority of oceanic and also many freshwater food webs (chemosynthesis is a notable exception). Since the 20th century, phytoplankton has declined by roughly 1% yearly, possibly linked to warming oceanic temperatures - as of 2010 this means a decline of 40% relative to 1950.

While almost all phytoplankton species are obligate photoautotrophs, there are some that are mixotrophic and other, non-pigmented species that are actually heterotrophic (the latter are often viewed as zooplankton). Of these, the best known are dinoflagellate genera such as Noctiluca and Dinophysis, that obtain organic carbon by ingesting other organisms or detrital material.

There are about 5,000 species of marine phytoplankton. There is uncertainty in how such diversity has evolved in an environment where competition for only a few resources would suggest limited potential for niche differentiation. In terms of numbers, the most important groups of phytoplankton include the diatoms, cyanobacteria and dinoflagellates, although many other groups of algae are represented.

Zooplankton are the heterotrophic (sometimes detritivorous) type of plankton. Zooplankton is a broad categorisation spanning a range of organism sizes that includes both small protozoans and large metazoans. It includes holoplanktonic organisms whose complete life cycle lies within the plankton, and meroplanktonic organisms that spend part of their life cycle in the plankton before graduating to either the nekton or a sessile, benthic existence.

Although zooplankton are primarily transported by ambient water currents, many have some power of locomotion and use this to avoid predators (as in diel vertical migration) or to increase prey encounter rate.

Important **metazoan zooplankton** include cnidarians such as jellyfish and the Portuguese Man o' War; crustaceans such as copepods and krill; chaetognaths (arrow worms); molluscs such as pteropods; and chordates such as salps and juvenile fish. This wide phylogenetic range includes a similarly wide range in feeding behavior: filter feeding, predation and symbiosis with autotrophic phytoplankton as seen in corals.

Zooplankton feed on bacterioplankton, phytoplankton, other zooplankton (sometimes cannibalistically), detritus (or marine snow) and even nektonic organisms. As a result, zooplankton are primarily found in surface waters where food resources (phytoplankton or other zooplankton) are most abundant. Through their consumption and processing of phytoplankton (and other food sources), zooplankton play an important role in aquatic food webs, both as a resource for consumers on higher trophic levels (including fish), and as a conduit for packaging the organic material in the biological pump. Since they are typically of small size, zooplankton can respond relatively rapidly to increases in phytoplankton abundance, for instance, during the spring bloom. Aside from this role in aquatic food webs, zooplankton can also act as an important disease reservoir. They have been found to house the bacterium Vibrio cholerae, causative agent of cholera, by allowing the cholera vibrios to attach to their chitinous exoskeletons. This symbiotic relationship greatly enhances the bacterium's ability to survive in an aquatic environment, as the exoskeleton provides the bacterium with an abundant source of carbon and nitrogen.

Dinoflagellates are an ecologically important protozoan zooplankton group. The dinoflagellates are a large group of flagellate protists. Most are marine plankton, but they are common in fresh water habitats as well. Their populations are distributed depending on temperature, salinity, or depth. About half of all dinoflagellates are photosynthetic, and these make up the largest group of marine eukaryotic algae aside from the diatoms. Being primary producers makes them an important part of the aquatic food chain. An algal bloom of dinoflagellates can result in a visible coloration of the water colloquially known as red tide.

Movement

Phototaxis is a kind of taxis, or locomotory movement, which occurs when a whole organism moves in response to the stimulus of light. This is advantageous for phototrophic organisms as they can orient themselves most efficiently to receive light for photosynthesis. Phototaxis is called positive if the movement is in the direction of increasing light intensity and negative if the direction is opposite.

Diel vertical migration (DVM) is a common behaviour of many pelagic zooplankton species. Diel vertical migration, also known as diurnal vertical migration, is a pattern of movement that some organisms living in the ocean and in lakes undertake each day. Usually organisms move up to the epipelagic zone at night and return to the mesopelagic zone of the oceans or to the hypolimnion zone of lakes during the day. The word diel comes from the Latin dies day, and means a 24-hour period.