Solar Electric Generating System (SEGS) Assessment for Hawaii

(State of Hawaii Contract #32639)

Final Report

Prepared for

State of Hawaii
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NOMENCLATURE

ATC	Authority to Construct
BACT	Best Available Control Technology
BBL	barrel (unit of measure for liquid petroleum products; equal to 42 gallons)
BOP	Balance of Plant
CC	Combined Cycle
CDUP	Conservation District Use Permit
CESA-1	1 MWe central receiver experiment in early 80's at Almeria, Spain
CO_2	Carbon dioxide
CRT	Cathode Ray Tube
CT	Combustion Turbine
CZM	Coastal Zone Management
°C	Degrees Centigrade
DBEDT	State of Hawaii Department of Business, Economic Development and Tourism
DC	Direct Current
DLNR	Department of Land and Natural Resources
DNI	Direct Normal Insolation
DOE	Department of Energy
DOH	Hawaii Department of Health
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPC	Engineering, Procurement and Construction
ETC	Energy Tax Credit
FERC	Federal Energy Regulatory Commission
FSC	Field Supervisory Control (solar field)
GCA	Ground Water Control Area
gpm	Gallons per minute
GWRZ	Potential Ground Water Resource Zones
H_2O	Water vapor
HCE	Heat Collection Element
HECO	Hawaiian Electric Company
HEI	Hawaiian Electric Industries, Inc.
HELCO	Hawaii Electric Light Company
HH	Hawaiian Homelands
HI	State of Hawaii
HP	High Pressure
HRS	Hawaii Revised Statutes
HTF	Heat Transport Fluid; Heat Transfer Fluid
Hz	Hertz (cycles per second)
IEA-SSPS	International Energy Agency-Small Solar Power Systems project
IPP	Independent Power Producer
IRP	Integrated Resource Planning
K_2CO_3	Potassium Carbonate
KE	Kauai Electric Division of Citizens Utilities Companies
KNO_3	Potassium Nitrate
KOH	Potassium Hydroxide
kV	Kilovolts (thousands of volts)
kW, kWe	Kilowatt (electrical)
kWh	Kilowatt-Hour (electrical)
kWh/m^2-day	Kilowatt-Hours per meter squared per day (unit for solar thermal energy)
LOC	Local Controller (solar field)

LP	Low Pressure
LS-1, 2, or 3	Luz System 1, 2 or 3 solar collector model
LSFO	Low Sulfur Fuel Oil (equivalently No. 4 fuel oil)
LUC	State Land Use Commission
m	meter
MBTU	Thousand British Thermal Units
MECO	Maui Electric Company
mgd	Millions of gallons per day
MLO	Mauna Loa Observatory
MMBTU	Million British Thermal Units
MOECO	Molokai Electric Company (currently a division of Maui Electric Company)
MSFO	Medium Sulfur Fuel Oil (equivalently No. 6 fuel oil, Bunker C, Residual, Industrial)
MSL	Mean Sea Level
MVA	Millions Volt Amperes
MW, MWe	Megawatt (electrical)
MWth	Megawatt thermal (thermal energy)
Na_2CO_3	Sodium Carbonate
NaCl	Sodium Chloride
$NaNO_3$	Sodium Nitrate
NCDC	National Climatic Data Center
NELH	Natural Energy Laboratory of Hawaii
NEPA	National Environmental Policy Act
NIP	Normal Incidence Pyroheliometer
NOAA	U.S. National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxides
NPDES	National Pollution Discharge Elimination System
NPS	National Park Service
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NSPS	New Source Performance Standards
NSRDB	National Solar Radiation Data Base
O&M	Operation and Maintenance
O_2	Oxygen
O_3	Ozone
OEQC	Office of Environmental Quality Control
oUIC	Off-site injection wells
PCM	Phase Change Material
PGV	Puna Geothermal Venture
PMRF	Pacific Missile Range Facility
PSD	Prevention of Significant Deterioration
PTO	Permit to Operate
PUC	Public Utility Commission
PURPA	Public Utility Regulatory Policy Act of 1978
PVUSA	Photovoltaics for Utility Scale Applications project
QF	Qualifying Facility under PURPA
Re-use	Potential to re-use effluent from other facilities
SCA	Solar Collector Assembly
SCE	Southern California Edison utility
SCR	Selective Catalytic Reduction
SEGS	Solar Electric Generating Station
SMA	Special Management Areas (under CZM program)
SOLMET	Data Base for SOLar and METeorological parameters
SOx	Sulfur Oxides
SSV	Shoreline Setback Variance

TES	Thermal Energy Storage
TMY	Typical Meteorological Year
tpy	Tons per year
TSD	Hazardous Waste Treatment, Storage, and Disposal
UH	University of Hawaii
UIC	Underground Injection Control
UPS	Uninterruptable Power Supply
USA	United States Army
USFWS	U.S. Fish and Wildlife Service
USN	United States Navy
USNP	US National Park
UST	Underground Storage Tank
VAC	Volts Alternating Current
VOC	Volatile Organic Compounds
W	Watt
W/m^2	Watts per meter squared

EXECUTIVE SUMMARY

ABSTRACT

The potential for significant energy contributions from native non-fossil sources has motivated the State of Hawaii to explore the development of its renewable energy resources. This interest in renewables is reinforced by a rising energy demand related to a growing population and industrial base, a high dependence on imported petroleum, and environmental concerns related to energy use. Recognizing the success of the SEGS plants in California, where 354 MW_e of solar thermal electric generation systems have been installed, the state energy office initiated an assessment of the potential for similar facilties located in Hawaii. SEGS plants utilize concentrating parabolic trough solar collectors to collect heat for steam generation for use in a conventional steam Rankine cycle power plant. Nine such plants exist, ranging in capacity from 14 to 80 MWe.

The SEGS assessment for Hawaii evaluates the economic and technological potential of utility-scale solar thermal electric plants on the Islands, focusing on the issues of siting, design, utility requirements, operating characteristics, performance, and cost. The assessment was carried out by first examining the utility needs on the major islands through a categorization of installed capacity, power purchase commitments and resource planning. Next, capital costs were estimated for Hawaii conditions, and electrical generation performance projections were made based on a careful evaluation of potential solar resources throughout the islands. In parallel, preferred sites were identified based on an appraisal of numerous siting issues. Lastly, a preliminary economic analysis of levelized electricity costs was made to compare SEGS plants in Hawaii with conventional electric generation options.

Based on all aspects of this assessment, the following conclusions can be drawn regarding the viability of SEGS plants in the State of Hawaii:

- Suitable sites exist on the leeward sides of the major islands,
- Electric utility resource plans point to SEGS capacities of 30 MWe or smaller (except on Oahu for which an 80 MWe plant is suitable). Capital costs are significantly increased relative to the latest California SEGS plants due to physical siting characteristics, shipping, taxes and labor adjustment factors,
- The solar resource applicable to SEGS plants in Hawaii is about 25-30% lower than the Mojave Desert on an annual basis, leading to solar performance reductions possibly as high as 40-50%,
- The base case economic analysis finds that SEGS plants do not currently appear to be a cost-effective solar applications for the State of Hawaii,
- Inclusion of commonly discussed incentives for renewable energy technologies such as tax credits, property tax exemptions and incorporation of environmental externalities into generation planning improve the economics for SEGS but do not change this conclusion,
- The principal reasons for the unfavorable economic results are the higher capital costs and lower system performance projected for SEGS plants in Hawaii, even those located in the preferred sites. Significant capital cost reductions compared to current projections appear necessary to alter this finding.

It is important to bear in mind that these conclusions are drawn for SEGS plants only, and do not purport to reflect on the viability of other solar systems (such a photovoltaics) or even other solar thermal systems (such as parabolic dish Stirling concepts or industrial process heat applications), which have different cost and performance characteristics.

INTRODUCTION

During recent decades, the state of Hawaii has experienced rapid economic and population growth. Consistent with these developments have been commensurate increases in the state's appetite for energy. Hawaii, which has no local fossil fuel reserves, imports petroleum to supply over 90% of its energy needs. The near total dependence upon this non-native energy source has rendered the state increasingly vulnerable to the whims of the global oil market. The desire to diversify local energy supplies, coupled with increased concerns for the environment, have instilled among residents of Hawaii an intensified interest for the development of domestic alternative energy sources.

Spurred by the oil crisis of the early 1970's, Hawaii undertook numerous projects to produce electricity using a diverse range of alternative energy technologies. Pilot projects evaluating geothermal, ocean thermal, wind, solar, and biomass energy conversion were initiated during the 1970's. Aside from biomass energy--which, as a by-product of the local sugar industry, has long been an important source of electricity production in Hawaii--none of the technologies have yet proven to be reliable and significant sources for electricity. Meanwhile, the state's dependence on imported oil has continued to increase.

In 1990, given the continued and growing need to develop domestic alternative energy sources, the State of Hawaii's Department of Business, Economic Development & Tourism (DBEDT) contracted Luz International Limited to assess the technical and economic feasibility of their successful Solar Electric Generating System (SEGS) technology in the Hawaiian Islands. Since 1985, Luz had developed and operated nine large solar power plants in California's Mojave Desert. The cumulative firm capacity of the SEGS plants which are currently in operation, 354 MW in all, represents over 90% of all of the commercial solar electric generation in the world. The total electrical capacity of these facilities is equivalent to 19% of the total electric capacity of the entire state of Hawaii. Following the demise of the Luz group of companies in 1991, this assessment was continued by ex-Luz staff in order to fully utilize the experience of the SEGS developments.

The SEGS technology was developed to provide reliable solar thermal peaking power for electric utilities in southern California. To achieve this level of reliability, the SEGS concept incorporates a conventional Rankine primary steam cycle, a common power cycle which is utilized by most large oil, natural gas, coal, and nuclear power plants. Sunlight, the primary heat source for generating steam in a SEGS plant, is concentrated and absorbed by line-focusing parabolic troughs organized into rows in a large solar array field. Heat transport fluid (HTF) pumped through the solar field carries absorbed heat to the centrally located power block, where a conventional steam boiler and turbine-generator convert the thermal solar energy into electricity. For increased reliability and flexibility, an auxiliary fuel-fired heater is added to the system to provide supplemental HTF heating when the sunshine is inadequate to provide the desired plant output.

The overall SEGS assessment for Hawaii evaluates the economic and technological potential of utility-scale solar thermal electric plants on the major islands, focusing on the issues of siting, design, utility requirements, operating characteristics, performance, and cost. It is stressed that this study pertains to SEGS development only, and that the results herein should not be extrapolated to all solar electric technologies. Other types of solar electric generation, such as photovoltaics or Stirling engine-parabolic dish systems, are governed by somewhat different criteria and their potential success in Hawaii must be evaluated under the circumstances applicable to their respective technology.

The assessment was carried out by first examining the utility needs on the major islands through a categorization of installed capacity, power purchase commitments and resource planning. Next, an evaluation of SEGS technology for Hawaii yielded capital costs estimates for Hawaii conditions, as well as electrical generation performance projections based on a careful evaluation of potential solar resources on the major islands. In parallel, preferred SEGS sites were identified based on an appraisal of numerous siting issues. Lastly, a preliminary economic analysis of levelized electricity costs was made to compare SEGS plants in Hawaii with conventional electric generation options.

UTILITY REQUIREMENTS

There are effectively two electric utility companies in the state of Hawaii: Hawaiian Electric Industries, Inc. (HEI) and the Kauai Electric Division of Citizens Utilities Company (KE). Kauai Electric provides electric service to the island of Kauai. With the exception of Niihau, which has no electric utility service, the rest of the inhabited islands of the Hawaiian chain have their electrical demand supplied by HEI utilities. Hawaiian Electric Industries is a holding company for electric utilities which serve Oahu (Hawaiian Electric Company), Maui (Maui Electric Company), and Hawaii (Hawaii Electric Light Company). Molokai Electric Company, which serves the small rural population on the island of Molokai, was recently added to the HEI system as a division of Maui Electric Company. Maui Electric also maintains a division on the island of Lanai. Since there are currently no inter-island electric transmission facilities in the state, each island in Hawaii is electrically isolated and presents unique development opportunities for SEGS power plants.

It is noted that a substantial component of the electricity generated in Hawaii is purchased power from both conventional and renewable energy sources. Much of this generation is non-firm power. Although significant from an energy standpoint, non-firm power cannot be scheduled dependably and therefore is not identified as dispatchable generation capacity. Historically, the majority of purchased power in the state is from the burning of bagasse (sugar wastes) by sugar processing mills. The current ratios of total purchased power (firm + non-firm) to total net electric generation range from about 12% on Maui and Oahu, to over 25% on Hawaii and Kauai.

Table ES-1 summarizes the total installed capacity and firm purchased power contracts for each utility. Examining the makeup of the installed capacity as well as the resource plan for generation additions in each utility, judgments can be made on the appropriate target size for a SEGS plant in each system, which is also listed in Table ES- 1. While there are no active projects or assessments to install an underwater transmission cable between the islands, it is noted that a Oahu-Molokai cable would suggest the possibility of a large SEGS plant on the west side of Molokai.

Table ES- 1. Utility Capacity and SEGS Suitability

Utility	Approx. Installed Capacity (MW)	Firm Purchased Power (MW)	Target Capacity for SEGS Plant (MW)
HECO - Oahu	1260	180	80
MECO - Maui	143	12	30
- Molokai	8	0	0 w/o cable;80-200 with
- Lanai	10	0	0
HELCO - Hawaii	135	28	30
KE - Kauai	97	12	15

Daily electricity demand profiles have similar characteristics on all the islands. Summer use shows a rapid increase in demand during the morning hours, as citizens arise and go to work. The load remains quite flat over the course of the day, drops off after 4 p.m. as offices start to close, and then briefly increases by a few percent in the early evening, reflecting increased electrical usage associated with the preparation and clean-up of the evening meal. The profile is strikingly similar in winter, except that the magnitude of the relatively constant daytime demand is about 5% lower, partially attributable to lower air conditioning requirements, and the evening meal time peak is broader and more pronounced — a 10% spike lasting 2-3 hours. The increased evening demand evident in winter is driven by the shorter winter day length, which influences many residents of Hawaii to eat earlier and on a more routine schedule. In summer, residents are afforded more recreational opportunities and the lessened summer evening demand spike reflects a greater flexibility in lifestyle during the longer summer days.

SOLAR ELECTRIC GENERATING SYSTEM (SEGS) DESIGN

Current Status

The nine SEGS plants, independently owned by limited partnerships and selling electricity to So. California Edison utility, continue to operate at three sites in the Mojave Desert region of Southern California despite the demise of Luz. The first plant has 13.8 MW_e net capacity, the succeeding six plants have 30 MW_e net capacity and the final two plants are larger at 80 MW_e capacity. Each plant is operated by its owners to optimize plant revenues. Since the utility has time-of-use electricity rates, it is desirable that high electrical output be delivered to the grid during the utility on-peak hours when electricity revenues are highest. This is partially accomplished with the aid of a fossil-fired heat transport fluid heater which can either supplement the solar field or operate independently. The energy supplied by fossil fuel is limited to 25% of the total effective annual plant energy input by regulations of the U.S. Federal Energy Regulatory Commission.

While all the plants are in daily operation, the absence of the Luz group does affect the facilities. Up to 1991, Luz Engineering Corporation carried out the routine operation and maintenance (O&M) functions at each plant under separate contract to each owner group. In late 1991 and early 1992, this responsibility was assumed by three O&M companies set up by the owners at each of the three sites. Since Luz was the supplier of the solar field, spare parts for non-standard components of the solar field are not available and the owners have had to develop alternative sources. Maintenance needs include the normal component failures and repair requirements of any operating power plant as well as the unique requirements of the solar fields. Over the years of development and operation, much has been learned about SEGS solar field maintenance and, other than the spare parts problems mentioned earlier, the operation of these systems has matured into a routine pattern.

Design Features

A typical Hawaiian SEGS power plant would be comprised of the solar field, power block, plant services (water supply system, fossil fuel supply, power transmission lines), and water treatment system. The plant will require a land area of approximately 6 acres per MW for the solar field, power block, and balance of plant equipment. Maximum solar energy delivery with parabolic troughs is obtained with the axes of the solar collector assemblies oriented in the north-south direction; another orientation may be required due to the terrain of a specific site. The power block and balance of plant are located near the center of the solar field and cover an area of about three acres. This area contains all major mechanical and electrical equipment subsystems required for power production. Specific sites would impose differing needs for civil engineering requirements (grading, foundations, flood control) as well as other site-related design issues related to water supply, water waste handling, electrical interconnect to the local transmission system, and solar field sizing. The major features of a Hawaiian SEGS plant, however, are not site-dependent, other than plant capacity. A schematic process diagram of a SEGS plant is shown in Figure ES-1.

The solar field is an advanced LUZ solar system incorporating line-focus parabolic trough collectors that focus sunlight onto vacuum-insulated steel pipes. Heat transfer fluid (HTF) circulates through the solar field where it is heated and supplied through a main header to the solar heat exchangers located in the power block. The solar-heated HTF generates superheated steam in two sets of heat exchangers (each set with 50% of the total capacity). The superheated steam is then fed to the high-pressure (HP) casing of a conventional steam reheat turbine. The steam passes from the HP casing to a solar-fired reheater before being fed to the low-pressure (LP) casing. The spent steam from the turbine is condensed in a standard condenser and returned to the heat exchangers via condensate and feedwater pumps to be transformed back into steam. After passing through the HTF side of the solar heat exchangers, the cooled HTF is then recirculated through the solar field to repeat the process.

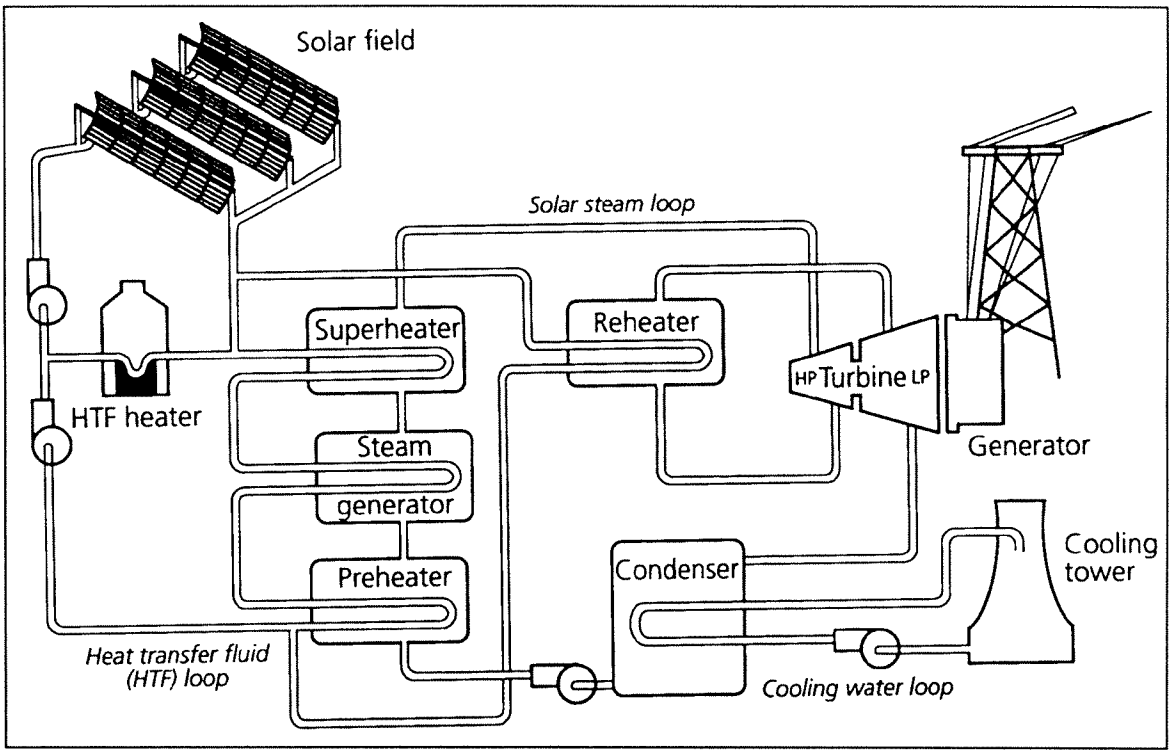


Figure ES-1. Schematic Representation of a SEGS Plant

The Luz system is built up from solar collector assemblies (SCAs), each consisting of a row of individual trough collectors driven by a single drive train. The mirrored parabolic troughs concentrate direct beam radiation onto a heat collection element (HCE), which is a steel pipe having a special selective coating surrounded by an evacuated annulus to enhance performance. An advanced local microprocessor controller, in conjunction with a sun sensor, tracks the sun and keeps the collectors focused during periods of sufficient insolation.

The SCAs are arranged in a large array consisting of parallel rows with three units per row. The row-to-row spacing is optimized to minimize piping costs and row-to-row shadowing in the morning and evening hours. The temperature of the HTF through the solar field increases from 559^{o}F at the inlet to an outlet of 735^{o}F. Both the solar field piping and the HTF expansion tank are suitably insulated to minimize thermal losses. The thickness of the insulation and the diameter of the piping is selected to reach a balance between surface area heat loss, parasitic pumping power, and overnight heat losses from the volume of HTF remaining in the field piping.

In Hawaii, an auxiliary diesel-oil fired HTF heater would supply an alternate source of energy to produce turbine inlet steam. This allows the production of electricity in evening hours or daytime hours with low insolation, if called for by the plant operating strategy.

The spent steam is condensed in the shell-and-tube condenser and cooling system. A control building houses a central microprocessor that monitors and controls plant operations. During reduced solar radiation conditions, the solar field and HTF heater can operate in parallel to provide electrical generation. Electrical power output from the plant would be supplied to the local transmission line from an on-site switchyard.

Projected Performance in Hawaii

SEGS performance can be projected using a plant performance model in conjunction with a data base of typical weather information. The existing SEGS performance model takes into account the relevant physical characteristics of the solar field, turbine/generator system, HTF piping and important balance-of-plant systems, utilizing one year of hourly solar radiation and meteorlogical data to assemble an annual projection.

An hourly solar radiation data base was assembled from measurements made at the University of Hawaii at Manoa during the years 1979-1987. The year 1979 was chosen as a typical solar year for this evaluation. Other data are available that allow estimates for other sites throughout the State. The annual average direct normal radiation at Manoa for 1979 was 5.01 kWh/m^2-day, compared to 7.44 in the Mojave desert where the existing SEGS plants are located. If seasonal totals of solar radiation are compared, the useful radiation in the plane of the collectors is notably higher in winter when the sun is higher in the sky in Hawaii than in California. Because of clouds, the variation in hourly solar radiation in Hawaii is quite high; in general, there is a significantly greater occurrence of lower insolation in Hawaii and very few hours of high insolation (above 900 W/m^2).

The insolation data were used in the SEGS performance model to project the performance of an 80-MW plant located on Oahu; monthly outputs are shown in Table ES-2. The annual output of 119,119 MWh/year on Oahu compares to 180,520 MWh/year in the Mojave, or a reduction of 34%. However, this result does not reflect the true impact of intermittent clouds on performance, as the effects of clouds are greater than might be predicted simply from the reduction in average solar radiation. The effects of these deficiencies in the radiation data base and the model tend to overproject performance, and hence the model projections are assumed to be high. In our judgment, the projections are optimistic by a factor of about 20%. Thus, the performance of an 80-MW SEGS on Oahu might be expected to be about 60% of the performance of an identical plant in Southern California. At a 60% level, the annual output would be about 108,300 MWh (solar only), corresponding to a capacity factor of 15.4%. Supplementary firing could bring this level up to any desired capacity factor. The insolation levels at the preferred sites on the other islands range up to 13% higher. This could result in a performance increase of about 15%, or an annual capacity factor of 17.8% in solar-only operation.

Table ES-2. Performance Projections for 80-MW Plant using Oahu Data
Annual Total 119,119 MW-hr

Month	MWh	Month	MWh
January	3393	July	13811
February	3870	August	15373
March	10216	September	14492
April	12534	October	9189
May	12484	November	7130
June	9903	December	6724

Cost Estimate

The electricity costs of SEGS plants in California reduced steadily from their introduction in 1984 through the construction of SEGS IX due to a reduction in unit capital costs and an increase in output per dollar invested. Capital costs dropped from about $4500/kW to just over $3000/kW as the solar collector technology reached its third generation and plant sizes increased from 14 MW to 80 MW.
The capital cost estimates presented here are based on reference cost data for the SEGS plants and factors specific to an installation in Hawaii. The costs are generalized in that they are not developed for a specific site. These costs assume a turnkey project with a lead EPC (engineering, procurement and construction) contractor. Cost elements in the SEGS estimate include the following:

- Site Preparation: grading, roads, flood protection, and land
- Buildings/Fence: control and maintenance buildings, security fencing
- Solar Field Material: collector and foundation equipment
- Solar Field Installation: installation costs of solar field
- HTF System: pumps, headers, fluid
- Turbine/Generator: turbine/generator set
- Boiler/Heater: auxiliary fossil-fired steam source
- Other Power Block Equipment: major steam-water cycle equipment other than turbine-generator
- Electrical: electrical wiring, motor control centers, other
- BOP: balance-of-plant equipment (e.g., cooling towers and pumps, solar heat exchangers, diesel set, air compressors)
- Substation/interconnect: transformers, switchgear, breakers, tower interconnect to transmission line
- Indirects: field supervision, field engineering, miscellaneous construction facilities. Sales tax, interest during construction and profit are not included in the indirects.
- Other: engineering, start-up
- Contingency: reserve margin for estimated uncertainties @ 15%

SEGS cost data from the California plants have been adjusted for Hawaii conditions. The final SEGS cost estimate resulting from the application of these adjustments to the reference SEGS costs is given in Table ES-3. The total cost is $3845/kW, though this can vary considerably depending on site conditions. As an example, consider a site in which grading is not an issue (e.g., the Pearl Harbor Blast Zone area), land costs are $30,000 per acre, both transmission and water costs are one-half of the assumed cost, and a contingency of 10% is applied. In this case, the total cost reduces to $3080/kW. Though it is hard to accurately portray the range of costs that could be incurred over a broad spectrum of sites, it is our recommendation that an uncertainty band of 15% be applied to the reference plant cost, resulting in an estimated range of $3500/kW to $4200/kW for a reference 80-MW SEGS plant in Hawaii. Smaller plants will be more costly; as a rule of thumb from SEGS construction experience, the cost increment over 80-MW plant costs is about 15% for a 30 MW plant and 30% for a 15 MW plant.

Thermal Energy Storage

Because seasonal and diurnal variations in electrical demand are relatively small in Hawaii, thermal energy storage (TES) is unlikely to be justified strictly for time-shifting of electrical production. A buffer TES system, on the other hand, can have a much more significant impact on the operation of a SEGS plant in Hawaii. Radiation changes due to intermittent weather conditions will -- without a buffer TES system -- directly affect the pattern and efficiency of electrical output, i.e., the efficiency of electrical production will degrade with intermittent radiation, largely because the turbine-generator will frequently operate at partial load and in a transient mode. If regular and substantial cloudiness occurs over a short period, turbine steam conditions and/or flow can even degrade enough to force turbine trips if there is no supplementary thermal source to "ride through" the disturbance.

An evaluation of possible TES media, experience with existing systems and recent design studies was conducted to identify suitable options for a SEGS plant in Hawaii. It was found that sensible heat thermal storage providing 1-3 hours of full-load plant capacity using molten salt or a liquid-solid media is feasible from both technical and economic aspects, though uncertainties exist in each area. Approximate estimates indicate that such storage systems could add $65-130/kW$_e$ to the capital cost, with potential performance gains on the order of 10%.

Table ES-3. Cost Estimate for Reference SEGS Plant in Hawaii (1992$)

Category		$/kW	Unit Cost $/kW	Cost % of Direct
Site Preparation				
Grading			295	10
Flood Protection			180	6
Land			210	7
Other			235	8
	Subtotal	920		31
Solar Field				
Equipment			860	29
Installation			150	5
	Subtotal	1000		34
HTF System				
	Subtotal	415		14
Power Equipment				
Power Block			325	11
Fire/Water Systems			60	2
BOP			90	3
Electrical			30	1
	Subtotal	505		17
Substation/Interconnect				
	Subtotal	120		4
				% of Total
Total Direct Costs			2960	77
Total Indirect Costs			245	6
Total Other			50	2
Contingency			590	15
Total			3845	100

SITING OF SEGS PLANTS in HAWAII

Siting Factors

The feasibility of pursuing SEGS facilities in Hawaii is contingent upon the identification of sites well suited to the technology. Desirable physical characteristics of a favorable SEGS site include high direct (beam) insolation, flat topography, suitable water supply and waste water discharge availability, access to nearby electric transmission facilities, and availability of auxiliary fuel supplies. Additionally, socio-political issues such as existing land use and cost, potential environmental and cultural impacts, and local public acceptance can strongly influence the feasibility of a SEGS project. Many of these characteristics are identical to those of conventional power plants, with the prominent exceptions of solar radiation levels, extensive land area needs, and the much reduced importance of air emissions, fuel delivery, and fuel and waste handling. If a SEGS plant design incorporates thermal storage rather than auxiliary fuel back-up, concerns over fuel related siting characteristics can be eliminated altogether.

Based on the experience of developing and evaluating numerous sites for SEGS plants over the past decade, siting issues can be put in categories of relative concern. Table ES-4 presents fifteen (15) siting

factors, categorized into three distinct levels of importance, as guidelines in screening potential sites for SEGS-type development in Hawaii. These groupings are based on *technical* potential. Characterization of these factors on some other basis—for instance, political or environmental potential—would probably lead to a reclassification of the relative importance of some siting factors.

This overall set of siting factors would be of general relevance for SEGS projects anywhere on the globe; however, the relative influence of individual siting factors may be rearranged. For example, land use and cost, which are not of great significance for remote desert sites on the mainland, are unquestionably primary issues on the Hawaiian Islands. In a detailed comparative siting analysis focused on a small number of sites, economic values would be assigned to all of the siting factors, where possible, and a quantitative trade-off study would be carried out. In a broader, more preliminary assessment of this type, the evaluation of potential sites using these siting criteria lean more heavily on subjective judgment developed from the extensive SEGS experience supplemented, to the extent possible, by site visits and cost estimates specific to Hawaii.

Few, if any, areas in Hawaii embody every desirable characteristic for a solar thermal electric plant at a single site. Hence, the evaluation of siting criteria is an important yet sensitive step in the assessment of SEGS potential in Hawaii.

Table ES-4. Siting Factors for SEGS Power Plants in Hawaii

Primary	Secondary	Tertiary
Insolation	Back-up/Storage	Accessibility
Topography/Geology	Natural/Military Hazards	Labor Pool
Water/Waste water	Surface Hydrology	Legal Issues
Land Use/Cost	Air Quality	Political Issues
Electric Transmission	Biology	
	Corrosion	

(Note: Groupings are based on authors' assessment of *technical* impact; different criteria or local input incorporating a diverse spectrum of interests may lead to reclassification of some siting factors.)

Site Evaluation Methodology

The initial step in the site selection procedure was a preliminary screening process which identified several general candidate areas on each of the five islands under consideration. The screening was principally based on solar radiation level, topography, and incompatible land use. The next step entailed evaluation of the candidate sites over the broad range of siting issues listed in Table ES-4. For each site, relative scores were assigned to each siting factor. The scores ranged from 1 (worst) to 5 (best). A score of zero (0) indicates that the particular siting issue was regarded as a fatal flaw.

Appropriate weighting factors were developed based on the perceived importance of each siting factor with respect to economic impact. The relative impact of the three categories of siting criteria were arbitrarily assigned relative weightings of 75 for all primary factors, 15 for all secondary factors, and 10 for all tertiary factors. The sum of all weighting factors is 100. The weighting factors for primary siting criteria were rooted in actual costs for mainland SEGS projects which were then adjusted, to the extent possible, to reflect Hawaiian conditions. Secondary and tertiary factor weightings resulted from our best judgment of their relative importance. Weightings assigned to each siting factor may differ if based on local opinion.

The product of the weighting factor and siting factor raw score yielded a weighted score for each of the siting criteria. By summing the weighted siting factor scores, a cumulative relative score was obtained for each site. Since the final scores are strongly influenced by subjective judgments, their absolute values are less important than their use in showing the relative attractiveness of the sites. Hence, the results of the evaluation have been used to classify the sites into three general categories: preferred, acceptable, and not recommended.

Selection of Candidate Sites

The matrix presented in Table ES-5 summarizes the results of the site selection. The matrix contains a unique line for each candidate site. The number immediately following the site name is the total relative score. Each line also contains value assignments for each primary, secondary, and tertiary siting factor. The weighting for each siting issue is included at the top of each column, immediately below the siting factor heading. The total relative score is obtained by summing all of the weighted siting factor scores for a particular site. The matrix also contains sub-totals for the cumulative impact of all primary siting factors, and a sub-total for the collective impact of all secondary and tertiary siting factors.

Since the maximum raw score is 5 in all cases, and the total siting factor weighting is 100, a hypothetical site which embodies exceptional qualities for each siting factor would produce a perfect total relative score of 500. An average site, that is a site which had typical characteristics of a candidate SEGS site scored as 3's for every siting factor, would produce a total relative score of 300 (3 x 100). Any site which includes a zero (0 = fatal flaw) as a score for any siting factor in the matrix is dropped from further consideration as a SEGS site.

The importance of the results of this site selection process is the organization of sites into several groups, rather than a sequential ranking of absolute scores. We emphasize that the techniques employed in this assessment rely more on subjective judgment based on experience than detailed site-specific information. The results of the matrix have been grouped into three categories: Preferred, Acceptable, and Not Recommended. The breakpoints chosen for these classifications are:

Preferred	Total score >= 325
Acceptable	275 < Total score < 325
Not Recommended	Total score <= 275.

Applying the grouping breakpoints to the candidate sites which were considered yields the recommendations contained in Table ES-6 and shown in Figure ES-2.

Table ES-6. Site Selection Results

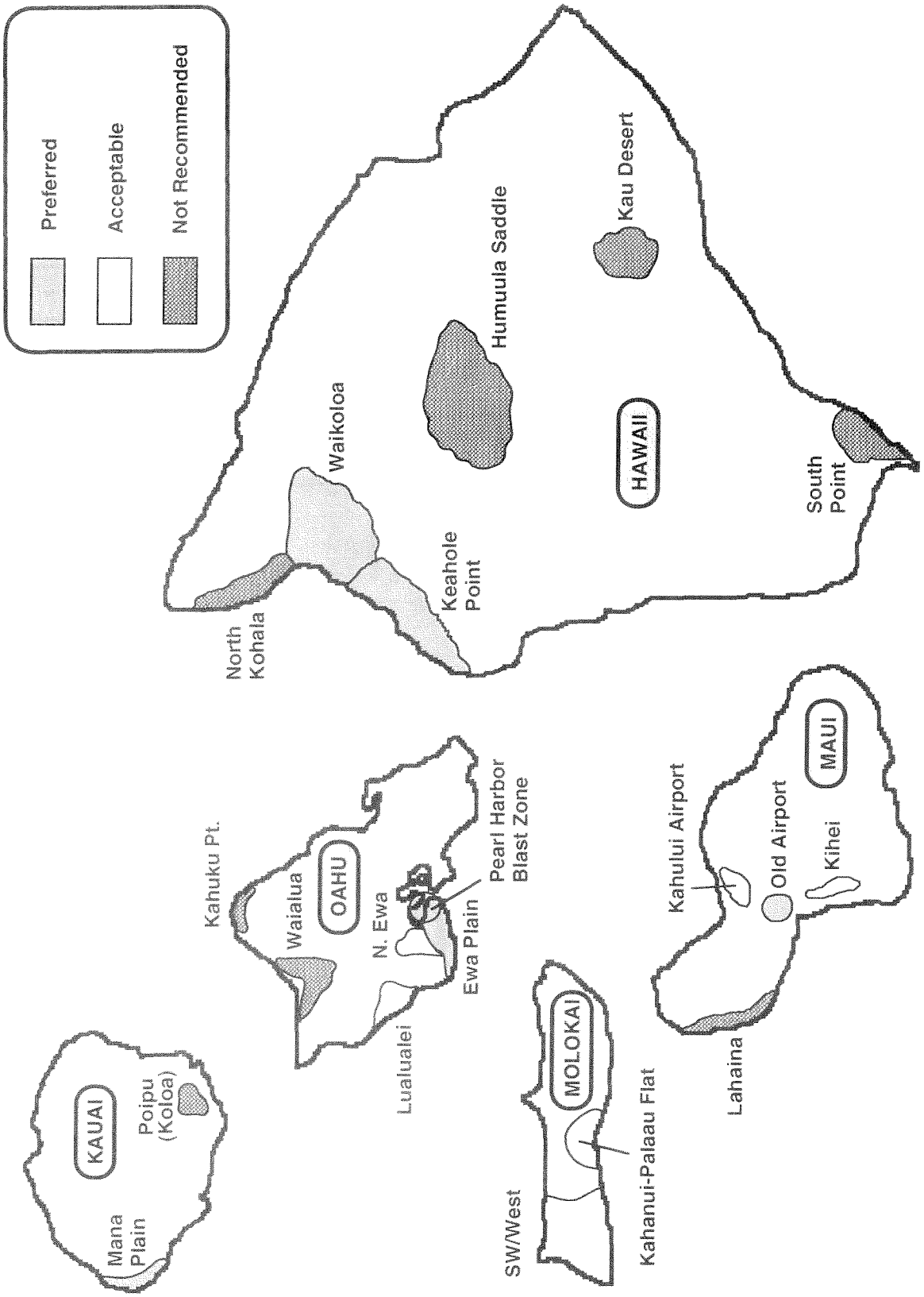
Preferred	Acceptable	Not Recommended
Pearl Harbor Blast Zone (Oahu)	North Ewa Plain (Oahu)	Wailua (Oahu)
Ewa Plain (Oahu)	Lualualei (Oahu)	Kahuku Point (Oahu)
Waikaloa (Hawaii)	Kihei (Maui)	South Point (Hawaii)
Keahole Point (Hawaii)	Kahului (Maui)	Saddle Road (Hawaii)
Old Airport (Maui)	Palaau Flat (Molokai)	Lahaina (Maui)
Mana Plain (Kauai)	SW/W Molokai (Molokai)	Poipu (Kauai)
		North Kohala (Hawaii)
		Kau Desert (Hawaii)

Under the strict application of the grouping breakpoints, the North Kohala site on Hawaii would be a preferred site. However, due to the excessive slope (10%) at that site, topography was judged to be a fatal flaw. The Kau Desert site, also on Hawaii, was dropped from consideration since we believe that the siting of a SEGS power plant in a National Park would be unacceptable.

Table ES-5. Evaluation Matrix for Candidate SEGS Sites in Hawaii

		PRIMARY FACTORS														SECONDARY FACTORS					TERTIARY FACTORS			
CANDIDATE SEGS SITE	TOTAL RELATIVE SCORE	Insolation Weight: 40		Topography/ Geology 15		Water Supply/ Waste Water 4		Land Use/Cost 10		Electric Transmission 6		SUB-TOTAL 75	Back Up 3	Air Qual 3	Hazrd 3	Corsn 3	Biolg 3	Access 2	Labor Pool 2	Legal/ Political 6	SUB-TOTAL 25
OAHU																								
Pearl HBZ	375	+5%	4	<.5%(sedm)	5	UIC	4	40K;USN	3	good(<5)	4	305	4	2	1	3	4	4	4	2	70
N. Ewa Plai	304	-3%	3	2-5%(clay)	3	oUIC	3	30K	3	ok(<5)	3	225	4	3	4	3	3	4	4	2	79
Ewa Plain	366	+5%	4	<1%(sedm)	4	UIC	4	40K	3	ok(<5)	3	284	4	2	3	3	4	4	4	3	82
Lualualei	280	same	3	1%(clay)	4	oUIC	3	USN&HH	1	poor(10)	2	214	3	3	2	3	3	3	3	2	66
Waialua	248	-10%	2	2-5%(clay)	3	oUIC	3	30K	3	ok(12)	2	179	3	3	2	2	3	3	3	3	69
Kahuku Pt.	230	-15%	1	<1%(sedm&clay)	4	UIC	4	40K	3	ok(20)	2	158	3	4	2	2	3	3	3	3	72
HAWAII																								
Waikoloa	350	+10%	4	2-5%(lava)	3	oUIC	3	10K	4	good(<5)	4	281	2	3	2	3	3	3	3	3	69
N. Kohala	332	+20%	5	10% (erod&stony	0	oUIC	3	40K	3	good(<5)	4	266	2	3	3	3	3	3	3	2	66
Keahole Pt.	347	+13%	4	0.5-5%(lava)	3	UIC(NELH)	4	40K;HI	3	good(<8)	4	275	2	3	2	3	4	3	3	3	72
South Pt.	266	-10%	2	2-5%(loam&lava)	3	UIC	4	5K;HH	5	poor(>25)	2	203	2	4	2	2	3	3	3	2	63
Kau Desert	261	+10%	4	3%(lava)	2	oUIC	2	USNP	0	ok(<5)	2	210	2	4	2	2	1	3	3	1	51
Saddle Rd.	233	-5%	2	2-3%(loam&lava)	3	(Dry)	1	USA&HI	2	ok(18)	3	167	2	4	2	4	2	3	3	2	66
MAUI																								
Old Airport	331	same	3	1-2%(loam)	4	UIC(re-use)	4	40K;HI	3	ok(<4)	3	244	3	3	4	3	4	3	3	4	87
Kihei	304	+3%	3	3-10%(stony clay	2	oUIC	3	10K	4	good(4)	4	226	3	3	4	3	3	3	3	3	78
Lihaina	266	+3%	3	6%(stony clay)	1	oUIC(GWR	2	35K	3	good(<4)	4	197	3	3	4	2	3	3	3	2	69
Kahului	312	-3%	3	1-3%(loam)	4	oUIC	3	45K	3	ok(<5)	3	240	3	3	3	3	2	3	3	3	72
KAUAI																								
Mana Plain	345	same	3	<.5%(sedm/sogy	5	UIC	4	7K;HI	5	poor(14)	2	273	3	4	2	2	3	3	3	3	72
Poipu	269	-10%	2	2-3%(clay&lava)	3	oUIC(GWR	2	10K	4	good(<4)	4	197	3	3	2	3	3	3	3	3	72
MOLOKAI																								
Palaau Flat	298	same	3	1-5%(mud flats)	3	UIC	4	7K	5	cable	1	237	3	4	2	2	2	3	2	2	61
SW/W	292	-3%	3	3-5%(erod&stony	2	UIC	4	5K	5	cable	1	222	3	4	4	3	2	3	2	2	70

Figure ES-2. Representative Map showing Site Evaluation Results for SEGS Plants in Hawaii



The levelized cost of electricity from a SEGS plant is determined from, among other contributions, the projected performance and estimated capital cost of the facility. An important element affecting both of these is the economy of scale improvements associated with increasing the size of the plant. Larger plants lead to lower unit costs and have higher turbine efficiencies than smaller plants. The envisioned plants located on both Oahu (80 MW) and Molokai (80-200 MW, assuming an Oahu-Molokai transmission cable) will benefit from the economy of scale factor relative to the smaller facilities which are envisioned for sites on Kauai, Maui, and Hawaii. This impact has not been reflected in the site selection process.

ECONOMIC ANALYSIS

Method of Analysis

A major consideration in the assessment of the SEGS viability in Hawaii is the analysis of the cost of energy or electricity produced by the system. Comparing the electricity costs of various generating systems is not as simple as it might first appear. To perform a meaningful comparison of SEGS system cost to that of conventional (or even non-conventional) alternatives, we must not only specify the assumptions in a detailed way, but we must also specify the type of analysis to be used. It is in this last area that confusion often arises.

For purposes of this section of the report, we will use levelized nominal bus bar power costs. Our analysis includes the following basic assumptions:

- It is assumed that the project is owned by the utility and not by an independent third party owner or Independent Power Producer (IPP). This has financial implications (affecting the cost of debt and equity and choice of discount rate among others) and tax implications (since utilities are not eligible for the Federal Business Energy Tax Credit or accelerated depreciation).

- The comparisons are made using a constant capacity factor of 35% for both the SEGS and the conventional system. It is assumed that the SEGS would achieve the 35% capacity factor by burning additional fossil fuels and that the conventional system would be dispatched to achieve 35% capacity factor.

This comparison is not meant to be the kind of detailed analysis that a utility would use before making a final decision on a power plant (such an evaluation would include use of a sophisticated production cost simulation model, for example); rather, it is meant to be a screening analysis of the type that a utility would use as a first-cut determination. The approach is to first determine the assumptions that would place SEGS in the range of economic competitiveness and then to do more detailed analysis if appropriate.

The analysis was carried out with a simple spreadsheet model that calculates the levelized bus bar electricity costs (bus bar refers to the fact that we are assessing the cost of power at the plant's bus bar as contrasted to the cost of power delivered to any specific point on a utility system). The input consists of key technical characteristics and economic assumptions pertinent to the utility. The model performs a year-by-year analysis for both a SEGS and a fossil fueled plant, calculating a bus bar cost of electricity in each year. A single annual cost of electricity is then determined which has the same net present value as the escalating stream of annual revenue requirements. This is the levelized bus bar electricity cost.

The economic analysis assumptions that are common to all the cases considered are presented in Table ES-7, using data supplied by HECO. The relatively high diesel fuel cost is only strictly applicable to the islands other than Oahu, where diesel fuel is the incremental fuel source. These values were used for all cases, however, to see if SEGS would be competitive under such favorable (for solar) assumptions.

Results

Table ES-8 presents the base case results for the analysis. As shown, the lowest cost SEGS configuration (the 80 MW SEGS with a cost of $0.254/kWh) is about 28% higher in cost that the highest cost fossil configuration (the Combustion Turbine with SCR at $0.198/kWh). A more realistic comparison (for Oahu) would contrast an 80 MW SEGS with a 56 MW Combined Cycle, revealing the SEGS to be some 68% more expensive. Or, for a neighbor island, one could compare a 30 MW SEGS with a 20 MW CT/SCR, with the SEGS being some 44% more expensive. Given that these results do not appear to be promising for SEGS, a series of sensitivity analyses were run to determine if any reasonable change in the assumptions would alter this result.

The parameters used in the sensitivity analysis were fuel price, fuel escalation rate, Federal energy tax credit, property tax exemption for solar facilities, a penalty on the fossil fueled options due to an assessment on environmental externalities, SEGS cost and SEGS performance. With regard to fuel price, the results indicate that a fuel price of $13/MMBTU (or about $78/barrel) would be required for the 80 MW SEGS to be competitive with the 70 MW CT. Alternatively, we would estimate that a SEGS capital cost of $1,600/kW would be required for the SEGS to be competitive under base case assumptions. It was also found that a fuel price escalation rate of 12% or more would be required for an 80 MW SEGS to be competitive with the smallest and most expensive combustion turbine option. These rates are in contrast to our most recent history of zero growth (and even decline) in oil prices, and would be some 7% above assumed inflation.

Adding consideration of environmental externalities adds about a 1.5¢/kWh increase in the levelized cost of the fossil fired options relative to the SEGS option. The property tax exemption substantially improves the economics of SEGS, subtracting approximately 2.5-3.0¢/kWh from the levelized cost of SEGS electricity. For an Oahu application, a SEGS would still not appear to be competitive with a combined cycle plant for reasonable values of fuel price escalation (we calculate that a fuel price escalation rate of about 16% would be required to make the 56 MW Combined Cycle plant more expensive than the 80 MW SEGS including the impact of all externalities and tax benefits). For a neighbor island plant, inclusion of environmental externalities and a property tax exemption would appear to make the 30 MW SEGS plant competitive with the 20 MW CT/SCR assuming a fuel cost escalation rate of about 11%.

Examining the impact of the various incentives on an 80 MW SEGS, at a fuel escalation rate of 6%, the effects on the levelized cost of electricity were found to be:

Without Hawaii ETC:	$0.281/kWh
Base Case	0.271
With Federal ETC:	0.267
With Property Tax Exemption:	0.246
With both Fed ETC + Prop Tax Exemption:	0.242

Further consideration was also given to significant variations in capital cost and performance (reflected by the capacity factor) of the SEGS plant. These results showed the following extremes:

Capital Cost	Solar Capacity Factor	Levelized Electricity Cost
$2,000/kW	0.25	$0.16/kWh
5,000	0.15	0.31

The 25% capacity factor represents the best that could be achieved in the California desert without thermal storage. In Hawaii, a 20 % capacity factor would be excellent without thermal storage, while higher values might be achieved with storage, but at a higher capital cost.

CONCLUSIONS OF THE OVERALL ASSESSMENT

Based on all aspects of this assessment, the following conclusions can be drawn regarding the viability of SEGS plants in the State of Hawaii:

- Suitable sites exist on the leeward sides of the major islands,
- Electric utility resource plans point to SEGS capacities of 30 MWe or smaller (except on Oahu for which an 80 MWe plant is suitable). Capital costs are significantly increased relative to the latest California SEGS plants due to physical siting characteristics, shipping, taxes and labor adjustment factors,
- The solar resource applicable to SEGS plants in Hawaii is about 25-30% lower than the Mojave Desert on an annual basis, leading to solar performance reductions possibly as high as 40-50%,
- The base case economic analysis finds that SEGS plants do not currently appear to be a cost-effective solar applications for the State of Hawaii,
- Inclusion of commonly discussed incentives for renewable energy technologies such as tax credits, property tax exemptions and incorporation of environmental externalities into generation planning improve the economics for SEGS but do not change this conclusion,
- The principal reasons for the unfavorable economic results are the higher capital costs and lower system performance projected for SEGS plants in Hawaii, even those located in the preferred sites. Significant capital cost reductions compared to current projections appear necessary to alter this finding.

It is important to bear in mind that these conclusions are drawn for SEGS plants only, and do not purport to reflect on the viability of other solar systems (such as photovoltaics) or even other solar thermal systems (such as parabolic dish Stirling concepts or industrial process heat applications), which have different cost and performance characteristics.

Table ES-7. Economic Assumptions Common to All Cases

Fixed Utility Parameters (same values used for all base case analyses)	
Fuel Cost (1992 Value, $/MMBtu)	4.99 (diesel)
Fuel Cost Escalation Rate, %	5.50
O&M Cost Escalation Rate, %	5.00
Fixed Charge Rate (Before Tax Cost of Capital), %	10.48
Discount Rate, %	10.48
Property Tax + Insurance Rate, %	3.00
Utility's Federal Income Tax Bracket, %	34.00

Table ES-8. Economic Analysis Assumptions and Base Case Results

Parameter	CT20	CT20 w/ SCR	CT70	CC56	SEGS15	SEGS30	SEGS80	SEGS200[d]
Unit Size (MW)	20	20	70	56	15	30	80	200
Capital Cost (1992 $/kW)	1300	1710	710	1375	5000	4420	3845	4870
Solar Output (MWh/yr)	0	0	0	0	19710	45990	126145	331130
Annual Capacity Factor (%)	35	35	35	35	35	35	35	35
Solar Capacity Factor (%)	0	0	0	0	15	17.5	18	18.9
Fuel Capacity Factor (%)	35	35	35	35	20	17.5	17	16.1
Full Load Heat Rate (Btu/kWh)	10970	10970	13045	8070	13800	11800	11500	10950
Fixed O&M Costs (mills/kWh)	23.86	31.41	12.29	32.59	99.33	90.00	81.13	76.60
Variable O&M Costs (mills/kWh)	4.06	8.28	7.33	3.04	0	0	0	0
State Solar Energy Tax Credit (%)	0	0	0	0	35	35	35	35
Levelized Bus Bar Electricity Cost[e] ($/kWh)	**0.169**	**0.198**	**0.158**	**0.151**	**0.333**	**0.286**	**0.254**	**0.292**

Notes: a) CT - combustion turbine
b) SCR - selective catalytic combustion
c) CC - combined cycle
d) SEGS 200 case includes $320 million ($1600/kWh) for 800 MW Molokai to Oahu cable. Without this full cable cost, the levelized bus bar electricity cost would be $0.223/kWh.
e) These results include the Hawaii state ETC for the SEGS cases. Without this credit, the levelized bus bar electricity costs would be approximately 1 cent higher for the SEGS cases.

I. INTRODUCTION

During recent decades, the state of Hawaii has experienced rapid economic and population growth. Consistent with these developments have been commensurate increases in the state's appetite for energy. Hawaii, which has no local fossil fuel reserves, imports petroleum to supply over 90% of its energy needs. The near total dependence upon this non-native energy source has rendered the state increasingly vulnerable to the whims of the global oil market. The desire to diversify local energy supplies, coupled with increased concerns for the environment, have instilled among residents of Hawaii an intensified interest for the development of domestic alternative energy sources.

Spurred by the oil crisis of the early 1970's, Hawaii undertook numerous projects to produce electricity using a diverse range of alternative energy technologies. Pilot projects evaluating geothermal, ocean thermal, wind, solar, and biomass energy conversion were initiated during the 1970's. Aside from biomass energy--which, as a by-product of the local sugar industry, has long been an important source of electricity production in Hawaii--none of the technologies have yet proven to be reliable and significant sources for electricity. Meanwhile, the state's dependence on imported oil has continued to increase.

In 1990, given the continued and growing need to develop domestic alternative energy sources, the State of Hawaii's Department of Business and Economic Development (DBED) contracted Luz International Limited to assess the technical and economic feasibility of their successful Solar Electric Generating System (SEGS) technology in the Hawaiian Islands. Since 1985, Luz had developed and operated nine large solar power plants in California's Mojave Desert. The cumulative firm capacity of the SEGS plants which are currently in operation, 354 MW in all, represents over 90% of all of the commercial solar electric generation in the world. The total electrical capacity of these facilities is equivalent to 19% of the total electric capacity of the entire state of Hawaii. Following the demise of the Luz group of companies in 1991, this assessment was continued by ex-Luz staff in order to fully utilize the experience of the SEGS developments.

The SEGS technology was developed to provide reliable solar thermal peaking power for electric utilities in southern California. To achieve this level of reliability, the SEGS concept incorporates a conventional Rankine primary steam cycle, a common power cycle which is utilized by most large oil, natural gas, coal, and nuclear power plants. Sunlight, the primary heat source for generating steam in a SEGS plant, is concentrated and absorbed by line-focusing parabolic troughs organized into rows in a large solar array field. Heat transport fluid (HTF) pumped through the solar field carries absorbed heat to the centrally located power block, where a conventional steam boiler and turbine-generator convert the thermal solar energy into electricity. For increased reliability and flexibility, an auxiliary fuel-fired heater is added to the system to provide supplemental HTF heating when the sunshine is inadequate to provide the desired plant output.

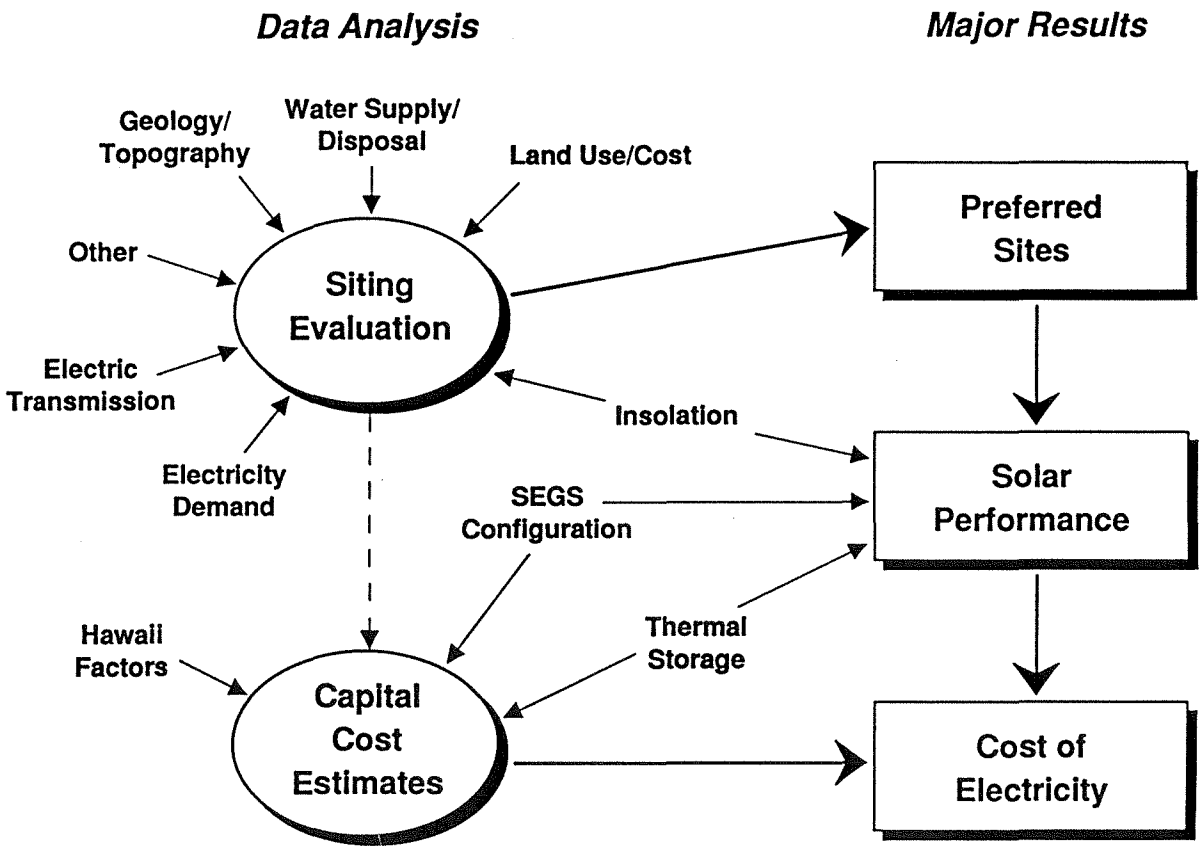
Hawaii has plentiful sunshine, high fuel costs, a need for new capacity, and significant concerns with respect to environmental quality and security of its energy sources. Large-scale solar thermal plants appear to offer an excellent solution to each of these concerns. A meaningful analysis, however, demands a closer look. To this end, the overall SEGS assessment for Hawaii evaluates the economic and technological potential of utility-scale solar thermal electric plants on the islands, focusing on the issues of siting, design, utility requirements, operating characteristics, performance, and cost. It is stressed that this study pertains to SEGS development only, and that the results herein should not be extrapolated to all solar electric technologies. Other types of solar electric generation, such as photovoltaics or Stirling engine-parabolic dish systems, are governed by somewhat different criteria and their potential success in Hawaii must be evaluated under the circumstances applicable to their respective technology.

Assessment Methodology And Report Organization

The assessment was carried out by first examining the utility needs on the major islands through a categorization of installed capacity, power purchase commitments and resource planning. Next, an evaluation of SEGS technology for Hawaii yielded capital costs estimates for Hawaii conditions, as well as electrical generation performance projections based on a careful evaluation of potential solar resources on the major islands. In parallel, preferred SEGS sites were identified based on an appraisal of numerous siting issues. Lastly, a preliminary economic analysis of levelized electricity costs was made to compare SEGS plants in Hawaii with conventional electric generation options. Figure I-1 illustrates this integration of the various issues into a unified assessment of the value of SEGS technology in Hawaii.

This report follows the sequence of steps described above. First, the utility demand requirements are described in Section II, leading to a selection of suitable SEGS capacities for different utilities. Next, Section III reviews SEGS design features, including performance and cost estimates for Hawaiian conditions. Section IV reviews siting criteria and develops a matrix of potential sites, ending with recommendations for preferred sites. Based on these various components, Section V evaluates the cost of electricity from a utility viewpoint. Finally, a set of conclusions are presented in Section VI.

Figure I-1. Features of the SEGS Assessment



II. UTILITY REQUIREMENTS

BACKGROUND

The purpose of this section is to evaluate Hawaiian electric utility requirements and to examine the general suitability of solar thermal power plants to meet the future needs of electric utilities in Hawaii. Since the islands of Hawaii are not electrically interconnected, determination of the applicability and cost-effectiveness of SEGS must be conducted on an island-by-island basis. For each island, the resident utility's current system and future needs for new capacity are examined.

The prospect of future inter-island electric transmission introduces expanded opportunities for SEGS. Recent utility studies which examined inter-island cables in conjunction with specific generation projects have not proven feasible for the near term. Consistent with these findings, SEGS scenarios involving inter-island transmission are identified in this report as possible future options but are not evaluated in depth.

A major consideration influencing SEGS economics is the optimum size of the plant. Economies-of-scale applicable to both capital cost and operation and maintenance requirements result in increased cost-effectiveness for the larger plants. The 80 MWe plant capacity chosen for recent mainland projects may well be too large for all but Oahu applications. If neighbor island utilities are restricted to use of smaller unit sizes, such plants will have to bear the economic penalty of reduced economies-of-scale.

CHARACTERIZATION OF THE STATE'S UTILITIES

Overview

There are effectively two electric utility companies in the state of Hawaii: Hawaiian Electric Industries, Inc. (HEI) and the Kauai Electric Division of Citizens Utilities Company (KE). Kauai Electric provides electric service to the island of Kauai. With the exception of Niihau which has no electric utility service, the rest of the inhabited islands of the Hawaiian chain have their electrical demand supplied by HEI utilities. Hawaiian Electric Industries is a holding company for electric utilities which serve Oahu (Hawaiian Electric Company), Maui (Maui Electric Company), and Hawaii (Hawaii Electric Light Company). Molokai Electric Company, which serves the small rural population on the island of Molokai, was recently added to the HEI system as a division of Maui Electric Company. Maui Electric also maintains a division on the island of Lanai.

Since there are currently no inter-island electric transmission facilities in the state, each island in Hawaii is electrically isolated and presents unique development opportunities for SEGS power plants. Each subsidiary electric company and individual island electric division within the HEI utilities system will be treated hereafter as a separate entity.

The following section provides a characterization of the respective electric entities in Hawaii. Efforts have been made to make this information as current as possible. The possibility exists that some inconsistencies may be present since different sources have been used. The format includes a comprehensive listing of utility-owned installed capacity as well as firm purchase power contracts with non-utility power producers. These two items represent the total installed firm capacity available to a utility.

It is noted that a substantial component of the electricity generated in Hawaii is purchased power from both conventional and renewable energy sources. Much of this generation is non-firm power. Although significant from an energy standpoint, non-firm power cannot be scheduled dependably and therefore is not reflected in the totals for dispatchable generation capacity. When available, the annual energy contributed by major non-firm power producers has been appended to the table of firm purchase power contracts. Historically, the majority of purchased power in the state is from the burning of bagasse (sugar wastes) by sugar processing mills. The current ratios of total purchased power (firm + non-firm) to total net electric generation range from about 12% on Maui and Oahu, to over 25% on Hawaii and Kauai.

Additional materials presented for each utility in this section include a system transmission map and figures depicting utility peak demand by month and typical daily summer and winter load profiles. The monthly peak demand plots presented for each utility are based on actual data for Kauai (1991) and projected data for Oahu (1990), Maui (1990), Hawaii (1990) and Molokai (1991). The typical load profiles are based on average hourly weekday data for a representative summer month (August for KE, July for all others) and winter month (November for KE, December for all others). Typical daily load profiles for weekends, which are not presented here, are similar in shape but exhibit a lower daily peak than the counterpart weekday profiles which are presented. The degree to which weekend peaks are lower than weekday peaks generally ranges from about 5-15% for all utilities.

HAWAIIAN ELECTRIC COMPANY (HECO)

Description

Hawaiian Electric Company (HECO) serves the electric needs of the island of Oahu and is the largest electric utility in Hawaii. While HECO affiliates provide electric service for the majority of the rest of the state, the information presented herein for HECO is restricted to the island of Oahu. Honolulu, the only major city in the state, provides HECO with industrial and commercial electric loads not widely represented on the other islands. The congested Waikiki-Diamondhead area, with its vast number of hotel rooms and extremely high real estate values, poses special problems for electric distribution and little opportunity for proximate generation facilities.

Hawaii's petro-chemical industries are located in southwestern Oahu. The majority of HECO's electric generation facilities are located in this general area and utilize petroleum products as fuel. Electric generation on the eastern (Diamondhead) side of Oahu would be desirable. A HECO system transmission map, included as Figure II-1, shows the utility's transmission network and existing power plant sites. Table II-1 describes HECO's installed capacity while Table II-2 summarizes the utility's firm purchase power contracts.

Discussion of Load Profiles

With moderate year-round temperatures, electric usage patterns on Oahu change little over the course of the year. In contrast to mainland utilities whose seasonal load fluctuations are principally driven by climate control equipment, electric demand fluctuations in Hawaii are attributable to rather subtle seasonal changes in lifestyle. The modest space heating and air conditioning loads on Oahu are mainly limited to hotels and large commercial spaces. Principal residential loads are water heating, refrigeration, cooking, and lighting.

HECO's summer diurnal demand profile of Figure II-2 shows a rapid increase in demand during the morning hours, as Oahu's citizens arise and go to work. The load remains quite flat over the course of the day, drops off after 4 p.m. as offices start to close, then bumps up by about 30 MW (3%) briefly in the early evening reflecting increased electrical usage associated with the preparation and clean-up of the evening meal. The profile is strikingly similar in winter, except that the magnitude of the relatively constant daytime demand is about 50 MW (5%) lower, partially attributable to lower air conditioning requirements, and that the evening "dinner time" peak is broader and more pronounced — a 110 MW (11%) spike lasting 2-3 hours. The increased evening demand evident in winter is driven by the shorter winter day length, which influences many residents of Hawaii to eat earlier and on a more routine schedule. In summer, residents are afforded more recreational opportunities and the lessened summer evening demand spike reflects a greater flexibility in lifestyle during the longer summer days.

HECO's monthly peak demand, which varies by less than 15% over the entire year, has been plotted in Figure II-3 so as to magnify month-to-month fluctuations. Highest demand occurs in November and December when early evening holiday season activities such as parties and shopping combine with elevated "dinner time" peaks. Among the more unusual sources of increased fall/winter demand identified by HECO in recent years was the discernable increase in demand which coincided with the telecast of a popular TV program in Hawaii — ABC's Monday Night Football. Since Hawaii's primary industry, tourism, is strong year round, it does not greatly influence seasonal fluctuations in demand. The reduced electric peaks occurring in spring are thought to be attributable to the milder temperature and humidity ranges which prevail during these months.

Table II-1 HECO Current Installed Capacity: Total = 1260 MW*

Location-Type-Unit (year installed)	Fuel	Unit MW	Type MW	Location MW
Honolulu (on Honolulu Harbor)				116
Steam Turbines			116	
Unit 8 (1954)	LSFO**	58		
Unit 9 (1957)	LSFO	58 (57)*		
Waiau (Pearl City)				502
Steam Turbines			400	
Unit 3 (1947)	LSFO	50 (49)		
Unit 4 (1950)	LSFO	50 (49)		
Unit 5 (1959)	LSFO	58 (57)		
Unit 6 (1961)	LSFO	58		
Unit 7 (1966)	LSFO	92		
Unit 8 (1968)	LSFO	92		
Combustion Turbines			102	
Unit 9 (1973)	Diesel***	52		
Unit 10 (1973)	Diesel	50		
Kahe (Waianae)				659
Steam Turbine			659	
Unit 1 (1963)	LSFO	92		
Unit 2 (1964)	LSFO	90		
Unit 3 (1970)	LSFO	92		
Unit 4 (1972)	LSFO	93 (?)		
Unit 5 (1974)	LSFO	146 (142)		
Unit 6 (1981)	LSFO	146 (142)		

* HECO's total installed capacity as of 3/31/92, reflecting recent derating of many of HECO's older turbines (partial information supplied by HECO on 6/1/92 has been included parenthetically above); the listing above was current as of April 1991 but does not reflect the derated values of individual units, hence, the arithmetic sum (1277 MW) of the units listed above is erroneous and overstates HECO's capacity by 17 MW.

** LSFO = Low Sulfur Fuel Oil (equivalently: No. 4 Fuel Oil)

*** Diesel (equivalently: No. 2 Fuel Oil)

Sources: HECO 1990 Electric Utility System Cost Data, July 1990; HECO Resource Plan 3/31/92; HECO correspondence April-July 1992.

Table II-2. HECO Currently Effective Firm Purchased Power Contracts: Total = 360 MW

Name (Location)	Fuel	Firm MW	GWh/yr
Firm:			
Kaleaeloa Partners(Barber's Point)	LSFO	180	
AES (Barber's Point)	LS Coal	180	

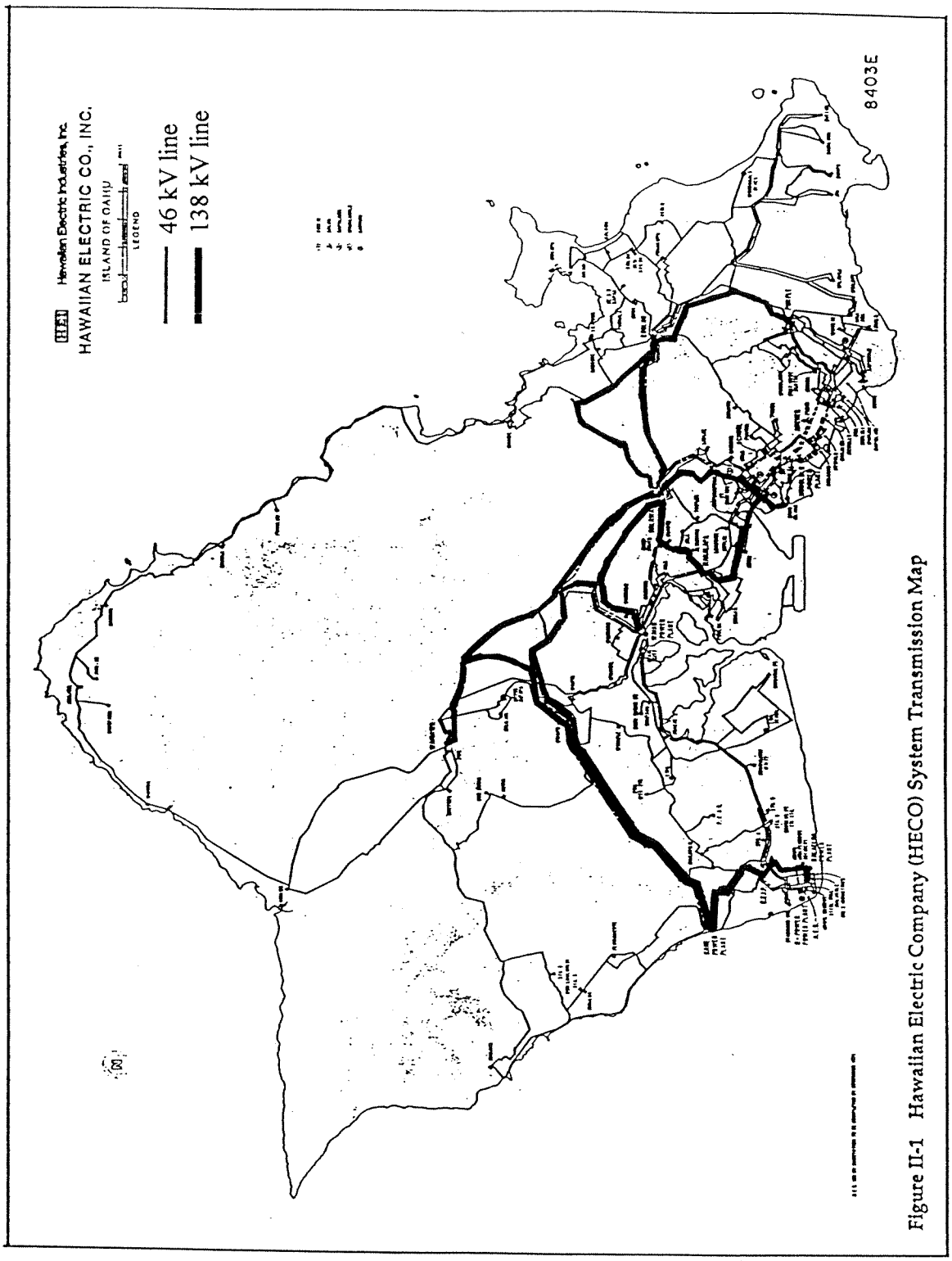


Figure II-1 Hawaiian Electric Company (HECO) System Transmission Map

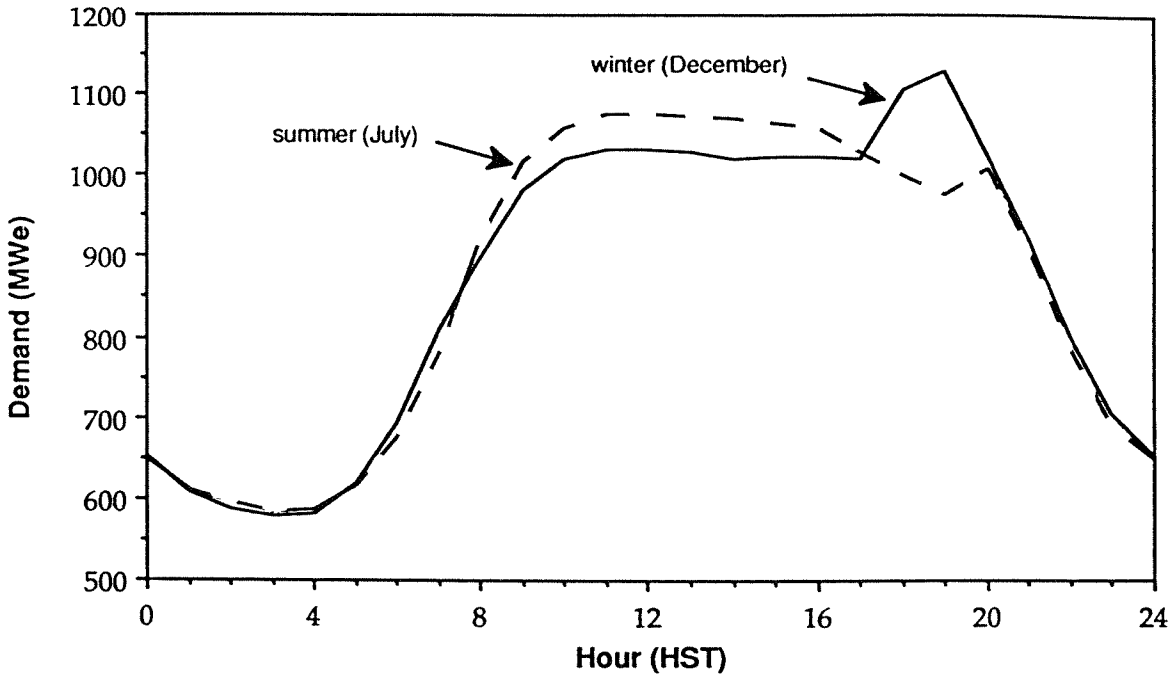


Figure II-2 HECO Typical Daily Load Profiles by Season (based on projected 1990 data)

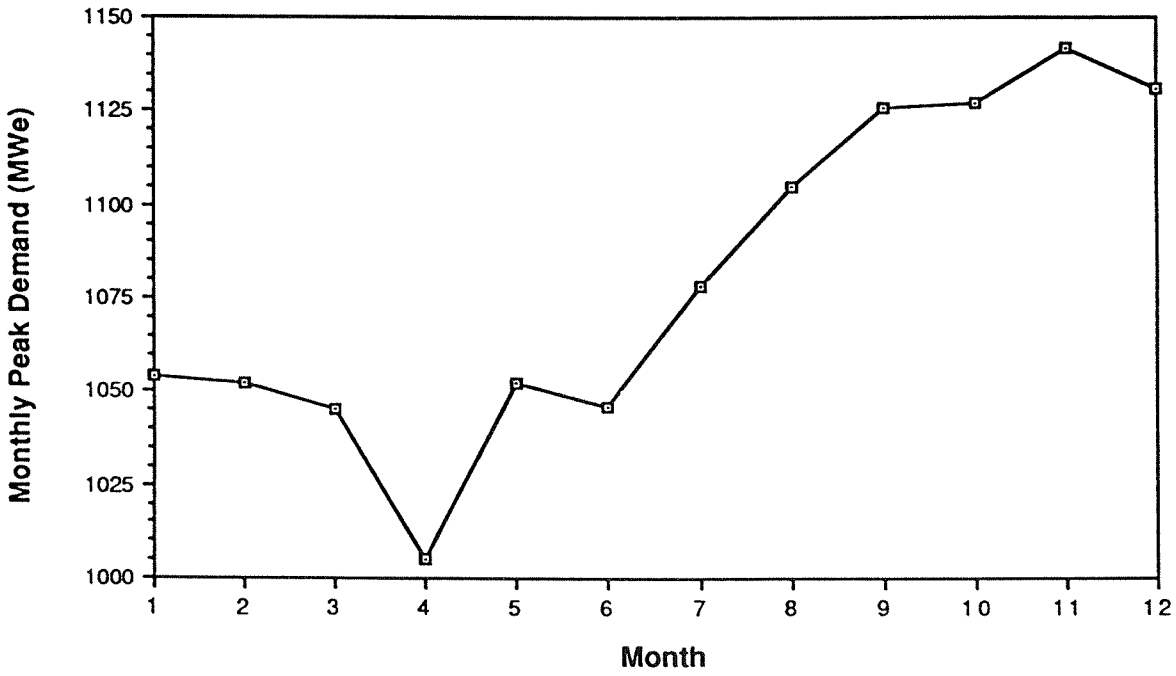


Figure II-3 HECO Peak Demand by Month (per Forecast Planning Committee's 1990 peak load forecast, 5/11/90)

MAUI ELECTRIC COMPANY (MECO)

Description

Maui Electric Company provides electric service for Maui County. The island of Lanai is served by MECO's Lanai Division, while Molokai is served by MECO's Molokai Division. The remaining island in Maui county, Kahoolawe, is uninhabited and has no electric service. This sub-section will be restricted to MECO's operations on the island of Maui. MECO's Molokai Division will be treated as a separate sub-section; discussion of the Lanai Division will be limited to a listing of current installed capacity and a mapping of the island's electric distribution system.

A map of MECO's transmission system on the island of Maui is included as Figure II-4. The island of Maui is composed of two shield volcanos connected by a flat isthmus. Much of the island's population, industry, and agriculture are located in this flat area between the volcanos. MECO's two electric generation facilities are located on opposite sides of the isthmus at Kahului and Maalaea. Table II-3 describes MECO's installed capacity at these locations while Table II-4 summarizes the utility's firm purchase power contracts.

The West Maui coast and the Kihei area on the western shores of Haleakala have experienced dramatic load growth over the past 20 years due to major development of the tourist industry. Future generation additions in these areas would be desirable.

Discussion of Load Profiles

Maui exhibits electric usage patterns which are very similar to those discussed for Oahu (HECO). Although Maui has a greater range in elevation and climate, the vast majority of Maui's residents live at elevations which embody climates similar to those found on Oahu. Similar to HECO, MECO's diurnal demand profiles reflect increased electrical usage associated with dinner (Figure II-5). The evening "dinner time" spike in winter is about 17 MW (13%) while in summer it is only about 5 MW (4%). The relatively constant daytime demand is nearly identical in both summer and winter, perhaps reflecting less commercial air conditioning loads on Maui than on Oahu. MECO's monthly peak demand varies by 15% over the entire year (Figure II-6). The highest demand occurs during the December holiday season while the lowest demand occurs in May.

Table II-3 MECO Current Installed Capacity: Total = 143.31 MW

Location-Type-Unit	Fuel	Unit MW	Type MW	Location MW
Kahului Harbor Generating Plant				37.60
Steam Turbines			37.60	
Unit 1	MSFO*	5.90		
Unit 2	MSFO	6.00		
Unit 3	MSFO	12.70		
Unit 4	MSFO	13.00		
Maalaea				105.71
Diesel Plants			105.71	
Unit 1	Diesel	2.75		
Unit 2	Diesel	2.75		
Unit 3	Diesel	2.75		
Unit 4	Diesel	6.16		
Unit 5	Diesel	6.16		
Unit 6	Diesel	6.16		
Unit 7	Diesel	6.16		
Unit 8	Diesel	6.16		
Unit 9	Diesel	6.16		
Unit 10	Diesel	13.75		
Unit 11	Diesel	13.75		
Unit 12	Diesel	13.75		
Unit 13	Diesel	13.75		
Unit X1	Diesel	2.75		
Unit X2	Diesel	2.75		

* MSFO = Medium Sulfur Fuel Oil (equivalently: No. 6 Fuel Oil, Bunker C, Residual, Industrial)

Source: MECO 1990 Electric Utility System Cost Data, July 1990

Table II-4 MECO Currently Effective Firm Purchase Power Contracts: Total = 12 MW

Name (Location)	Fuel	Firm MW	GWh/year
Firm:			
Hawaiian Commercial & Sugar (Keahua)	bagasse	12	-
Not-Firm:			
Hawaiian Commercial & Sugar (Keahua)	bagasse	4 (standby)	-
Pioneer Mill Company (Lahaina)	bagasse	8 (standby)	-

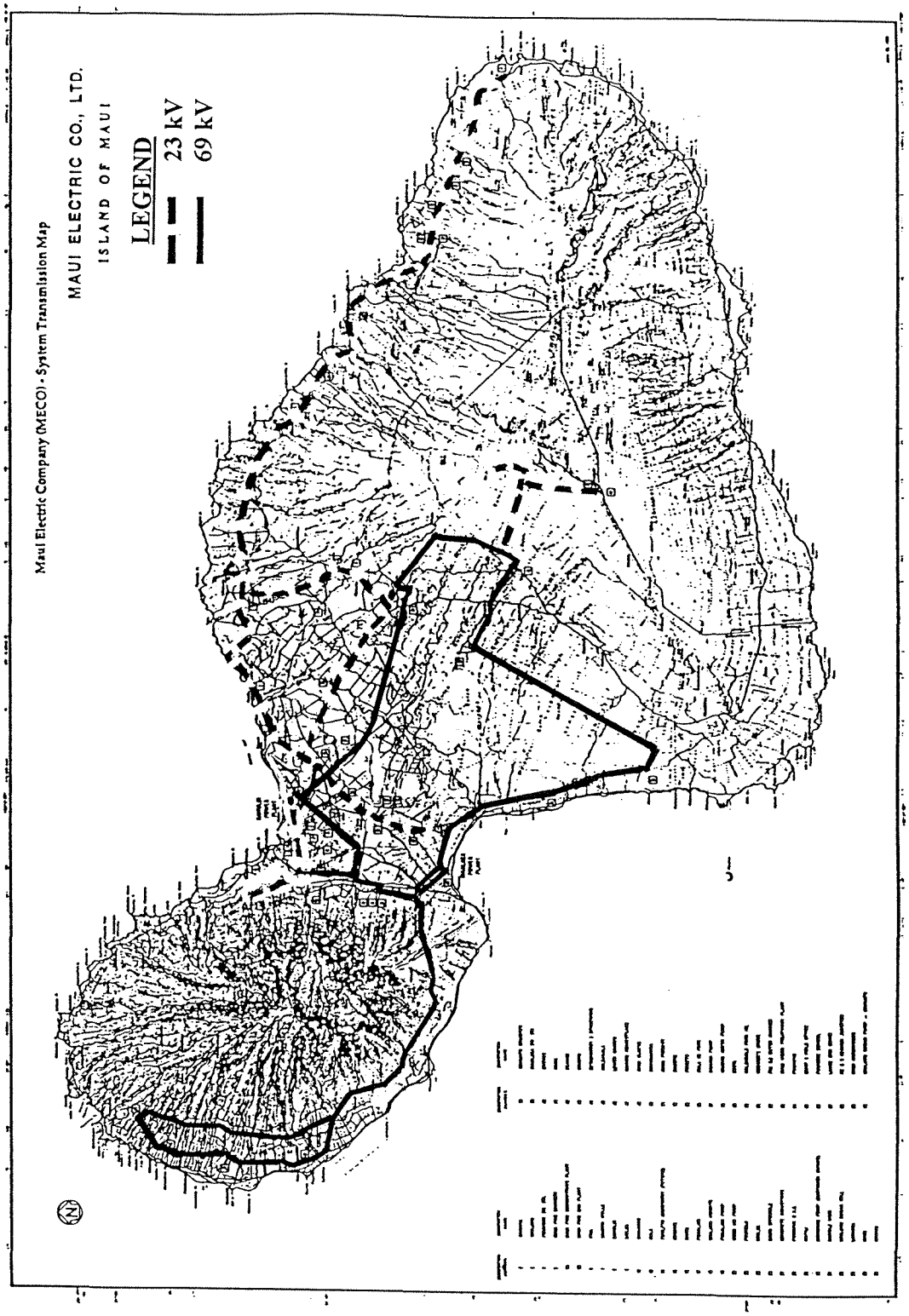


Figure II-4. Maui Electric Company (MECO) System Transmission Map

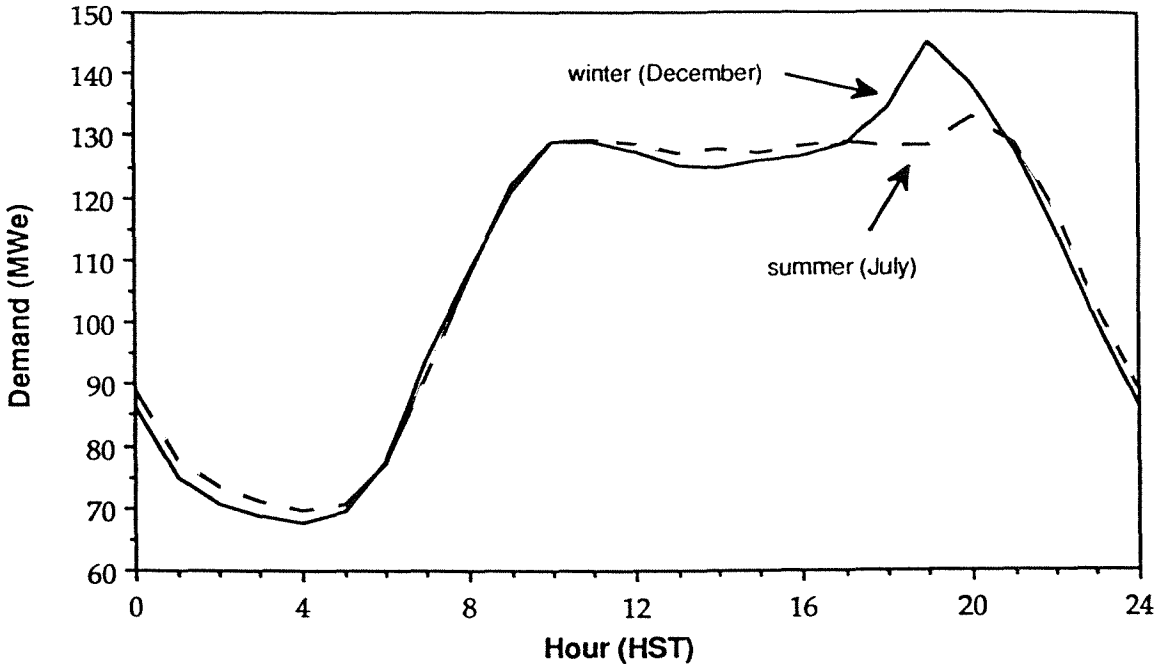


Figure II-5 MECO Typical Daily Load Profiles by Season (based on projected 1990 data)

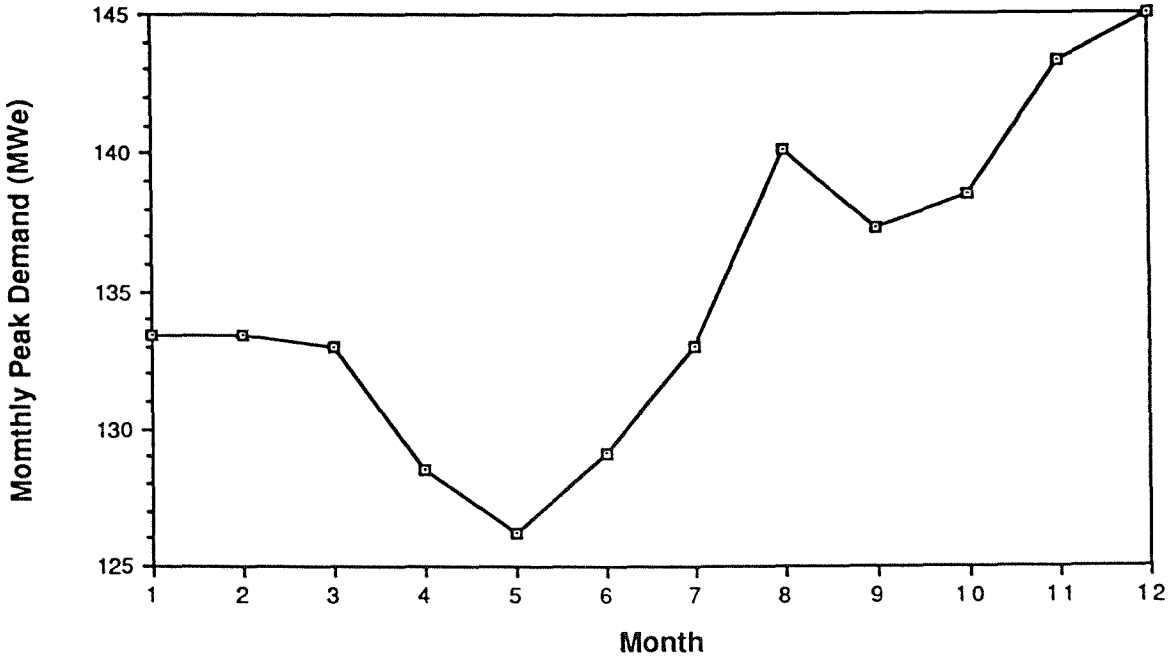


Figure II-6 MECO Peak Demand by Month (based on projected 1990 data)

MECO, MOLOKAI ELECTRIC DIVISION (MOECO)

Description

Molokai Electric Company, which became a division of Maui Electric Company in 1989, supplies electricity to the predominantly rural population on the island of Molokai. Although the island's economy has been depressed for many years, there is nevertheless strong opposition to extensive resort development which has proliferated in other areas. MOECO's electric rates are the highest in Hawaii. Table II-5 describes MOECO's installed capacity while Table II-6 summarizes the utility's purchase power contracts. Figure II-7 presents a map of the transmission system on Molokai.

Discussion of Load Profiles

In spite of its small population and intrinsically rural character, Molokai's electric demand profiles are quite similar to those presented for Oahu (HECO). MOECO's diurnal demand profiles (Figure II-8) are relatively flat throughout the day, then reflect increased electrical usage associated with dinner. The evening "dinner time" spike in winter is over 1 MW (25%) and is evident for 4-5 hours. In summer, elevated evening demand is only about 0.3 MW (8%). The relatively constant daytime demand is nearly identical in both summer and winter. This fact reflects the near total absence of climate control loads on Molokai. MOECO's monthly peak demand (Figure II-9) varies by 20% over the entire year and clearly reflects the usage trends of the dominant residential sector. Seasonal lifestyle changes associated with day length impact the relative "dinner time" peak which drives the peak demand throughout the year. MOECO's highest demand occurs during the November-December holiday season (shortest days of year) while the lowest demand occurs during the mid-summer months of June and July (longest days of year).

Table II-5 MOECO Current Installed Capacity: Total = 7.7 MW

Location-Type-Unit	Fuel	Unit MW	Type MW	Location MW
Palaau				7.70
Diesel Plants			5.49	
Unit 1	Diesel	1.29		
Unit 2	Diesel	1.29		
Unit 3	Diesel	0.97		
Unit 4	Diesel	0.97		
Unit 5	Diesel	0.97		
Gas Turbine			2.20	
Unit 1	Diesel	2.20		

Source: HECO System Planning Department, May 1, 1991

Table II-6 MOECO Currently Effective Firm Purchase Power Contracts: Total = 0 MW

Name (Location)	Fuel	Firm MW	GWh/year
Firm:			
None	-	-	-
Not-Firm:			
Various	-	-	11.5

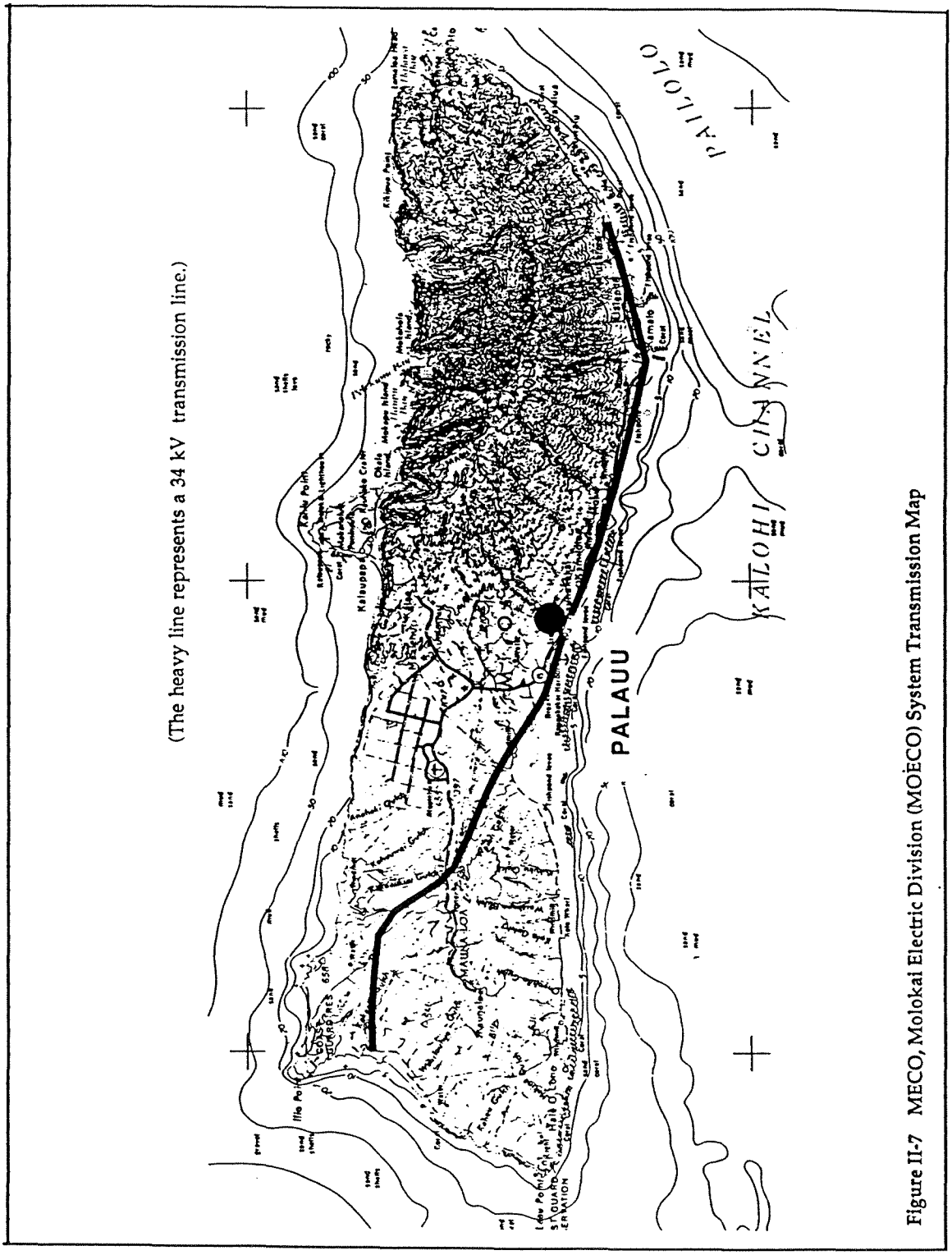


Figure II-7 MECO, Molokai Electric Division (MOECO) System Transmission Map

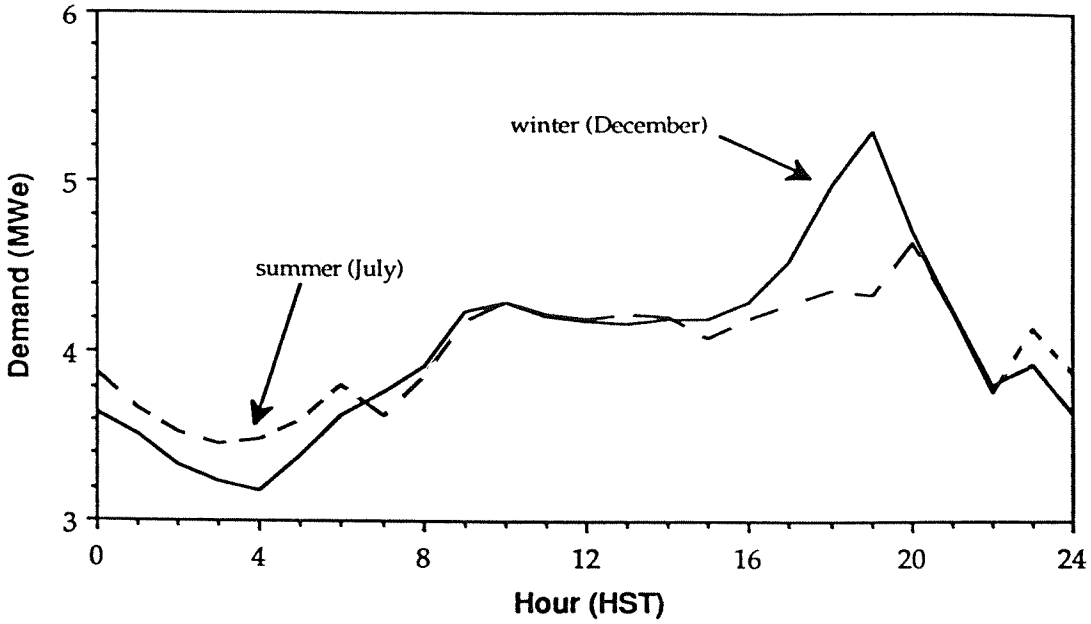


Figure II-8 MOECO Typical Daily Load Profiles by Season (based on historical data for 1989)

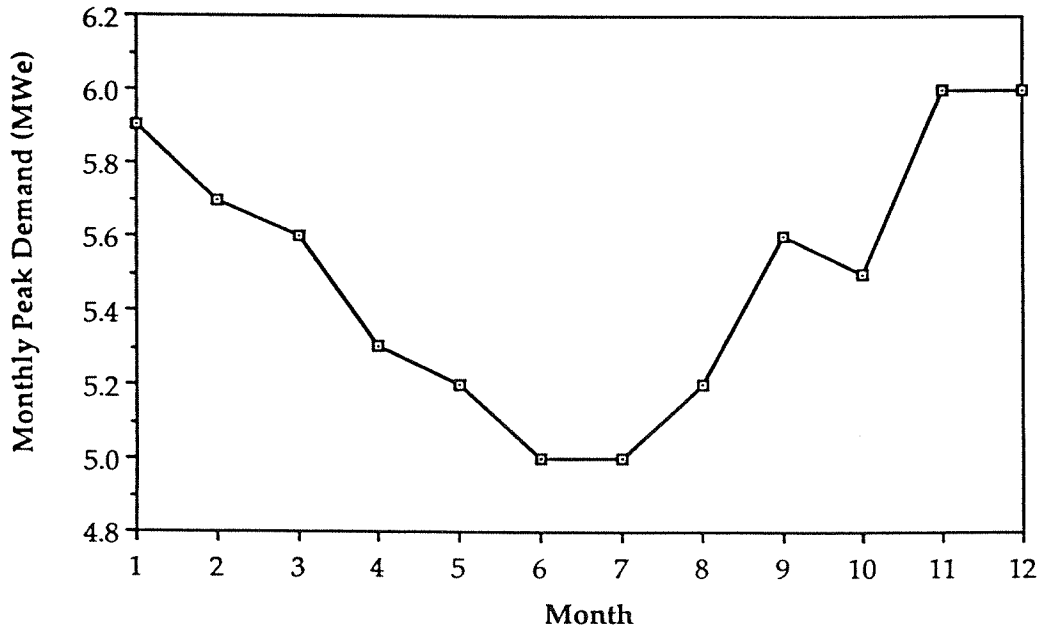


Figure II-9 MOECO Peak Demand by Month (based on projected 1991 data)

MECO, LANAI DIVISION

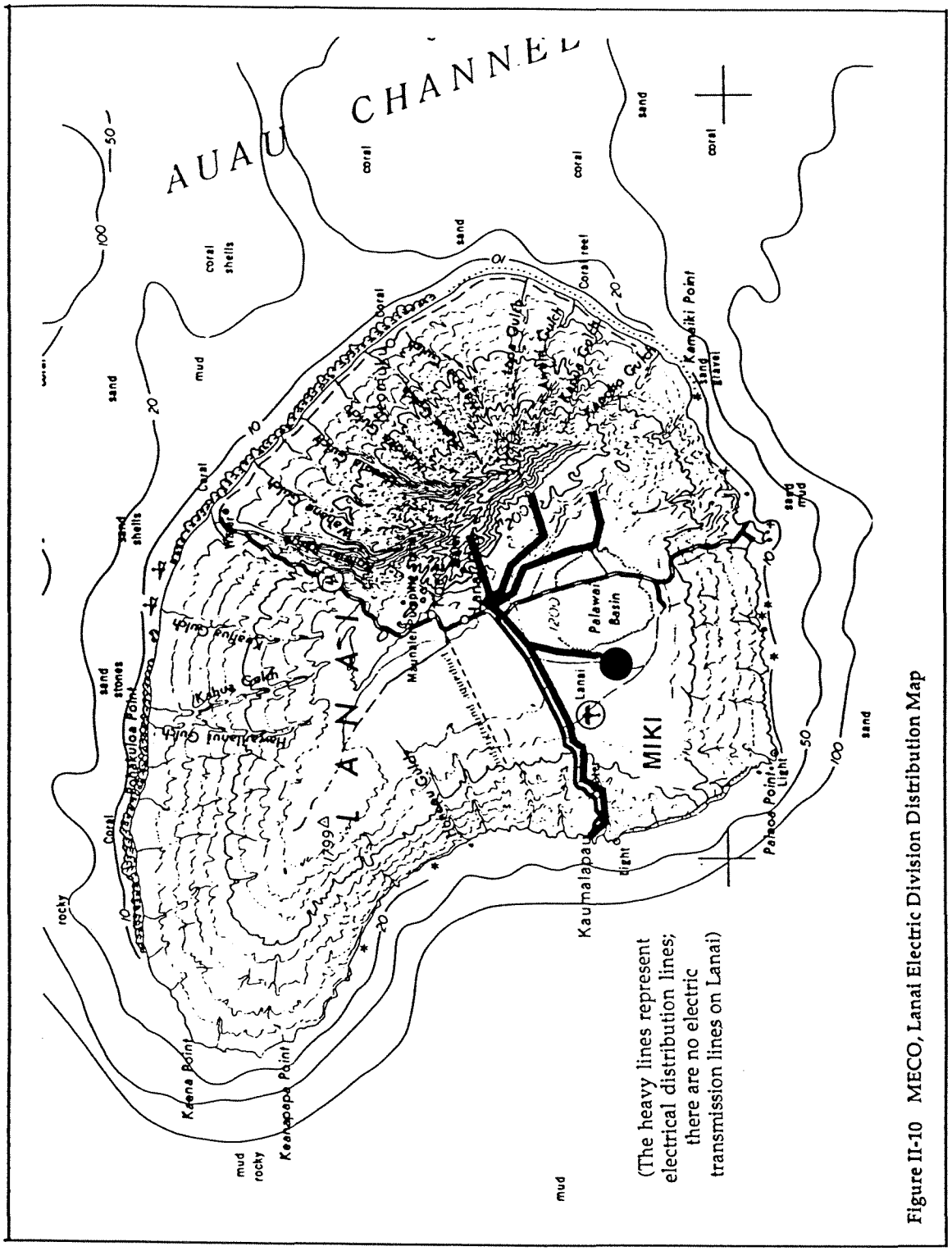
Description

The island of Lanai, also known as "Pineapple Island", is almost entirely owned by Castle and Cooke, Inc. (Dole Pineapple Company). In 1988, Dole sold their electric generation facilities to Maui Electric Company. Since that time, resort developments on Lanai have been planned. MECO, expecting substantial increases in electric demand, responded by adding one additional diesel plant at Miki. Current plans call for the old Lanai City Plant to be gradually retired. Lanai's topography, small electric demand, and current over-capacity do not lend themselves to significant SEGS opportunities. Further discussion of Lanai will be limited to a listing of current installed electric generation (Table II-7) and presentation of a system distribution map (Figure II-10).

Table II-7 MECO, Lanai Division, Current Installed Capacity: Total = 9.71 MW

Location-Type-Unit	Fuel	Unit MW	Type MW	Location MW
Lanai City				3.71
Diesel Plants			3.71	
Unit 1	Diesel	0.68		
Unit 2	Diesel	0.68		
Unit 4	Diesel	0.35		
Unit 7	Diesel	1.00		
Unit 8	Diesel	1.00		
Miki				6.00
Diesel Plants			6.00	
Unit 1	Diesel	1.00		
Unit 2	Diesel	1.00		
Unit 3	Diesel	1.00		
Unit 4	Diesel	1.00		
Unit 5	Diesel	1.00		
Unit 6	Diesel	1.00		

Source: HECO System Planning Department, May 1, 1991



(The heavy lines represent electrical distribution lines; there are no electric transmission lines on Lanai)

Figure II-10 MECO, Lanai Electric Division Distribution Map

HAWAII ELECTRIC LIGHT COMPANY (HELCO)

Description

Electric service for the island of Hawaii is provided by the Hawaii Electric Light Company. The "Big Island" of Hawaii comprises nearly two-thirds of the state's land mass. Accordingly, HELCO's service territory is by far the largest in the state. HELCO's system transmission network is depicted in Figure II-11. Table II-8 describes HELCO's installed capacity while Table II-9 summarizes the utility's firm purchase power contracts.

The major population center of Hilo, a seaport on the island's rainy eastern side, hosts the majority of HELCO's generation facilities. In recent years, the sunny Kona coast on the island's western side has experienced substantial electric load growth due to increased tourism. Localized load growth, the relatively extensive nature of the island's transmission network, and problems in getting the 25 MW Puna Geothermal Venture on line have combined to strain HELCO's current ability to provide electric service without occasional brownouts and blackouts.

Discussion of Load Profiles

Although the Big Island has a greater range of climatic conditions than Oahu, HELCO's electric demand profiles are nonetheless quite similar to those presented for HECO. HELCO's diurnal demand profiles (Figure II-12) are relatively flat throughout the day, then reflect increased electrical usage associated with dinner. The evening "dinner time" spike in winter is over 25 MW (23%) and is evident for 4-5 hours. In summer, elevated evening demand is less than 10 MW (9%). There is a slight difference in nighttime demand between summer and winter of about 5 MW (6%). High elevation areas on the Big Island get cold enough on winter nights to require heating. Higher winter nighttime demand is thought to reflect this requirement through winter electric space heating loads.

HELCO's monthly peak demand (Figure II-13) varies by about 15% over the entire year. Like Molokai, monthly peak demand patterns clearly reflect the usage trends of the residential sector. Seasonal lifestyle changes associated with day length impact the relative "dinner time" peak which drives the peak demand throughout the year. HELCO's highest demand occurs during December (shortest days of the year) while the lowest demand occurs in June (longest days of the year).

Table II- 8 HELCO Current Installed Capacity: Total = 135.4 MW

Location-Type-Unit	Fuel	Unit MW	Type MW	Location MW
Hilo Area (Shipman, Kanoelehua, Puna)				91.65
Steam Turbines (Shipman, Kanoelehua, Puna)			71.40	
Shipman 1	MSFO	3.40		
Shipman 3	MSFO	7.50		
Shipman 4	MSFO	7.50		
Hill 5	MSFO	14.00		
Hill 6	MSFO	23.00		
Puna	MSFO	16.00		
Combustion Turbine (Kanoelehua)			10.00	
CT Number 1	Diesel	10.00		
Diesel Plant (Kanoelehua)			10.25	
Diesel 11	Diesel	2.00		
Diesel 15	Diesel	2.75		
Diesel 16	Diesel	2.75		
Diesel 17	Diesel	2.75		
Wiamea				11.25
Diesel Plants			11.25	
Diesel 8	Diesel	1.00		
Diesel 9	Diesel	1.00		
Diesel 10	Diesel	1.00		
Diesel 12	Diesel	2.75		
Diesel 13	Diesel	2.75		
Diesel 14	Diesel	2.75		
Keahole				32.50
Diesel Plants			16.50	
Diesel 18	Diesel	2.75		
Diesel 19	Diesel	2.75		
Diesel 20	Diesel	2.75		
Diesel 21	Diesel	2.75		
Diesel 22	Diesel	2.75		
Diesel 23	Diesel	2.75		
Combustion Turbine			16.00	
CT Number 2	Diesel	16.00		

Source: HELCO 1990 Electric Utility System Cost Data, July 1990

Table II- 9 HELCO Firm Purchase Power Contracts: Total 28 MW

Name (Location)	Fuel	Firm MW	GWh/year
Firm:			
Hilo Coast Processing	bagasse	18	87.5
Hamakua Sugar Company	bagasse	10	62

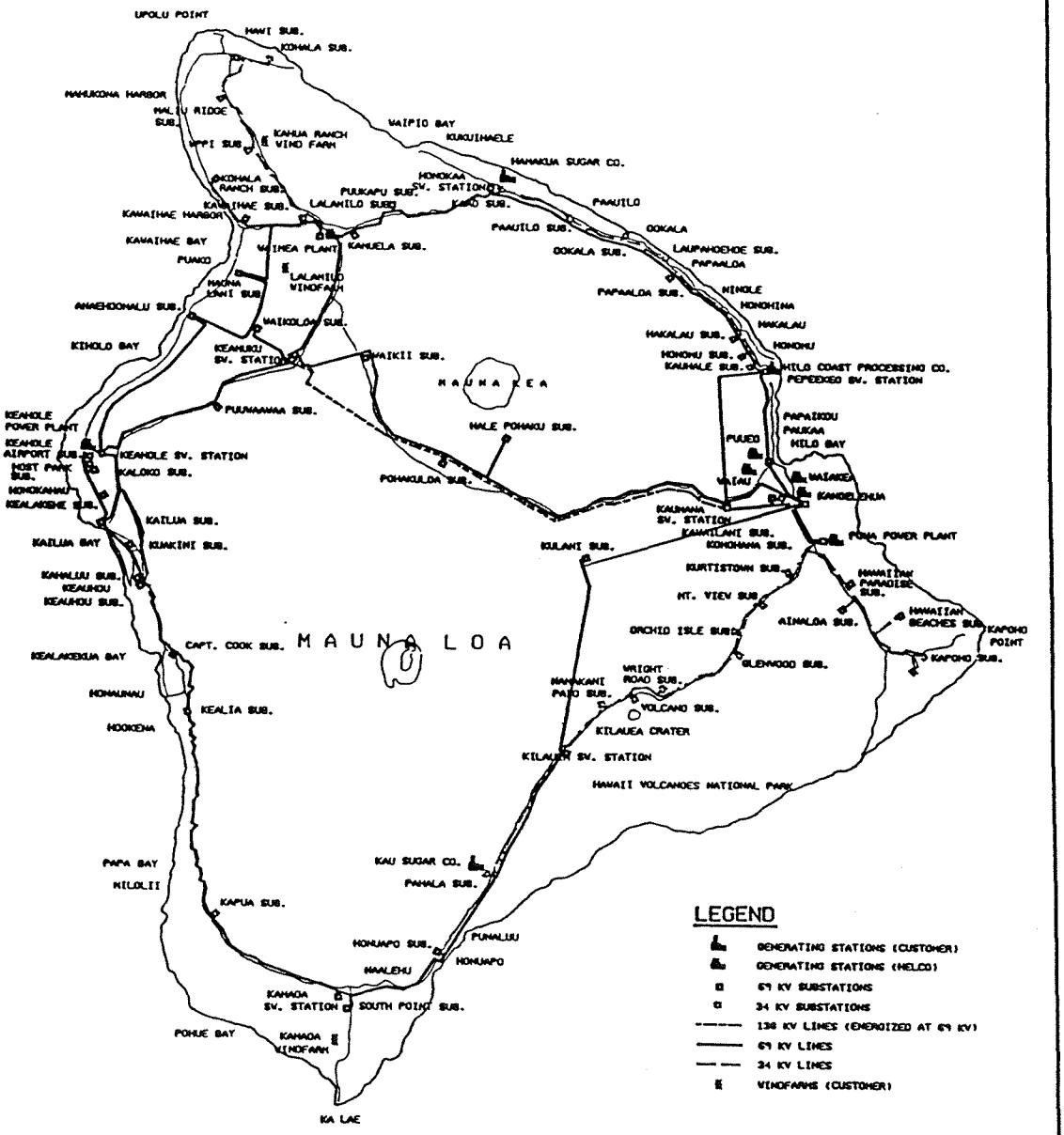


Figure II-11 Hawaiian Electric Light Company (HELCO) System Transmission Map

Figure II- 12 HELCO Typical Daily Load Profiles by Season (based on projected 1990 data)

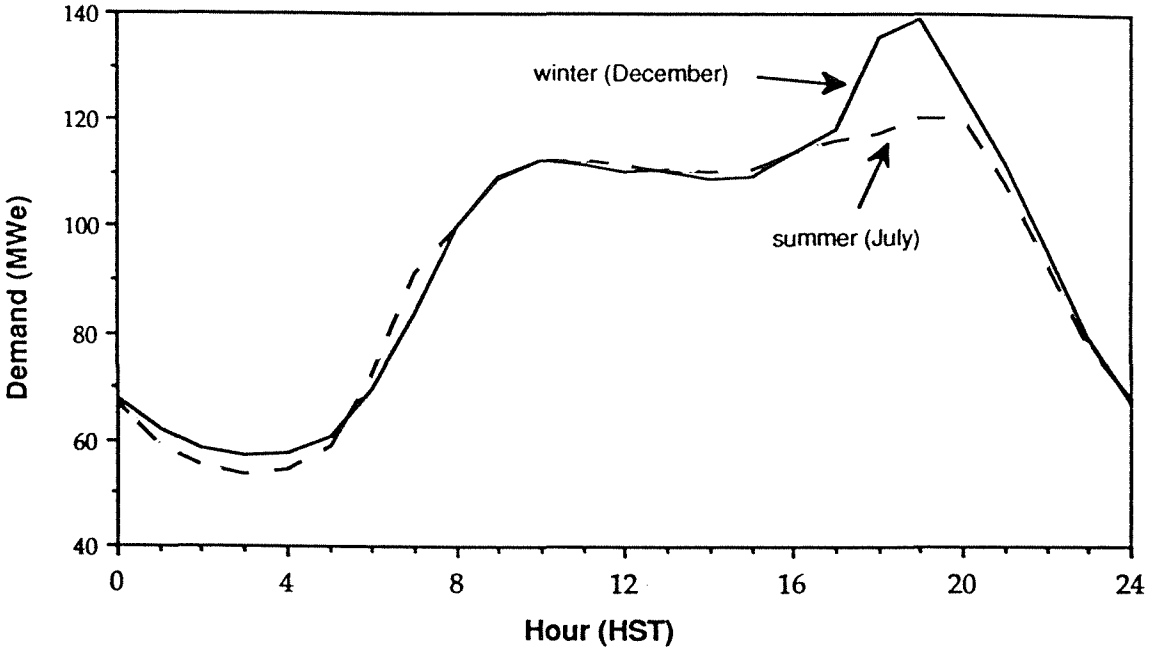


Figure II- 12 HELCO Typical Daily Load Profiles by Season (based on projected 1990 data)

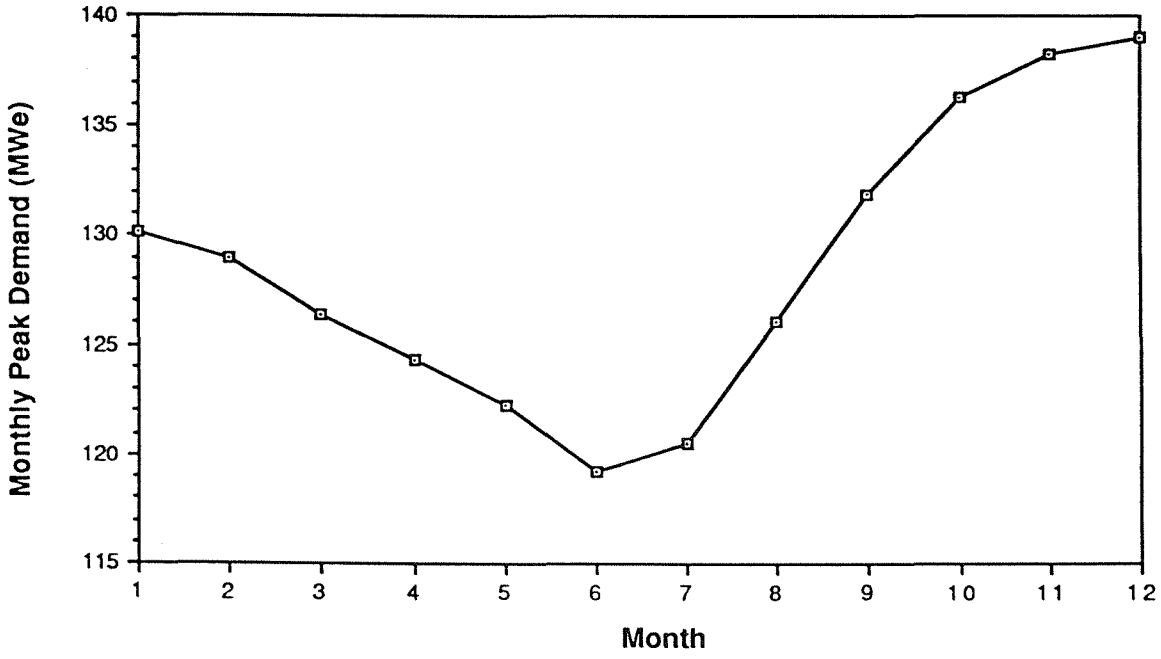


Figure II- 13 HELCO Peak Demand by Month (based on projected 1990 data)

KAUAI ELECTRIC DIVISION OF CITIZENS UTILITIES COMPANY (KE)

Description

Kauai Electric Division of Citizens Utilities Company, is the only electric utility in Hawaii which is not a member of the HEI utilities system. Kauai Electric provides electric service to the island of Kauai. KE's system transmission map is presented in Figure II-14. As Table II-10 describes, KE has only one power plant located at Eleele (Port Allen). This generation is supplemented by numerous purchase power agreements (summarized in Table II-11). The coastal areas in northern and western Kauai, particularly Princeville, Poipu and Lihue, have experienced significant recent growth due to resort development.

Discussion of Load Profiles

The electric demand profiles (Figure II-15) for Kauai are quite similar to those discussed for Oahu (HECO) — flat daytime usage and increased winter month peak demand reflecting more substantial winter "dinner time" peaks. KE's plot of peak demand by month (Figure II-16) is somewhat distorted compared to long-term average conditions due to a major new load which came on line during October 1990.

Table II-10 KE Current Installed Capacity: Total = 96.55 MW

Location-Type-Unit (year installed)	Fuel	Unit MW	Type MW	Location MW
Port Allen Generating Plant (Eleele)				96.55
Diesel Engine			43.65	
Diesel 1 EMD (1964)	Diesel	2.00		
Diesel 2 EMD (1964)	Diesel	2.00		
Diesel 3 EMD (1968)	Diesel	2.75		
Diesel 4 EMD (1968)	Diesel	2.75		
Diesel 5 EMD (1968)	Diesel	2.75		
Diesel 6 SWD (1990)	Diesel	7.85		
Diesel 7 SWD (1990)	Diesel	7.85		
Diesel 8 SWD (1991)	Diesel	7.85		
Diesel 9 SWD (1991)	Diesel	7.85		
Steam Turbine			10.00	
Steam Plant CE (1968)	MSFO	10.00		
Gas Turbine			42.90	
Hitachi #1 (1973)	Diesel	19.20		
Brown #2 (1977)	Diesel	23.70		

Source: Denny Polosky (KE Director of Planning and Regulatory Affairs, April 9, 1992)

Table II-11 KE Firm Purchase Power Contracts: Total = 12 MW

Name (Location)	Fuel	Firm MW	GWh/year
Firm:			
Lihue Power Plant (Lihue)	bagasse	12	70-82
Not-Firm:			
McBryde Sugar Company (Koloa)	bagasse	-	16-28
Kekaha Sugar Company (Kekaha)	bagasse	-	5-10
Olokele Sugar Company (Olokele)	bagasse	-	≈ 1

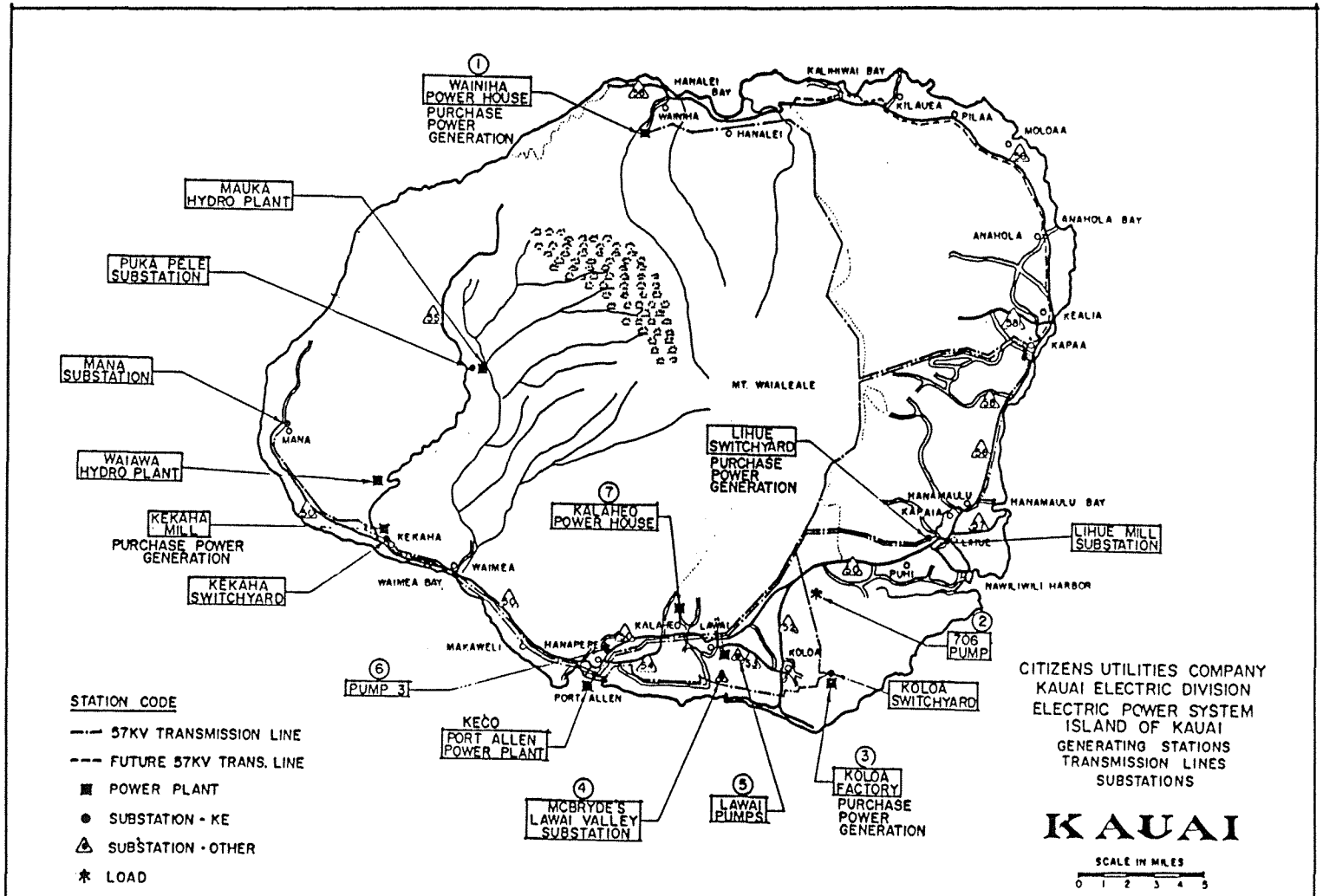


Figure II-14 Kauai Electric Division of Citizens Utilities Company (KE) System Transmission Map

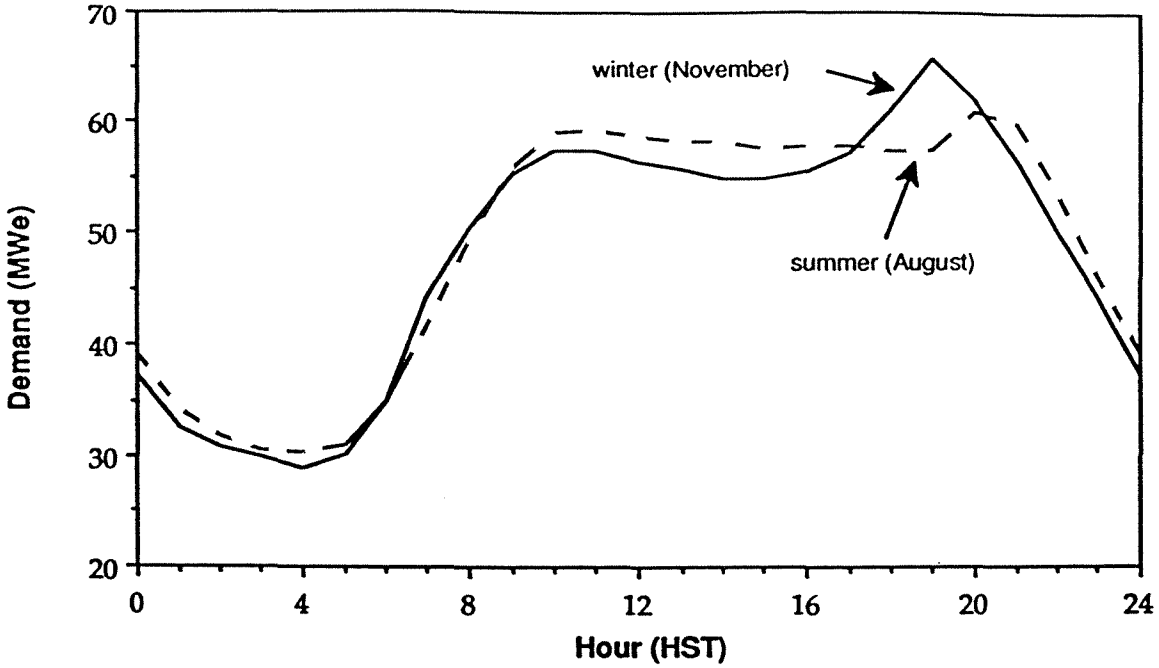


Figure II-17 KE Typical Daily Load Profiles by Season (based on historical data for 1990)

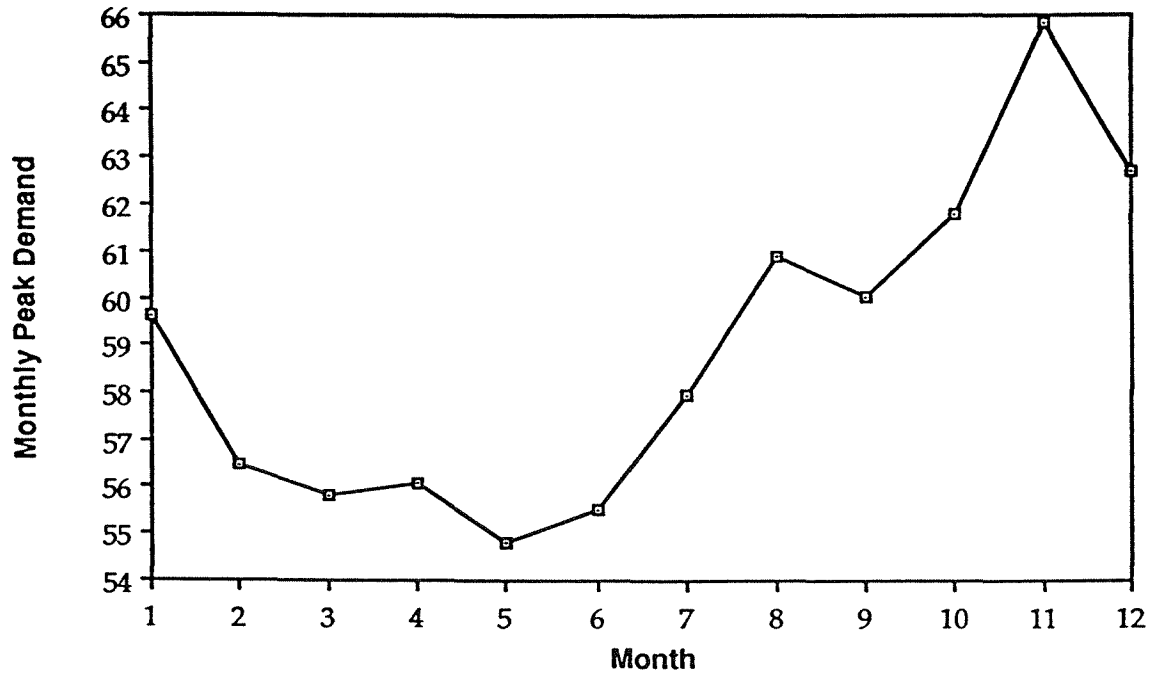


Figure II-16 KE Peak Demand by Month (based on historical data for 1990)

UTILITY NEEDS AND RESOURCE PLANS FOR THE FUTURE

Overview

Hawaii has experienced rapid economic and electrical growth primarily fueled by the state's growing tourist industry. Many of the islands' utilities have faced difficult challenges in providing adequate service to meet increasing electric demand. This section presents planning data and proposed additions for each utility's strategy for supplying the future electric generating requirements of their system.

HECO has been evaluating long-term plans by private developers to construct an undersea electric transmission cable to provide Oahu with geothermally produced electricity from the Big Island. The viability of geothermal plants to provide adequate energy to warrant this project has not yet been established. HECO's base resource plan does not include the geothermal venture, but is flexible enough to accommodate the project should it come to fruition. Given the significant expansion of opportunities for future SEGS projects that inter-island electric transmission would provide, this report includes a cursory review of several inter-island cable proposals. Additionally, Hawaii is in the process of developing integrated resource planning and an externalities policy. These topics, which could significantly shape prospects for renewable energy projects in the state, are considered in this section.

After consideration of these issues, the ensuing material in this section provides details on the current resource plans of each electric utility in the state. Information supplied for each utility includes a chart indicating 20 year projections for system peak demand, system capacity, and planned generating capacity retirements and additions. Details on projected load growth, generation capacity additions, and fuel cost forecasts are provided in narrative form.

During the past year, shipping companies operating in Hawaii have been held to be fully liable for damages caused by cargo spills which impact Hawaiian waters. Since heavier petroleum distillates such as MSFO (medium sulfur fuel oil) and LSFO (low sulfur fuel oil) are much more difficult to clean up after accidents than diesel, shipping companies have essentially refused to transport these heavier fuels in the future. Oahu is the only Hawaiian island where crude oil is refined. Accordingly, diesel is the only fuel which is expected to be available for power plant use on islands other than Oahu. A recent fuel forecast containing 20 year projections for the price of diesel, LSFO, and coal is included for HECO. Since all HEI-member utilities utilize a common fuel forecast, the fuel forecast discussion for MECO and HELCO are based on the HECO values listed for diesel and differ only according to appropriate transportation and handling costs. The material presented for Kauai Electric includes KE's fuel forecast for diesel and MSFO.

Details of future resource plans for HECO, MECO, and HELCO were provided by HECO System Planning in mid-April, 1992. Information included in the discussion of fuel forecasts and the summary of capacity cost and energy cost for each planned capacity addition were taken from each utility's 1990 Electric Utility System Cost Data filing to the Hawaii PUC, as per the Commission's Section 6-74-17 requirements. Kauai Electric is not subject to the PUC's avoided cost data disclosure rule due to its smaller size. No summary of capacity cost and energy cost for KE additions is provided. Updated information on KE's system resource plan was provided by KE's Director of Planning & Regulatory Affairs in late April, 1992.

Efforts to update this report with the most current information available have not met with complete success. Since this document represents a compilation of different resources, there may be some slight inconsistencies between updated and outdated information.

Inter-Island Electric Transmission Cable Projects

Deep-Sea Cable / Geothermal Development:

For many years there has been serious interest in developing the geothermal resources of Hawaii — a native energy supply which, if utilized, could reduce the state's near total dependence on imported petroleum. Matching geothermal power sites from the volcanoes region of the Big Island with Hawaii's major electric load centers on Oahu requires an undersea electric cable traversing about 150 miles of ocean at depths of up to 7000 feet. Considerable resources have been invested in exploring the technical and economic feasibility of this cable project. Yet geothermal development on the island of Hawaii has progressed slowly — saddled by vocal opposition and the uncertainty of successfully permitting and drilling commercial wells. Thus far, the Puna Geothermal Venture has been unable to satisfy a 25 MW purchase power contract with HELCO. Until geothermal power can be proven viable both commercially and socially on the island of Hawaii, serious consideration of massive geothermal development suitable for supplying electricity to Oahu is premature. Appropriately, the status of the deep-sea cable project has been placed on hold indefinitely.

Maui County Tri-Island Cable:

MECO recently examined the prospects of electrically interconnecting the islands of Maui, Lanai and Molokai with an undersea tri-island cable. This project envisioned locating a 56 MW combined cycle power plant on Molokai which would be connected with Maui and Lanai via an undersea transmission cable. In addition to supplying additional capacity for Maui, the project had the potential benefit of providing cheaper, more reliable electricity to the inhabitants of both Molokai and Lanai — presenting the opportunity for uniform electric rates throughout Maui County. MECO has since committed to the construction of the 56 MW combined cycle plant at a site on Maui and an associated 69 kV transmission line circling around west Maui to serve growth in the Lahaina area. The cost of the combined cycle plant was about $76 million for either site. Transmission costs, on the other hand, were dramatically different: $100 million for the tri-island cable (approximately 80 MW of capacity) versus $7 million for the necessary land-based transmission additions on Maui. The tri-island cable is no longer an active project but could resurface in future years as Maui County continues to grow.

Molokai-Oahu Cable:

Most areas designated for power plant and industrial development on Oahu are concentrated in the southwest corner of the island. Unfortunately, the vast majority of HECO's generating capacity and purchased power are already located in this area. From an electric transmission stability standpoint, generating sources near Waikiki and southeast Oahu would be very desirable. However, locating generating facilities in these areas, particularly a large coal plant, would be quite difficult if not impossible.

The western shores of Molokai are less than 30 miles from southeast Oahu, or approximately equidistant to this load growth area as HECO's current generating facilities at Kahe Point and Barber's Point. HECO is considering a large coal baseload generating facility on Molokai as a future resource option in their long range forecast. Conceptually, a power plant on Molokai, where land is relatively cheap and available, could be economically preferred to generating options on Oahu, in spite of the considerable expenditure which would be required for an undersea electric transmission cable. Black & Veatch has estimated the cost for a Molokai-Oahu cable with 800 MW of capacity at $320 million ($400/kW; 1991$).

A public meeting on Molokai to discuss this potential project drew a response that was overwhelmingly opposed to large-scale energy projects developed on Molokai for the primary benefit of residents of Oahu. While there may be technical and economic feasibility, the current political environment is not conducive to the success of such a project in the near future. Whether a large renewable energy development would draw comparable opposition as HECO's proposed coal facility is unknown. Any undersea electric cable

project, however, can be expected to encounter opposition from environmental groups concerned about potential impacts on marine life, particularly on the area's humpback whales. Since speculation on the future political environment in Hawaii is clearly beyond the scope of this report, it is appropriate that the current study consider the large Molokai SEGS/cable to Oahu scenario based on its technical and potential economic merits.

Externalities / Integrated Resource Planning

In most states, including Hawaii, competing electric generating options have traditionally been evaluated through a process which identifies the project with the lowest direct cost. Direct costs include land, equipment, and labor to construct a power plant, fuel expenditures, operating and maintenance costs, and certain financing charges. Electric rates are calculated based on the internalization of a utility's historical, imbedded direct costs. Yet a power plant clearly impacts residents of Hawaii in ways not reflected on their monthly utility bills. The construction and operation of a power plant may impact public health, cultural resources, and numerous environmental factors such as air quality, water quality, and biological and botanical health and diversity. Benefits accruing to power plant construction include job creation and the potential to spur economic development. Collectively, these considerations, which do not directly impact the cost of a project, are termed "externalities".

Incorporating externalities into the utility planning process is a regulatory concept still in its infancy. Several states have adopted Integrated Resource Planning (IRP) in order to evaluate a broader range of supply-side and demand-side options with greater public participation and sensitivity to externalities. A handful of states have already developed specific methodologies for evaluating certain externalities, primarily residual emissions. Table II-12 compares monitized values of externalities for the states which currently embrace rules which attempt to monitize externalities. Based on the values in Table II-12 and typical power plant characteristics, Table II-13 gives the residual environmental costs attributable to different types of power plants. Both tables are taken from "The New Environmental Accounting: A Status Report" by the Honorable Stephen Wiel, *The Electricity Journal*, November 1991.

Although the values attributed to environmental costs in Tables II-12 and II-13 are not precise, solar thermal power plants embody distinct environmental benefits relative to conventional fossil-fired generation which should be meaningfully considered when new electric generating facilities are selected. An equitable integrated resource planning process should strive to reflect a comprehensive assessment of costs and benefits. It should also be noted that monitization of externalities is site specific. For example, the residual environmental cost in Table II-13 attributed to geothermal development in Nevada may not be appropriate for geothermal development on the Big Island.

In March of 1992, the Hawaii PUC mandated consideration of externalities as one component of its new integrated resource planning process. The initial burden for establishing an equitable framework for the evaluation of externalities has been given to the utilities. HECO has contracted a survey of how other states and mainland utilities have evaluated externalities. Additional inputs may include a direct survey of utility customers to obtain their views on this subject. At the completion of the information gathering phase, advisory groups representing government, business, community, cultural, and environmental interests will collaboratively develop a externalities policy for Hawaiian utilities. If the resultant IRP externalities framework is not deemed to be in the best interest of the people of Hawaii, the state PUC will dictate more explicitly the methods by which utilities will be required to adequately account for external costs and benefits.

Table II-12. Comparison of Evaluations of Externalities in the U.S.

(Residual emission units are 1989 $/lb; water and land use units are 1989 ¢/kWh)

Externality	New York PSC	Massachusetts DPU	Nevada PSC	California PUC (SDG&E/SCE)	California PUC (PG&E)	Pace University
SO_2	0.41	0.75	0.78	9.15	2.03	2.03
NO_x	0.89	3.25	3.40	12.25	3.55	0.82
VOC's	ne	2.65	0.59	8.75	1.65	ne
CO	ne	0.43	0.46	ne	ne	ne
Particulates	0.16	2.00	2.09	2.65	11.19	1.19
CO_2	0.001	0.011	0.011	0.013	0.013	0.007
CH_4	ne	0.11	0.11	ne	ne	ne
N_2O	ne	1.98	2.07	ne	ne	ne
water use	0.10	ne	ss	ne	ne	ne
land use	0.40	ne	ss	ne	ne	ne

ne = not estimated ss = site specific California values in 1987 dollars

Table II-13. Residual Environmental Costs

(Units are ¢/kWh)

Type of Power Plant	Value in New York	Value in Massachusetts	Value in Nevada	Value in Pace Study
Coal-Fired (meeting NSPS)	1.4	4.4	4.3	4.5
Coal Fluidized Bed	—	3.0	4.9	3.3
Natural Gas Combined Cycle	—	1.1	2.2	1.1
Solar Thermal (25% gas backup; 35% capacity factor)	—	—	0.5	0 to 0.4
Geothermal (flash with reinjection)	—	—	0.001	—
Demand Management	0	0	0	0

HAWAIIAN ELECTRIC COMPANY (HECO)

Projected Annual Load Growth

HECO's peak electric demand is expected to increase by 6.7% from 1991 to 1992. Approximately half of this growth is real growth (about 3.5%); the other half is expected recovery from the lower than usual demand recorded during the economically depressed 1991. Electric demand growth on the order of 2-3% is expected for the next few years. Long range projections call for less than 2% annual growth during the next decade. Much of the anticipated load growth is expected to occur in the Kapolei area in southwestern Oahu.

Proposed Generation Capacity Additions

Additional generation facilities to be added between 1995 and 2000 include a 200 MW combined cycle power plant (to be constructed in 3 phases) and two 77 MW simple cycle combustion turbines. Based on the projected relative cost attractiveness of coal versus petroleum, future baseload additions in years after 2000 are currently expected to be 200 MW fluidized bed steam turbine plants. The relative attractiveness of coal in future years will be sensitive to residual emmisions valuations if such an analysis becomes a component of HECO's integrated resource planning process. It is noted that HECO's resource plan could be greatly modified if adequate geothermal energy becomes available.

HECO's system resource plan as of March, 1992 is summarized in Table II-14. This table contains projected peak demand, firm capacity, reserve margin, and projected capacity additions and retirements. The HECO system resource plan is summarized graphically in Figure II-18. Table II-15 contains a summary of estimated capacity cost and energy cost for each generation addition scheduled by HECO from 1990-2000.

Fuel Forecasts

The fuel forecast in Table II-16 is based on the May, 1991 draft fuel forecast of HECO's Forecast Planning Committee. An additional column is included for diesel in the units of $/BBL with values taken from HECO's Forecast Planning Committee forecast of July, 1991. The list also includes a non-site specific cost forecast for Indonesian low-sulfur (0.4%) bituminous coal. The coal price estimates — which include limestone, ash disposal, handling, and tax — reflect an average escalation rate of 5% per year. The long-term petroleum fuel escalation rate inherent in Table II-16 is 6.8%, down from the almost 9% reflected in HECO's December, 1989 fuel forecast. In the spring of 1992, HECO has been using long-term diesel escalation rates of about 5%. Clearly there is considerable uncertainty in this critically important planning factor which strongly impacts future utility generation addition selections.

LSFO fuel costs included in Table II-16 apply to the Kahe power plant. Additional transportation and handling costs to other HECO generation sites are estimated for the 1990 year as $ 0.05/BBL to Waiau and $ 0.25/BBL to Honolulu. Transportation costs are expected to increase by 5% per year after 1990. Diesel costs pertain to Waiau, which is the sole HECO facility with diesel units. Transportation and storage cost estimates are based on the December, 1989 fuel price forecast of HECO's Forecast Planning Committee.

Table II-14. Hawaiian Electric Company (HECO) System Resource Plan

Year	System Peak (MW)	System Capacity (MW)	Reserve Margin (%)	Capacity Modifications		
				Unit	Retired (MW)	Added (MW)
1991	1141	1440	26.2			
1992	1217	1620	33.1	AES	-	180
		1666	36.9	H-POWER	-	46
1993	1254	1666	32.9	-	-	-
1994	1285	1610	25.3	Honolulu 8	56	-
		1553	20.9	Honolulu 9	57	-
1995	1309	1620	23.8	Barbers Point 1, Ph1	-	70
		1620	29.1	Barbers Point 1, Ph2	-	70
1996	1340	1750	30.6	Barbers Point 1, Ph3	-	60
1997	1378	1750	27.0	-	-	-
1998	1406	1827	29.9	Combustion Turbine 1	-	77
1999	1435	1827	27.3	-	-	-
2000	1464	1827	24.8	-	-	-
2001	1488	2027	36.2	Fluidized Bed 1	-	200
2002	1513	2027	34.0	-	-	-
2003	1538	2027	31.8	-	-	-
2004	1563	2027	29.7	-	-	-
2005	1589	2027	27.6	-	-	-
2006	1617	2027	25.4	-	-	-
2007	1646	2227	35.3	Fluidized Bed 2	-	200
2008	1675	2175	29.9	Waiau 9	52	-
		2125	26.9	Waiau 10	50	-
2009	1705	2202	29.1	Combustion Turbine 2	-	77
2010	1736	2153	24.0	Waiau 3	49	-
		2104	21.2	Waiau 4	49	-
2011	1767	2181	23.4	Combustion Turbine 3	-	77

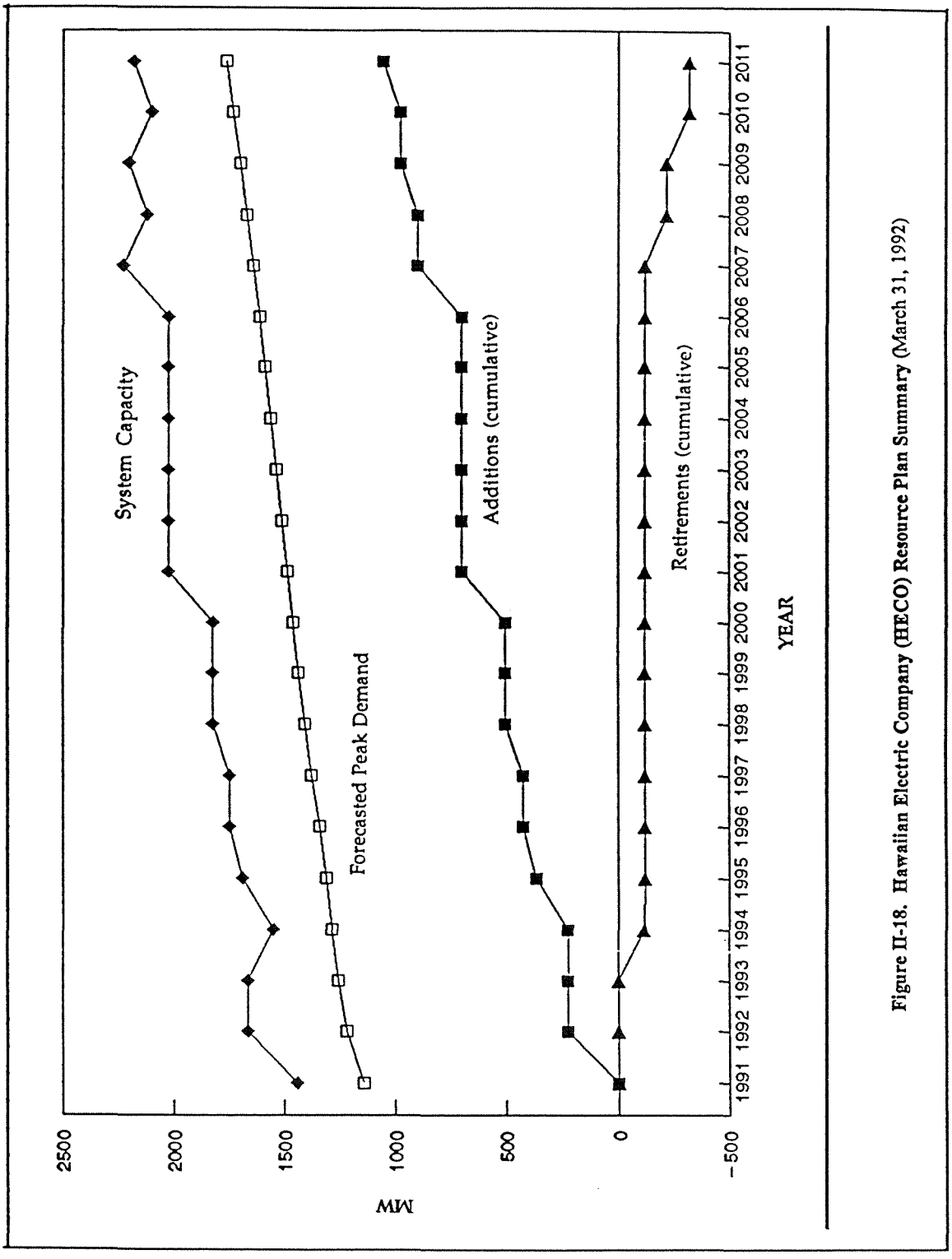


Figure II-18. Hawaiian Electric Company (HECO) Resource Plan Summary (March 31, 1992)

Table II-15. Energy and Capacity Cost of Recent and Projected HECO Capacity Additions

	Year	Size (MW)	Unit Owner	Unit Type	Capacity Cost ($)	Energy Cost (¢/ gross kWh)	
1)	1990	80	HECO	CT	*	6.036	
2)	1991	100	Kalaeloa	Combined Cycle 2	167.51/kW-year (25 years)	3.874	net
3)	1992	180	AES-BP	Fluidized Bed	342.48/kW-year (30 years)	1.74	net
	1995	77	HECO	Comb. Cycle Ph. 1	*	5.336	
	1995	77	HECO	Comb. Cycle Ph. 2	*	5.336	
4)	1996	47	HECO	Comb. Cycle Ph. 3	758.00/kW	2.694	
	1998	77	HECO	Simple Cycle CT	657.00/kW	5.336	
	2000	77	HECO	Simple Cycle CT	615.00/kW	5.336	

Notes:

(1) The combustion turbine was temporarily leased by Kalaeloa Partners to HECO prior to the facility's completion as a combined cycle. Capacity cost was not applicable. The energy cost shown, which pertains to its use as a combustion turbine, is based on a gaseous fuel price of $4.7641/MMBtu.

(2) Energy cost is in units of ¢/net kWh.

(3) Energy cost (¢/net kWh) does not reflect fixed O&M cost of 1.1 ¢/available kWh.

(4) Capacity cost shown applies to all three phases of the combined cycle plant.

Table II-16. HECO Fuel Cost Forecast

(Per HECO draft fuel forecast May 20, 1991; except * per HECO fuel forecast July 17, 1991)

Year	LSFO ($/MMBTU)	Diesel ($/MMBTU)	Diesel* ($/BBL)	Coal ($/MMBTU)
1991	3.78	4.81	28.20	2.027
1992	3.93	4.99	29.30	2.114
1993	4.15	5.27	30.90	2.209
1994	4.37	5.55	32.50	2.300
1995	4.60	5.83	34.20	2.399
1996	4.90	6.22	36.40	2.524
1997	5.23	6.62	38.80	2.655
1998	5.57	7.05	41.30	2.793
1999	5.93	7.51	44.00	2.937
2000	6.31	7.98	46.80	3.088
2001	6.81	8.61	50.50	3.254
2002	7.34	9.27	54.40	3.428
2003	7.90	9.98	58.50	3.611
2004	8.50	10.73	62.90	3.803
2005	9.12	11.52	67.50	4.005
2006	9.82	12.40	72.70	4.238
2007	10.58	13.34	78.20	4.483
2008	11.37	14.34	84.00	4.742
2009	12.21	15.39	90.20	5.014
2010	13.10	16.51	96.70	5.302

MAUI ELECTRIC COMPANY (MECO)

Projected Annual Load Growth

MECO's peak electric demand is expected to increase by almost 9% from 1991 to 1992. The substantial increase is partially attributable to the lower than usual increase in demand recorded during 1991. Electric demand growth on the order of 5% is expected for the next several years thereafter. Long range projections call for annual growth of 3.7% during the decade 2001-2011.

Proposed Generation Capacity Additions

MECO intends to meet future increases in electric demand with additions of 56 MW dual-train combined cycle units. The first of these combined cycle plants is to be added at Maalaea in three phases. The first phase is a 20 MW combustion turbine to be added in 1992. An additional 20 MW simple CT (phase 2) and a 16 MW steam turbine with two heat recovery boilers (phase 3) are scheduled for completion in 1993. Subsequent additions will be constructed in two equal phases of 28 MW by installing the steam turbine at the same time as the initial CT. These units may be located at a new power plant site.

MECO's system resource plan as of March, 1992 is summarized in Table II-17. This table contains projected peak demand, firm capacity, reserve margin, and projected capacity additions and retirements. The MECO system resource plan is summarized graphically in Figure II-18. Table II-18 contains a summary of estimated capacity cost and energy cost for each generation addition scheduled by MECO from 1990-2000.

Fuel Forecasts

Given recent ocean transportation problems associated with MSFO, diesel is the only power plant fuel which will be used by MECO in the foreseeable future. MECO's diesel forecast is equivalent to HECO's (Table II-16) except for slight modification to reflect additional transportation costs. The long-term fuel escalation rate inherent in Table II-16 is 6.8%, down from the almost 9% reflected in HECO's December, 1989 fuel forecast. In the spring of 1992, HECO has been using long-term diesel escalation rates of about 5%. All fuel shipped to Maui is received at Kahului. For 1991, ocean transportation cost was $.80 /BBL and storage was $.44/BBL. Fuel used at Maalaea incurs additional overland shipping charges. Shipping, storage, and trucking costs are expected to escalate at about 5% per year.

Table II-17. MECO System Resource Plan

Year	System Peak (MW)	System Capacity (MW)	Reserve Margin (%)	Capacity Modifications Unit	Retired (MW)	Added (MW)
1991	149	159.3	6.9	-	-	-
1992	162	179.3	10.7	Maalaea Unit 14	-	20
1993	171	199.3	16.5	Maalaea Unit 16	-	20
		215.3	25.9	Maalaea Unit 15	-	16
1994	179	215.3	20.3	-	-	-
1995	187	235.3	25.8	56MW DTCC #2 Ph 1	-	20
1996	194	232.6	19.9	Maalaea Unit 1	2.75	-
1997	200	252.6	26.3	56MW DTCC #2 Ph 2	-	20
		247.1	23.5	Maalaea Unit 2 & 3	5.5	-
1998	207	263.1	27.1	56MW DTCC #2 Ph 3	-	16
		257.2	24.2	Kahului Unit 1	5.9	-
1999	213	277.2	30.1	Combustion Turbine #3	-	20
		271.2	27.3	Kahului Unit 2	6	-
		255.2	19.8	HC&S 16MW Contract	16	-
2000	220	283.2	28.7	56MW DTCC #3 Ph 1	-	28
2001	228	283.2	24.2	-	-	-
2002	235	311.2	32.4	56MW DTCC #3 Ph 2	-	28
2003	243	298.8	23.0	Maalaea Units 4&5	12.32	-
2004	251	318.8	27.0	Combustions Turbine #4	-	20
		306.1	22.0	Kahului Unit 3	12.7	-
2005	259	334.1	29.0	56MW DTCC #4 Ph 1	-	28
		321.8	24.3	Maalaea Units 6&7	12.32	-
2006	268	321.8	20.1	-	-	-
2007	277	349.8	26.3	56MW DTCC #4 Ph 2	-	28
		343.6	24.1	Maalaea Unit 8	6.16	-
2008	286	337.5	18.0	Maalaea Unit 9	6.16	-
2009	295	357.5	21.2	Combustion Turbine #5	-	20
		343.7	16.5	Maalaea Unit 10	13.75	-
2010	305	371.7	21.9	56MW DTCC #5 Ph1	-	28
		358.0	17.4	Maalaea Unit 11	13.75	-
2011	315	386.0	22.5	56MW DTCC #5 Ph 2	-	28

Table II-18. Energy and Capacity Cost of Recent and Projected MECO Capacity Additions

	Year	Size (MW)	Unit Owner	Unit Type	Capacity Cost ($)	Energy Cost (¢/ gross kWh)
1)	1990	4	HC&S	Steam	167/kW-year (10 yrs)	5.670
	1991	20	MECO	Comb. Cycle #1, Ph. 1	1,094/kW	4.931
	1993	36	MECO	Comb. Cycle #1, Ph. 2&3	1,029/kW	3.704
	1996	28	MECO	Comb. Cycle #2, Ph. 1	1,464/kW	3.737
	1999	28	MECO	Comb. Cycle #2, Ph. 2	675/kW	3.704
	2000	28	MECO	Comb. Cycle #3, Ph. 1	1,464/kW	3.737

Note: (1) Capacity cost based on 12 MW.

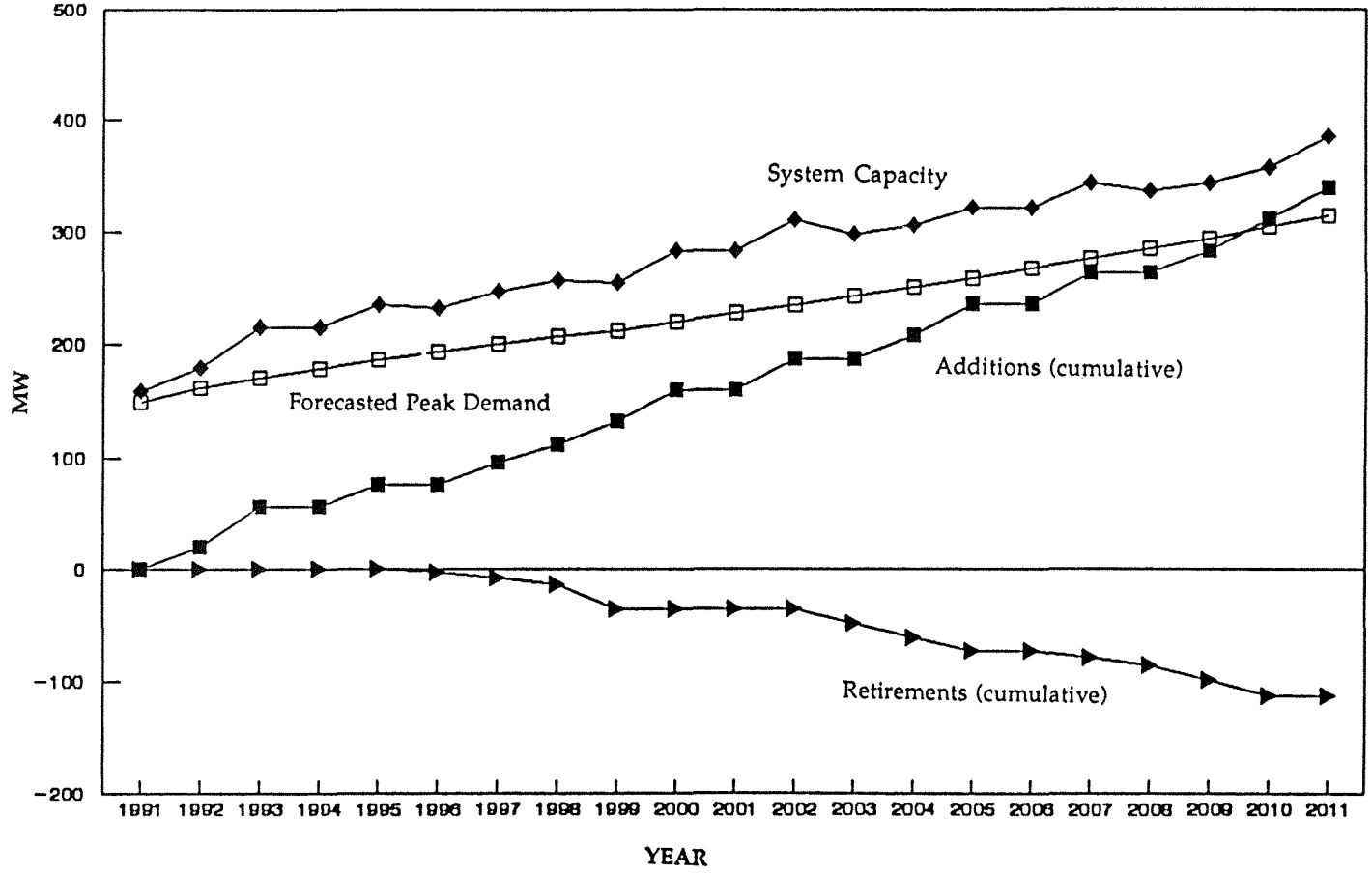


Figure II-19. Maui Electric Company (MECO) Resource Plan Summary (March 31, 1992)

HAWAII ELECTRIC LIGHT COMPANY (HELCO)

Projected Annual Load Growth

HELCO's peak electric demand is projected to increase by about 5% per year over the next several years, with an extreme increase of 7.2% predicted from 1992 to 1993. Long-term growth rate in peak demand is expected to stabilize at about 3.7% per year during the next decade. As has been the case in recent years, much of the load growth is expected to be located in the Kona coast-Kohala-Wiamea region.

Table II-19. HELCO System Resource Plan

Year	System Peak (MW)	System Capacity (MW)	Reserve Margin (%)	Capacity Modifications Unit	Retired (MW)	Added (MW)
1991	145	161.80	10.8	-	-	-
1992	152	186.80	22.9	PGV Geothermal	-	25.00
		206.80	36.1	Puna CT-3	-	20.00
		197.80	30.1	Kanoelehua CT-1	9	-
1993	163	197.00	20.9	Waimea D-8	0.80	-
		196.10	20.3	Waimea D-9	0.90	-
		195.10	19.7	Waimea D-10	1.00	-
1994	171	215.10	25.8	CT-4	-	20.00
1995	180	211.70	17.6	Shipman 1	3.40	-
		209.70	16.5	Kanoelehua D-11	2.00	-
		206.95	15.0	Waimea D-12	2.27	-
1996	186	226.95	22.0	CT-5	-	20.00
1997	194	215.95	11.3	Waimea D-13, 14 & Kanoelehua D-15, 16	11.00	-
1998	202	231.95	14.8	Convert CT-4 & CT-5 to Combined-cycle-1	-	16
		229.20	13.5	Kanoelehua D-17	2.75	-
1999	209	249.20	19.2	CT-6	-	20.00
		243.70	16.6	Keahole D-18, 19	5.50	-
2000	215	271.70	26.4	Combined-cycle 2 ph 1	-	28.00
		260.70	21.3	Keahole D-20, 21, 22, 23	11.00	-
2001	226	260.70	15.4	-	-	-
2002	234	288.70	23.4	Combined-cycle 2 Ph2	-	28.00
2003	243	288.70	18.8	-	-	-
2004	253	288.70	14.1	-	-	-
2005	262	316.70	20.9	Combined-cycle 3 Ph1	-	28.00
		309.20	18.0	Shipman 3	7.50	-
2006	272	337.20	24.0	Combined-cycle 3 Ph2	-	28.00
2007	283	337.20	19.2	-	-	-
2008	293	329.50	12.5	Shipman 4	7.70	-
2009	304	349.50	15.0	CT-7	-	20.00
2010	316	377.50	19.5	Combined-cycle 4 Ph1	-	28.00
2011	325	377.50	16.2	-	-	-

Proposed Generation Capacity Additions

HELCO's recent supply shortages are in part due to the unavailability of the Puna Geothermal Venture (PGV). The original purchase power agreements contracted for 7.5 MW of geothermal power in 1990, and an additional 17.5 MW in 1991. As of July 1992, this facility was still not on line. The relative success of the PGV operation should provide some indication of the capability of geothermal energy to supply a large share of Hawaii's future electrical needs. During 1992, HELCO also plans to install a 20 MW combustion turbine at Puna to serve as a peaking unit and emergency unit.

Scheduled generation additions after 1992 are 56 MW dual-train combined cycle units. The initial phase of this program is a 20 MW combustion turbine to be installed at Kawaihae in 1994. In 1996, another 20 MW combustion turbine will be added. When additional capacity is expected to be needed in 1998, a heat recovery boiler and a 16 MW steam turbo-generator will be installed in conjunction with the existing Kawaihae CT's. Thereafter, several dual-train combined cycle units, installed in 20-28 MW increments, are envisioned between 1999 and 2011.

HELCO's system resource plan as of March, 1992 is summarized in Table II-19. This table contains projected peak demand, firm capacity, reserve margin, and projected capacity additions and retirements. The HELCO system resource plan is summarized graphically in Figure II-20. Table II-20 contains a summary of estimated capacity cost and energy cost for each generation addition scheduled by HELCO from 1990-2000.

Fuel Forecasts

Given recent ocean transportation problems associated with MSFO, diesel is the only petroleum fuel which will be used by HELCO in the foreseeable future. HELCO's diesel forecast is equivalent to HECO's (Table II-16) except for slight modification to reflect additional transportation costs. The long-term fuel escalation rate inherent in Table II-16 is 6.8%, although HECO has more recently used long-term diesel escalation rates of about 5%. All fuel shipped to the island of Hawaii is received at Hilo. For 1991, ocean transportation was $1.53/BBL and storage was $.45/BBL. Additional overland transportation costs to HELCO generation sites are estimated for the 1992 year as (additional $/BBL): Kanoelehua (.8682), Puna (.8682), Puu Anahulu (.8682), Waimea (1.447), Keahole (1.447). Shipping, storage, and trucking costs are expected to escalate at about 5% per year.

Table II-20. Energy and Capacity Cost of Recent and Projected HELCO Capacity Additions

	Year	Size (MW)	Unit Owner	Unit Type	Capacity Cost ($)	Energy Cost (¢/ gross kWh)
1)	1991	7.5	PGV	Geothermal	160/kW-year (35 yrs)	6.560
	1991	17.5	PGV	Geothermal	160/kW-year (35 yrs)	6.560
	1992	20	HELCO	Combustion Turbine 3	896/kW	5.024
	1994	20	HELCO	Combustion Turbine 4	937/kW	5.024
2)	1996	8	HELCO	Comb. Cycle Ph. 1	1464/kW	3.807
	1997	28	HELCO	Comb. Cycle Ph. 2	675/kW	3.775
	1999	28	HELCO	Comb. Cycle Ph. 1	1,464/kW	3.807

Notes:

(1) The 25 MW geothermal facility was originally expected to come line during 1990 and 1991; current expectations call for all 25 MW to come on line during 1992 .

(2) This unit involves the conversion of CT 4 into a combined cycle plant and is listed in HELCO's 1990 PUC filing as a 28 MW addition.

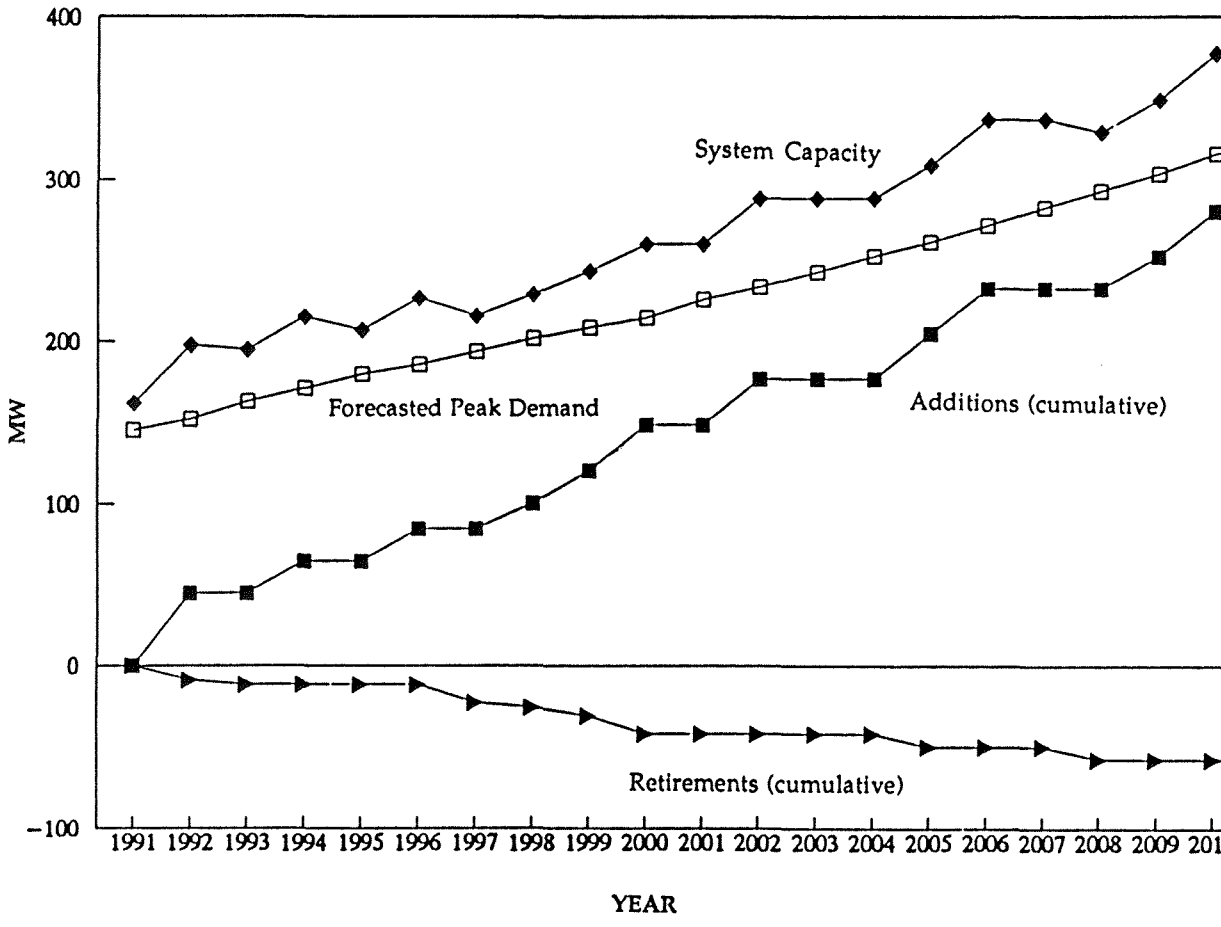


Figure II-20. Hawaiian Electric Light Company (HELCO) Resource Plan Summary (Mar. 31, 1992)

KAUAI ELECTRIC DIVISION OF CITIZENS UTILITIES COMPANY (KE)

Projected Annual Load Growth

Growth of Kauai Electric's system peak load is expected to average 4% per year over the next 19 years. Short-term annual growth rates are expected to be higher — between 5 to 7% over the next three years. KE's system is small enough that the addition of major resort developments is noticeably reflected in fluctuations in their load growth.

Proposed Generation Capacity Additions

Kauai Electric's system resource plan is summarized in Table II-21. This table contains projected peak demand, firm capacity, reserve margin, and projected capacity additions and retirements. Kauai Electric added two highly efficient 7.85 MW diesel engine units in 1991 at the Port Allen generating facility. Future additions of similar scale are expected in 1995, 1999, 2003, and 2007. Historically, KE has eagerly obtained purchase power contracts with any available sources. Future plans for non-firm purchase power contracts for hydroelectric power have been placed on hold indefinitely. Kauai Electric is developing an integrated resource plan per the plan framework provided by the State PUC. This plan will include both supply-side and demand-side options. For these reasons, specifics of KE's future generating additions have not yet been identified. It is noted that no capacity retirements are specified over the course of the 19 year projection. KE's maintenance policy is expected to keep their diesel units active through 2010.

Fuel Forecasts

The fuel costs included in Table II-22 were taken from the Chevron U.S.A. forecast of KE's 1988 long-term residual fuel forecast. The average annual cost escalation rate over the 15 year forecast (1988-2002) is 7.69%. KE's long-term escalation rate for diesel fuel is also 7.69%. Although this fuel forecast, which is several years old, includes MSFO, it is likely that all of KE's utility-owned capacity will burn diesel for the foreseeable future.

Table II-21. Kauai Electric System Resource Plan

Year	System Peak (MW)	System Capacity (MW)	Reserve Margin (%)	Capacity Modifications Unit	Retired (MW)	Added (MW)
1991	69.8	108.3	55.2			
1992	73.7	108.3	46.9	-	-	-
1993	78.7	108.3	37.6	-	-	-
1994	83.6	108.3	30.0	-	-	-
1995	87.6	123.9	41.4	additions	-	15.6
1996	91.5	123.9	35.4	-	-	-
1997	95.5	123.9	29.7	-	-	-
1998	99.4	123.9	24.6	-	-	-
1999	103.4	139.5	34.9	additions	-	15.6
2000	107.3	139.5	30.0	-	-	-
2001	111.3	139.5	25.3	-	-	-
2002	115.2	139.5	21.1	-	-	-
2003	118.2	155.1	31.2	additions	-	15.6
2004	123.1	155.1	26.0	-	-	-
2005	127.1	155.1	22.0	-	-	-
2006	131.0	155.1	18.4	-	-	-
2007	135.0	170.7	26.4	additions	-	15.6
2008	138.9	170.7	22.9	-	-	-
2009	142.9	170.7	19.5	-	-	-
2010	146.8	170.7	16.3	-	-	-

* system capacity total includes a 12 MW firm power contract with the Lihue Power Plant

Table II-22. Kauai Electric Fuel Cost Forecast (based on 1988 fuel forecast)

Year	MSFO ($/BBL)	Diesel ($/BBL)
1992	19.88	27.50
1993	21.33	29.62
1994	22.78	31.90
1995	24.24	34.35
1996	25.69	36.99
1997	27.14	39.84
1998	28.59	42.90
1999	30.05	46.20
2000	31.50	49.75
2001	33.92	53.58
2002	36.53	57.70

MECO, MOLOKAI ELECTRIC DIVISION (MOECO)

Projected Annual Load Growth

Long term growth of Molokai Electric's system peak load is expected to average 2.5% according to MOECO President John Urauchi. Growth is expected in southwestern Molokai due to the Alpha USA development. Projections for load growth and capacity additions reflect a high level of uncertainty due to MOECO's small system size and the significant impact of potential large load additions.

Proposed Generation Capacity Additions

MOECO is currently negotiating a purchase power contract for a 1 MW unit to be interconnected with their system during 1991 or 1992. Additional capacity will likely be required thereafter within a 2-5 year time interval.

MATCHING UTILITY NEEDS TO SEGS CHARACTERISTICS

Using the data presented above on utility plant capacities, needs and resource plans, tentative selections can be made for the capacities of SEGS plants which appear to be appropriate for each utility service territory. Consistent with the earlier discussions, utility needs and their relationship to SEGS characteristics will be discussed on an island-by-island basis.

Hawaiian Electric Company (HECO)

With the recent and pending base load capacity additions at the Campbell Industrial Complex (Kalaeloa Partners, Phase 1 & 2 at 180 MW in 1991, and AES at 180 MW by the end of 1992), HECO's capacity needs will be for cycling plants for some time into the future. Cycling combined cycle plants and simple cycle gas turbines are scheduled capacity additions for HECO during the next few decades. The 77 MW size planned for a number of these units suggests that an 80 MW SEGS would be a reasonable addition for the island of Oahu. Operationally, SEGS would be most similar to a combustion turbine. In the comparative economics presented below, the most appropriate comparison for HECO is between the 80 MW SEGS and the 70 MW combustion turbine.

Maui Electric Company (MECO)

MECO's resource plan identifies several 56 MW dual-train combined cycle plants and three 20 MW combustion turbines as the primary capacity additions to be installed over the next two decades. These proposed additions suggest an appropriate sizing for a SEGS unit of 30 MWe. At this size, the SEGS unit would represent approximately 12% of the MECO system in 1997. In the comparative economics presented below, the most appropriate comparisons for MECO are between the 30 MW SEGS and the 20 MW combustion turbines.

Hawaii Electric Light Company (HELCO)

The delay in bringing the Puna geothermal units on line has placed HELCO in a severe capacity crunch which has, at times, made it necessary to cut load. This urgent need is being met by the installation of a 20 MW combustion turbine at Puna. Additional plans include provision for 20 MW combustion turbines with possible conversion to combined cycle in west Hawaii during the mid-1990's. These proposed additions suggest an appropriate sizing for a SEGS unit of 30 MWe. At this size, the SEGS unit would represent approximately 14% of the HELCO system (mid-1990's). In the comparative economics presented below, the most appropriate comparisons for HELCO are between the 30 MW SEGS and the 20 MW combustion turbines.

Kauai Electric Division of Citizens Utilities Company (KE)

Kauai Electric has a peak demand that is slightly more than half the magnitude of the peak demands of MECO and HELCO. As a result of its smaller size, the size of the unit additions to the KE grid have been considerably smaller. Among KE's system planning criteria is a stipulation that adequacy of supply be maintained even with the outage of the utility's largest generating unit. Accordingly, KE has no plans to add generation in increments larger than the largest unit on their system, 23.7 MWe. In fact, all planned additions consist of 7.85 MW diesels with the next installation planned for the 1995 time frame. This suggests an appropriate sizing for a SEGS unit of 15 MWe. At this size, the SEGS unit would represent approximately 12% of the KE system (mid-1990's). In lieu of cost data for KE's diesel units, the most appropriate comparisons for KE in the material below are between the 15 MW SEGS and the 20 MW combustion turbines.

Molokai-Cable

With a peak demand of less than 6 MW, the Molokai Electric Division of MECO is clearly too small to seriously consider using SEGS technology on a commercial scale. However, in conjunction with suitable underwater electric transmission to either Maui or Oahu, a very large SEGS plant on Molokai could prove feasible. In such a scenario, a portion of the capacity of the plant could be used to service local needs on Molokai. If considered in conjunction with an underwater electric transmission project, 80 MWe and 200 MWe are reasonable sizes for SEGS facilities on Molokai.

CONCLUSIONS

The purpose of this portion of the SEGS assessment has been to evaluate the applicability of SEGS plants in the context of utilities' needs. Through an examination of the current and planned structure of the electric utilities in Hawaii, with respect to their potential use of SEGS technology, we reach the following conclusions:

- SEGS plant capacities from 15 MWe to 30 MWe are suitable for the majority of the islands in Hawaii. SEGS plant capacities up to 80 MWe are appropriate for Oahu. In conjunction with undersea electric transmission, SEGS plant capacities up to 200 MWe may be feasible on Molokai.

- The seasonal and diurnal peaks that characterize the utilities' demand curves, while not perfectly matched to SEGS's solar output, are nevertheless compatible with the output of a SEGS plant using fossil-fueled backup. The exact amount of fossil fuel supplement will depend on generation dispatch economics for each of the islands.

III. SEGS DESIGN DESCRIPTION

GENERAL DESCRIPTION

Solar Electric Generating System (SEGS) Concept

The basic concept of the SEGS plants is to supply thermal energy via the solar field to produce steam to drive a "Rankine cycle" steam turbine, which in turn drives an electric generator to produce power. A Rankine cycle, which is a particular type of thermodynamic power cycle, is used in all conventional coal, oil-fired or gas-fired steam plants. A very important characteristic of the Rankine cycle is that its power conversion efficiency increases significantly with an increase in the temperature and pressure of the steam supplied to the steam turbine. Thus it is advantageous to supply steam to the power cycle at the highest pressure and temperature possible given the energy source, piping systems, and other plant equipment and support systems.

Starting in 1984, solar parabolic trough technology was matched with this power cycle at SEGS I, the first large solar thermal electric commercial power facility. This and later SEGS plants were developed by Luz International, a company engaged in the design, development, financing and marketing of solar energy technology systems used in the generation of electricity. From 1984 through 1990, Luz developed nine facilities for a total of 354 MW_e on-line power. Each facility was developed as an independent power producer which sold power to the local utility -- in all cases Southern California Edison Company (SCE) --under terms of a power sales agreement between the owners of the plants and the utility. The owners of the plants are investor groups typically composed of large corporations, insurance firms, utility investment arms and some individual participants. The role of Luz was to develop the projects from inception to operating plants, and to run the plants under separate contracts to the owners. The Luz company failed in 1991 prior to the planned development of the SEGS X plant.

Since the inception of SEGS I, advancements in the mechanical structure and operating parameters of the Luz solar collector technology resulted in a steady increase in the outlet temperature of the solar field, from 585°F in the first generation LS-1 collector design to 660°F in the second generation LS-2 used in SEGS III-V. Further advances, notably the introduction of a sputtered cermet selective coating on the heat collection element (HCE), further increased solar field outlet temperatures to close to 750°F in SEGS VII-IX. This temperature increase led to better steam turbine inlet conditions and higher power block performance.

Operating Plants

The nine SEGS plants, independently owned by limited partnerships, continue to operate in the Mojave Desert region of Southern California despite the demise of Luz. The first plant has 13.8 MW_e net capacity, the succeeding six plants 30 MW_e net capacity and the final two plants are larger at 80 MW_e capacity. Each plant is operated by its owners to optimize plant revenues. Since SCE has time-of-use electricity rates, it is desirable that high electrical output be delivered to the grid during the utility on-peak hours when electricity revenues are highest. This is partially accomplished with the aid of a natural gas oil heater which can either supplement the solar field or operate independently. The energy supplied by natural gas is limited to 25% of the total effective annual plant energy input by regulations of the U.S. Federal Energy Regulatory Commission. The historical capacity additions of the SEGS installations as well as a summary of electrical output and revenues through 1991 are illustrated in Figure III-1.

The basic characteristics of the nine operating plants (SEGS I-IX) are given in Table III-1. The first two plants are located at Daggett, California, about 110 miles northeast of Los Angeles. The next five plants are located at Kramer Junction, California, about 40 miles west of the Daggett site. The two 80 MW_e

plants are at Harper Lake, between the previous sites. The annual average solar radiation experienced in this region is close to the highest found in the mainland U.S.

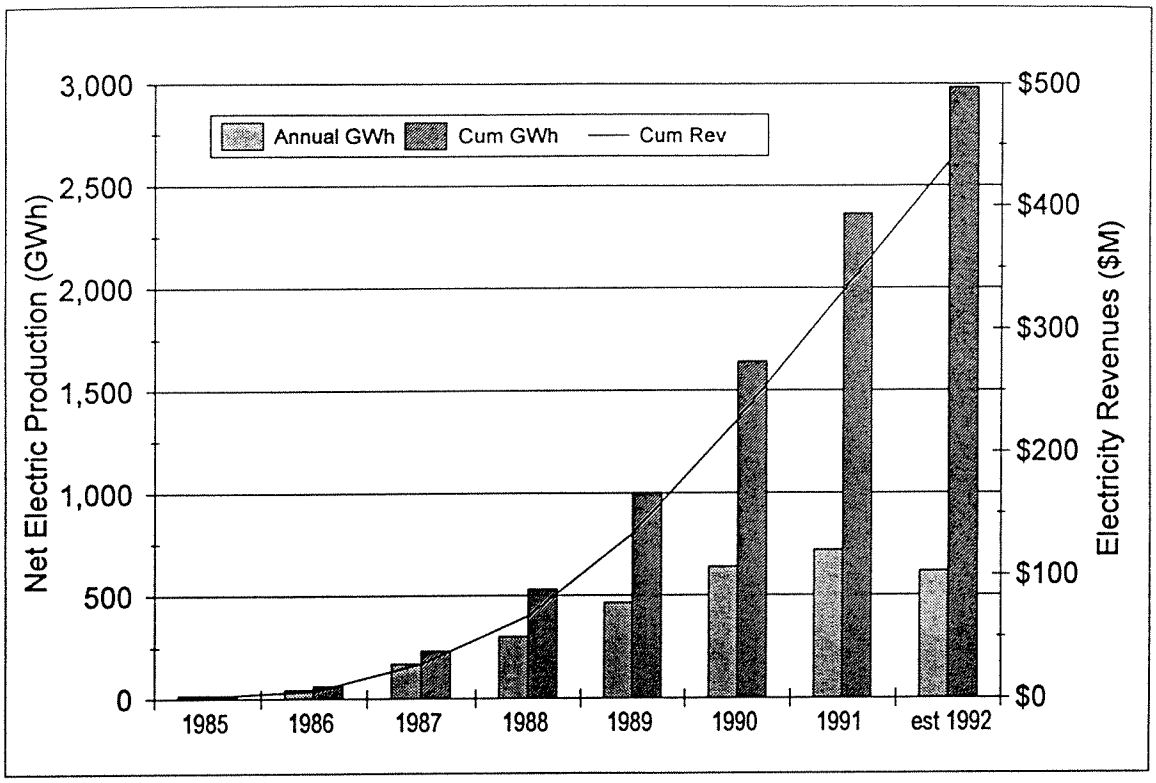
While all the plants are in normal daily operation, the absence of the Luz group does affect the facilities. Up to 1991, Luz Engineering Corporation carried out the routine operation and maintenance O&M functions at each plant under separate contract to each owner group. In late 1991 and early 1992, this responsibility was assumed by three O&M companies set up by the owners at each of the three sites. Since Luz was the supplier of the solar field, spare parts for non-standard components of the solar field are not available and the owners have had to evaluate alternative sources.

The design levels of annual electrical output can be seen in Table III-1. Plant performance projections are derived from an hour-by-hour performance model that was developed by Luz and has been in use since SEGS III. The model utilizes published insolation data and takes into account all of the significant factors influencing the solar field and turbine performance. To illustrate the actual measured performance of the plants, Figure III-2 shows data on direct normal insolation at the site as well as normalized solar field availability and plant capacity factor. These results are for the plants in operation during the year of interest. *Solar field availability* is the annual average fraction of the solar field able to track the sun if desired; *capacity factor* is the ratio of annual electrical output to the maximum possible output were the plants run at full load for every hour of the year. The significant decrease in insolation and capacity factor in 1990 and beyond is due to the weather effects of the El Nino phenomenon and the upper atmospheric effects of the Mt. Pinatubo volcanic eruption in 1991. The influence of decreasing spare parts availability in also beginning to become apparent in 1992.

Maintenance needs include the normal component failures and repair requirements of any operating power plant as well as the unique requirements of the solar fields. Over the years of development and operation, much has been learned about SEGS solar field maintenance and, other than the spare parts problems mentioned earlier, the operation of these systems has matured into a routine pattern.

Table III-1. Summary Characteristics of the SEGS Plants

Plant	1st Year Operation	MWe net	SF Temp. (°C)	SF Area (m^2)	Turbine Effic. (%) Solar	Turbine Effic.(%) Nat. Gas	Annual Output (MWh)
I	1985	13.8	307	82960	31.5	--	30100
II	1986	30	316	190338	29.4	37.3	80500
III/IV	1987	30	349	230300	30.6	37.4	92780
V	1988	30	349	250560	30.6	37.4	91820
VI	1989	30	399	188000	37.5	39.5	90850
VII	1989	30	399	194280	37.5	39.5	92646
VIII	1990	80	399	464340	37.6	37.6	252750
IX	1991	80	399	483960	37.6	37.6	256125



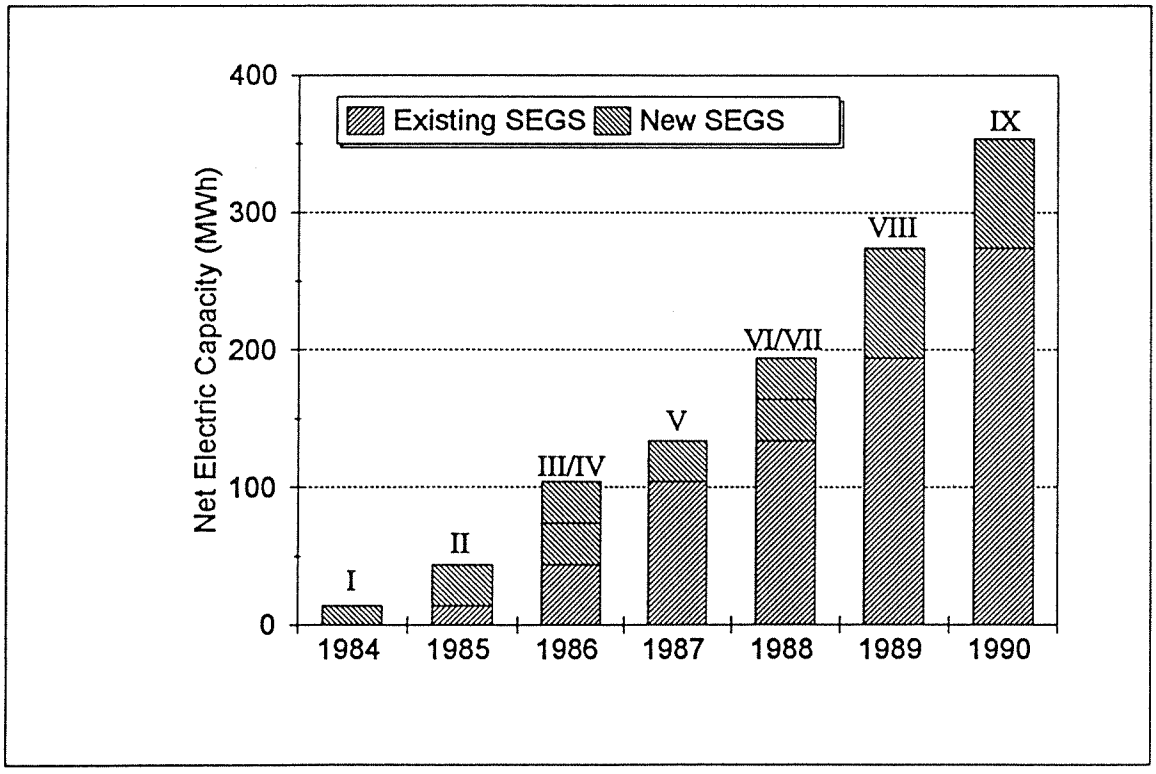


Fig. III-1. Capacity, Electrical Output and Revenue History of the SEGS Plants

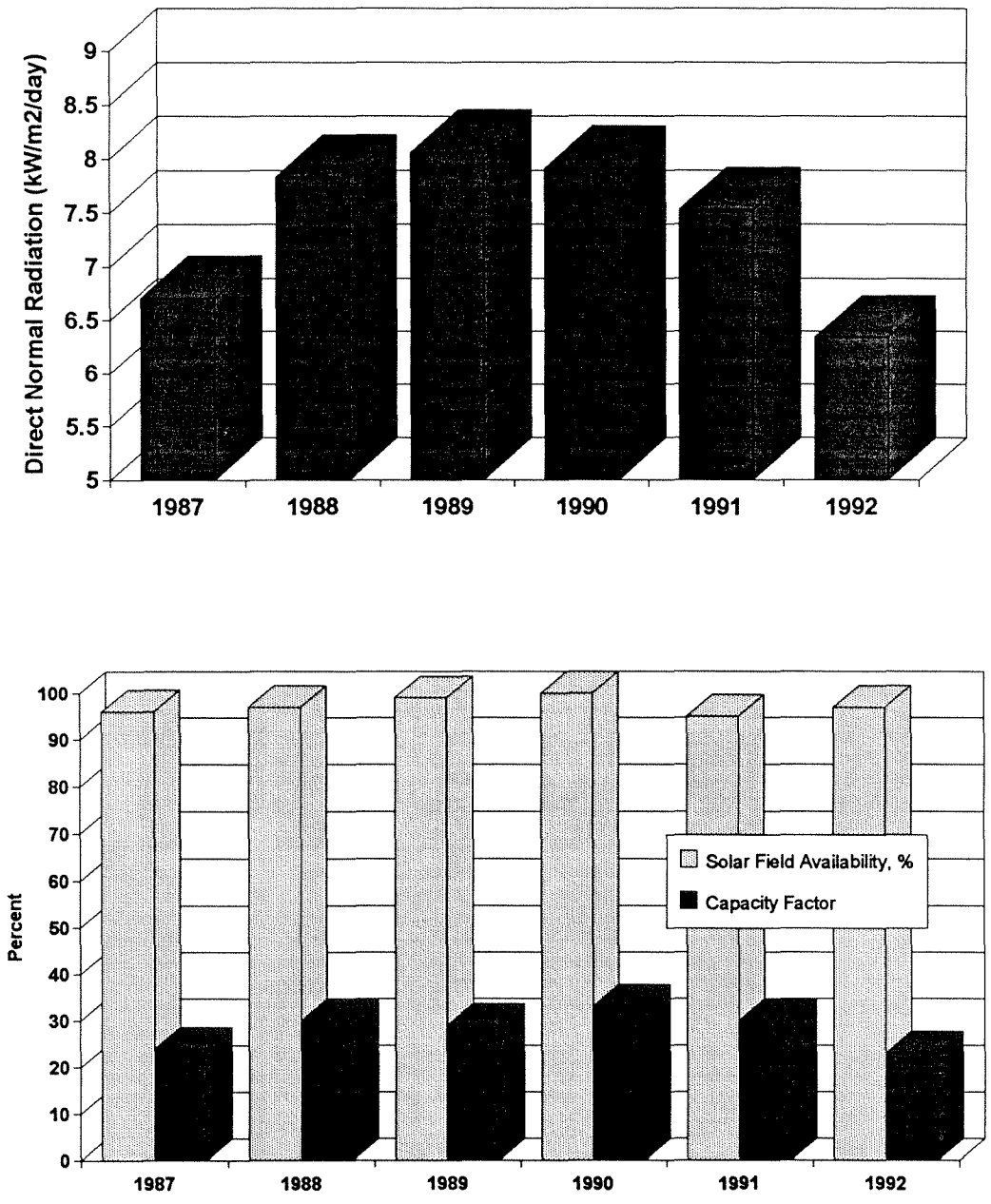


Fig. III-2. Annual Performance of the SEGS III-VIII Group for 1987-1992

DESIGN ASPECTS OF A SEGS PLANT

Introduction

SEGS plants situated in different Hawaiian sites could range in capacity from 15 MW_e to over 80 MW_e depending on utility needs, site conditions and the existence of an inter-island undersea transmission cable. These points are discussed in sections II and IV on utility needs and siting. Specific sites would impose differing needs for civil engineering requirements (grading, foundations, flood control) as well as other site-related design issues related to water supply, water waste handling, electrical interconnect to the local transmission system, and solar field sizing. The major features of an Hawaiian SEGS plant, however, are not site-dependent, other than plant capacity. The configuration of the power block, the design of the solar field collectors, and the method of operation would be essentially identical.

System Design

For purposes of this report, we will assume a plant capacity of 80 MWe. The reference Hawaiian SEGS power plant concept is comprised of the solar field, power block, plant services (water supply system, fossil fuel supply, power transmission lines), and water treatment system. The plant will require a land area of approximately 500 acres for the solar field, power block, and balance of plant equipment. Maximum solar energy delivery with parabolic troughs is obtained with the axes of the solar collector assemblies oriented in the north-south direction, although other orientation are possible and may be required due to the terrain of a specific site. The power block and balance of plant are located near the center of the solar field and cover an area of about three acres. In this area would be all the major mechanical and electrical equipment subsystems required for power production.

A process flow diagram of the system is shown in Fig. III-3. The solar field is an advanced Luz solar system incorporating line-focus parabolic trough collectors, illustrated in Fig. III-4, that collect and focus sunlight onto vacuum-insulated steel pipes. A heat transfer fluid (HTF) is circulated through the solar field where it is heated and supplied through a main header to the solar heat exchangers located in the power block. The solar-heated HTF generates superheated steam in two sets of heat exchangers (each set with 50% of the total capacity). The superheated steam is then fed to the high-pressure (HP) casing of a conventional steam reheat turbine. The steam is reheated in two solar reheaters before being fed to the low-pressure (LP) casing. The spent steam from the turbine is condensed in a standard condenser and returned to the heat exchangers via condensate and feedwater pumps to be transformed back into steam. After passing through the HTF side of the solar heat exchangers, the cooled HTF is then recirculated through the solar field to repeat the process.

The Luz system is built up from solar collector assemblies (SCAs), each consisting of a row of individual trough collectors driven by a single drive train. The mirrored parabolic troughs concentrate direct beam radiation onto a heat collection element (HCE), which is a steel pipe having a special selective coating surrounded by an evacuated annulus to enhance performance. An advanced local microprocessor controller, in conjunction with a sun sensor, tracks the sun and keeps the collectors focused during periods of sufficient insolation.

The SCAs are arranged in a large array typically consisting of parallel rows with three units per row. The row-to-row spacing is optimized to minimize piping costs and row-to-row shadowing in the morning and evening hours. The temperature of the HTF through the solar field increases from 559^{o}F at the inlet to an outlet of 735^{o}F. Both the solar field piping and the HTF expansion tank are suitably insulated to minimize thermal losses. The thickness of the insulation and the diameter of the piping has been selected to reach a balance between surface area heat loss, parasitic pumping power, and overnight heat losses from the volume of HTF remaining in the field piping.

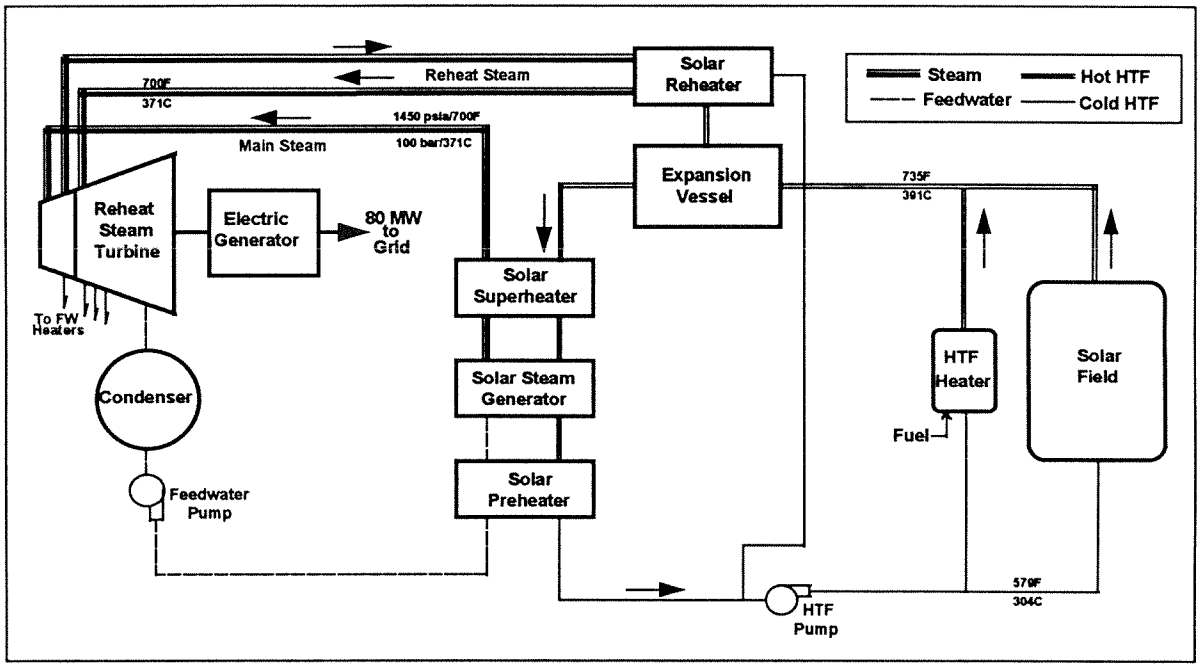


Fig. III-2. Process Flow Diagram of Latest SEGS Design Configuration

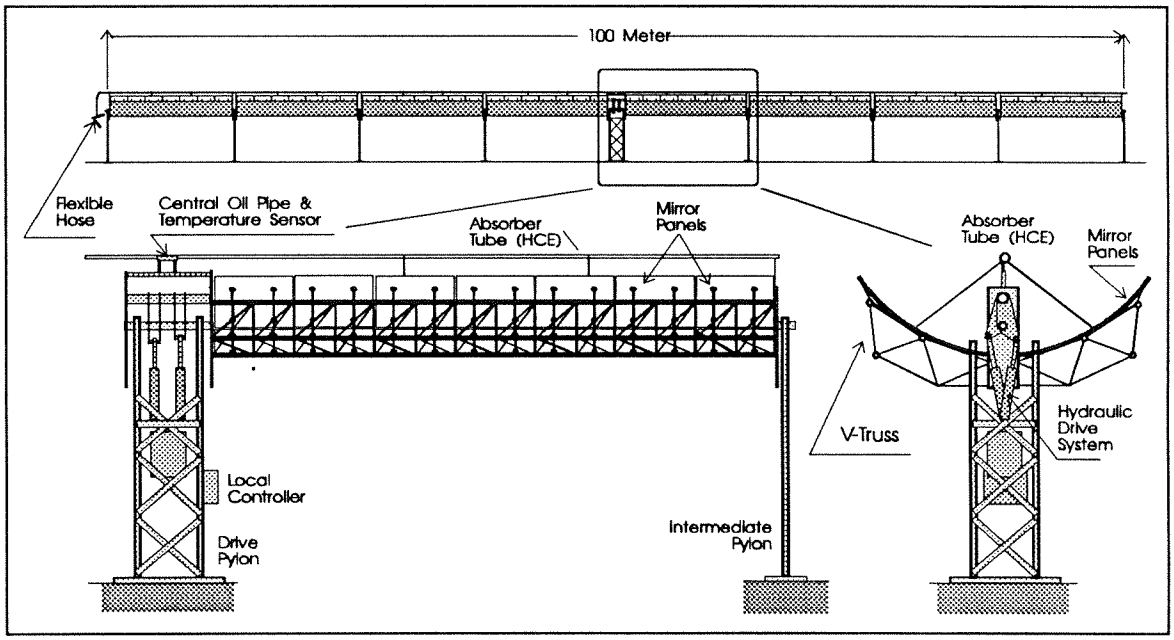


Fig. III-3. LS-3 Solar Collector Assembly

An auxiliary diesel-oil fired HTF heater supplies an alternate source of energy to produce turbine inlet steam. This allows the production of electricity in evening hours or daytime hours with low insolation, if called for by the plant operating strategy.

The spent steam is condensed by the cooling system, which includes a shell-and-tube condenser and a cooling tower. A control building houses a central microprocessor that monitors and controls plant operations. During reduced insolation conditions, the solar field and HTF heater can operate in parallel to provide electrical generation. Electrical power output from the plant is supplied to the local transmission line from an on-site switchyard.

Major Equipment And Systems

The following paragraphs describe the major components and subsystems of the plant.

Solar Field

Solar Collector Assembly

The basic component of the solar field is the Solar Collector Assembly (SCA). The parabolic trough solar collector is a mirrored glass reflector which focuses direct radiation on an efficient evacuated receiver, or heat collection element (HCE). The Luz-designed solar field is based on three generations of solar collector technology. A total collecting surface of 2.2 million square meters are currently in operation. The primary components of an SCA are the line concentrating device or reflector (made up of mirrored glass); the metal support structure; the heat collection element, or receiver; and the tracking system (drive, sensors, controls). The full solar field, consisting of a number of SCAs, is controlled by the Field Supervisory Control (FSC) system.

Table III-2 shows the evolving characteristics of the three SCA designs. The control system and heat collection elements are virtually identical in the latter designs, with the significant changes being in the reflector aperture area, structural design and drive systems.

Table III-2. Characteristics of LUZ Parabolic Trough SCAs

	LS-1	LS-2	LS-3
SCA			
Aperture Area (m^2)	128	235	545
Aperture (m)	2.55	5.0	5.76
Length (m)	50.2	47.1	95.2
Concentration ratio	61	71	82
Optical Efficiency	0.734	0.737	0.80
SCAs in Service	1096	4670	1956
Heat Collection Element			
Diameter (m)	0.042	0.070	0.070
Length (m)	3	4	4
HCE's per SCA	16	12	24
Selective Surface	BC	BC	Cermet
Transmittance	.95	.95	.95
Absorptance	.95	.95	.96
Emittance	0.30	0.24	0.19
at Temperature (°C)	300	300	350

Reflector Panels

The reflector is made up of hot-formed mirrored glass panels, supported by the truss system which gives the SCA its structural integrity. The aperture, or width, of the parabolic reflectors is 5.76 meters and the overall SCA length is 95.2 meters (net glass).

The glass itself is produced by the standard float-glass method, in which molten glass is conveyed onto a bath of molten metal, such as tin. The high temperature of the molten metal smoothes out any irregularities on the surface, making a flat, even sheet. As the glass floats on top of the bath, the temperature of the molten metal is gradually reduced until the glass solidifies. The glass used for solar applications (and car rear view mirrors) has an especially low iron content to maximize the transmissivity of solar radiation as it passes through the glass. (The iron content is 0.015% maximum, compared to 0.13% in normal glass, giving a transmissivity of 98%.)

After being cut to the proper sizes, the float-glass is silvered on the back, and four protective coatings - one copper and three lacquer - are added. The final protective lacquer also covers the edges of the glass. The glass panels are conveyed on very accurate parabolic molds through a long, gas-fired oven, allowing the glass to sag into the parabolic shape. Finally, ceramic pads (previously metal pads) for attachment to the collector structure are installed with a special adhesive. The precision shape of selected glass panels is tested for accuracy with a laser test device.

There are 224 reflector panels in each SCA, each panel 3.2 mm thick and an average 2.24 sq. meters in area. The reflectors are designed with a concentration ratio of 82. The quality and accuracy of the panels yield a reflectivity of 94%, with 97% of the reflected rays being incident on the HCE.

Heat Collection Element

The HCE consists of a 70 mm steel tube with a cermet selective surface, surrounded by an evacuated glass tube, as illustrated in Figure III-5. The HCE incorporates glass-to-metal seals and metal bellows to achieve the vacuum-tight enclosure. The vacuum enclosure serves primarily to protect the selective surface and to reduce heat losses at the high SEGS operating temperatures; the vacuum level is about 10-4 torr (a torr is a unit of pressure equal to approximately 1 mm Hg or 1/760 bar). The cermet selective surface has an absorptivity of 0.96 for direct beam solar radiation, and a design emissivity of 0.19 at 350°C. The outer glass cylinder has anti-reflective coating on both surfaces. Getters (metallic substances which are designed to absorb gas molecules) are installed in the vacuum space to absorb hydrogen and other gases which have been released into the vacuum annulus over time. Luz Industries Israel has developed a modern, high quality manufacturing plant to produce this component.

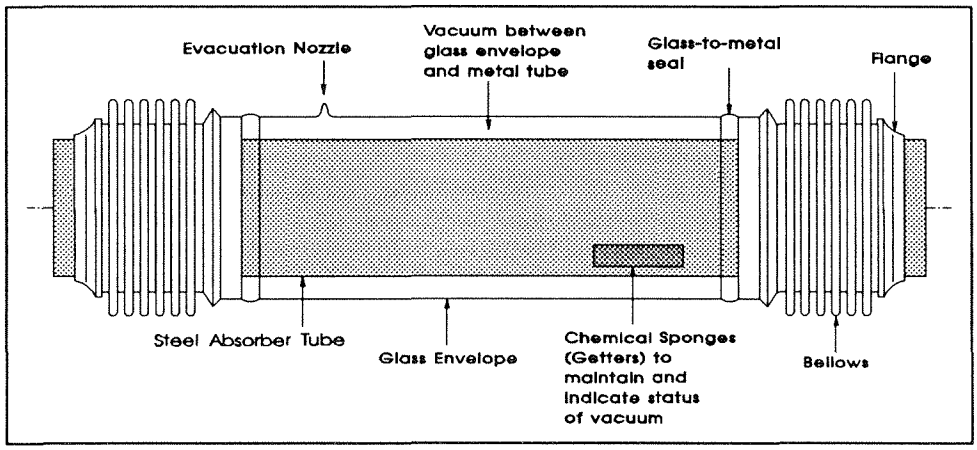


Fig. III-5. Heat Collection Element

The Luz cermet surface consists of a ceramic material and a refractory metal, and is continuously graded from a predetermined ratio of the two components at the metallic tube surface to pure ceramic at the outside surface. The total thickness of the coating is approximately 1/3 micron (1 micron = 10^{-6} meters), or 3500 Angstroms.

The cermet coating is applied to the steel absorber tube by sputtering, which is a widely-used process for applying thin coatings. Sputtering is a vacuum deposition technique in which a coating is deposited by ion bombardment of a surface. The ions are energized by a high electric field created by a cathode/anode configuration, with the cathodes excited either by a simple DC voltage or by an RF (radio frequency) field. The process takes place in a vacuum of 10^{-2} torr, with a background gas of inert argon. In general, the substrate (surface being coated) can be cooled or heated, depending on the desired properties of the coating.

Sputtered cermet selective surfaces are known for their high temperature stability (very stable at temperatures above 1000°F), and for their excellent durability and long lifetime under high solar radiation flux levels. The coating on the heat collection element is in fact made up of four layers, namely, an anti-diffusion layer, an IR reflective layer (for the very low emissivity), the cermet layer, and an anti-reflective coating (AR layer).

In operation, the metal bellows shown in Fig. III-5 take up the difference in thermal expansion between the hot absorber tube and the cool outer glass tubular envelope as the HCE heats from standby temperature (in the morning before solar field startup) to operating temperature. The bellows is welded to the absorber tube on one side and to the glass by a glass-to-metal seal on the other. The integrity of both of these sealing welds has proven to be excellent in actual field operation.

Tracking System

A closed loop tracking system relies on a sun sensor for the precise alignment required to focus the sun on the HCE in operation, and sends commands to a hydraulic drive system to position the SCA. The SCA can move from the maximum stow position (-30° below the sunrise horizon) to a few degrees above the sunset horizon. Normal stow position is -30° to minimize wind loads. Overall positioning accuracy is about ± 0.1 degree.

Tracking of each SCA is controlled by the local controller (LOC), which is a powerful microprocessor that includes two printed circuit boards used, respectively, for primary control and communications, and for motor control. The LOC performs its task working in conjunction with the sun sensor, position indicator and motor-drive unit. It also monitors the temperature of the heat transfer fluid in the SCA via a temperature sensor, and performs important functions with respect to operating condition alarms, maintenance diagnostics and communication with the FSC.

The sun sensor utilizes a unique convex lens which focuses light on two light-sensitive diodes separated by a narrow non-sensitive strip. Resolution is about 0.05°. The sun sensor has proven its tracking ability in actual operation, and is unaffected by clouds, hazy weather or dirt accumulating on the lens. A position indicator is used to give the position of the SCA about its axis, but this is primarily required for initial morning orientation of the SCA until the sun sensor acquires the sun. The potentiometer (or equivalent) is mounted on the axis of the drive system, giving an overall resolution of 0.3° over the entire range of 210°.

The LS-3 drive system must deliver the torque required to move the SCA in windy conditions. In the LS-3 design, a hydraulic power unit moves two cylinders. Control of these cylinders is exercised by two selectors or valves (one for each cylinder) which determine the direction of motion for each cylinder. The power unit consists of a hydraulic pump, 3/4 HP-230 VAC-60 HZ motor, pressure reducer and the two selectors. The cylinders rotate the SCA in a direction controlled by the selectors according to commands from the LOC. The cylinder is locked between motion commands by an over-center device. Cylinders are

either 55 mm or 70 mm in diameter, depending on SCA location, with a stroke length of 700 mm. The hydraulic power unit is located within the pylon structure. During tracking, the motor operates the pump for 1 second nominally on a 10 second interval. The pump builds up the hydraulic pressure in the cylinders, according to selector position, in a controlled fashion; that is, instantaneous full loading is impossible.

The reflector panel structure and drive system are designed for normal operation and accuracy in winds up to 20 mph, and at a somewhat reduced accuracy in winds up to 45 mph. However, for safety reasons the field is stowed when average wind speeds are above 35 mph. At night, during high winds, or during other times when the solar field is not operating the SCAs are stowed in a face-down position at -30° for protection. The SCAs are designed to withstand a maximum wind velocity of 70 mph while in the stow position.

SCA Structure

The LS-3 collector is slightly over twice as long as the earlier LS-2 collector, with a 14% larger reflector aperture width. However, more than just an increase in scale, the LS-3 design reflects a fundamental change in design philosophy. While the LS-2 mechanical components were designed to high tolerances and erected in place in order to obtain the required optical performance, the LS-3 assembly is a central truss which is built up in a jig and aligned precisely before being lifted into place for final assembly. The result is a structure that is both stronger and lighter, in which the torque tube of the LS-2 has been replaced by parallel triangular truss members to which the reflector support arms are attached. This configuration provides the torsional strength for accurate tracking and for stowing against wind loads.

The heart of the structure is a pair of two V-trusses formed into an assembly by two end truss plates. Attached to the V-trusses are reflector support arms to which the reflector panels are fastened. Assembly of the trusses is carefully monitored for quality, ensuring that the initial focus of the assembly meets specifications for accuracy.

Field Control System

In the current plants, the solar field control system consists of a field supervisory controller (FSC) located in the central control building and local microprocessor controllers (LOC) located on each SCA. The FSC, a powerful microcomputer, monitors insolation, wind velocity, and HTF pump/flow status, and communicates with all of the LOCs. When the appropriate conditions exist, the FSC initiates the commands to send the SCAs to track the sun, and at the end of the day stows the solar field. If major alarm conditions occur during operation, the FSC or LOCs automatically take action to protect the solar field equipment. From the FSC the operators can monitor the status of the SCAs in the solar field. Once the FSC sends a command to the solar field, the LOCs take over and control the actions of the individual SCAs. The LOC utilizes the positioning system components to accurately focus the SCA.

Heat Transfer Fluid (HTF) System

System Design

The HTF system is the closed loop through which the Heat Transfer Fluid, a synthetic diphenyl/biphenyl oxide oil, flows at a nominal rate of 8 million pounds per hour. The loop begins at the HTF expansion vessel, which allows thermal expansion of the HTF. A nitrogen service unit maintains a 165 psia inert atmosphere above the fluid level in the expansion vessel. HTF degradation gases are removed from the expansion vessel through the ullage venting system. The HTF pumps draw fluid from the expansion vessel for circulation to the cold headers in the solar field. The cold header feeds, in parallel, flow loops of 6 SCAs each. Valves at the inlet to each loop are used to balance the flow through the loops.

After being heated to 735°F in the solar field, the HTF is transported via the hot headers to two parallel trains of 50% full-load capacity heat exchangers. The HTF flows counter-current to the feedwater flow of the turbine steam-water system, which also passes through the heat exchangers. First the HTF passes through a heat exchanger that superheats the inlet steam to the turbine. The HTF then flows through a steam generator and a preheater, respectively generating saturated steam and preheating the feedwater to the steam generator. In parallel with these trains of heat exchangers, a portion of the HTF flows to two heat exchangers that reheat the steam that is flowing from the high-pressure to the low-pressure stage of the turbine. The HTF temperature drops from 735°F to 559°F as its energy is transferred to the steam cycle in the heat exchangers.

The HTF flow can bypass the heat exchangers through a bypass line. The bypass is used during warm-up operation until the solar field heats the HTF to a temperature sufficient to generate turbine steam. The bypass also opens after a turbine trip when in solar mode in order to shut off the supply of turbine steam. The HTF flows from the heat exchangers to the expansion vessel to repeat the cycle.

HTF Pumps

The HTF is circulated by two 50%-full flow variable-speed centrifugal pumps operating in series or individually to provide flow at any desired flow rate. (A third standby 50% variable-speed pump provides backup capacity, with a maximum of two pumps in series). The design full-load HTF flow is 19,600 gallons per minute at 559°F, at a head of 318 psi. The pumps are driven by a 4160V variable frequency drive (VFD) with a combined rating of 6000 hp. The VFD is used on all pumps to control the HTF flow to maintain a constant HTF temperature of 735°F at the exit of the solar field.

Auxiliary HTF Heater

The energy provided by the solar system is normally collected during each day of adequate solar conditions. During periods of low insolation and in non-daylight periods when electrical generation is planned, a supplemental fossil-fired HTF heater can be operated to provide energy to produce turbine steam. In the earlier SEGS plants, a fossil-fired boiler was used to supply supplemental steam. In the later plants, the full heater system consists of four separate 25% capacity units. The heater system also supplies heat to the HTF system at part load or to prevent HTF freezing during cold conditions.

Power Block And Balance-of-Plant

Figure III-6 gives the expected layout of the power block and BOP equipment for the SEGS plant. Brief descriptions of the major equipment follow.

Steam Generation Equipment

The steam generation system includes two superheaters rated at 393,257 pounds per hour each at 705°F superheated steam with 1,500 psia nominal outlet pressure, and two steam generators rated at 393,257 pounds per hour each at 597°F saturated steam at 1,504 psia. Hot HTF heated to 735°F by insolation is used to produce the steam. Feedwater at 454°F for the steam generators comes from the final feedwater heater outlet, first passing through the preheater where it is brought to 597°F. The superheated steam enters the turbine at 700°F and 1,450 psia.

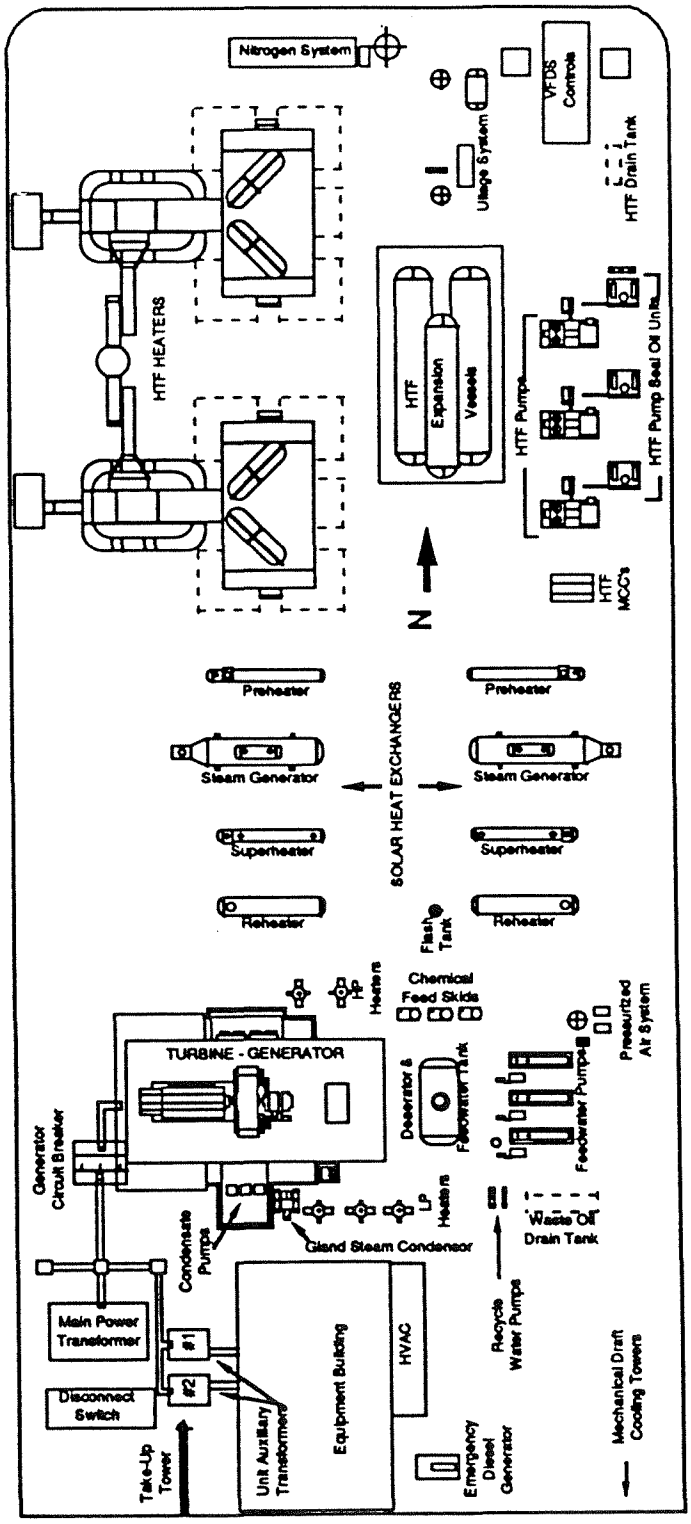
The hot HTF also flows to the reheater in parallel to the preheater-steam generator-superheater train. Steam at 265 psia is reheated from 405°F to 705°F in the reheater units.

Steam Turbine

The turbine consists of high- and low-pressure sections. It receives high-pressure (1,450 psia), medium-temperature (700°F) steam from the steam generators supplied either by the solar field (solar

mode), the fossil-fired HTF heater (fossil-fired mode) or a combination of steam from both sources (hybrid mode).

Fig. III-6. Typical SEGS Power Block Layout



The steam exiting from the high-pressure casing is reheated in the reheater before feeding the low-pressure casing. Exhaust steam from the turbine is directed to the condenser; extraction steam is used to heat and deaerate the feedwater supplied to the steam generators. The turbine/generator is installed on a turbine support table and exhausts downward into the condenser.

Generator

The generator set is a totally enclosed, water/air-cooled type with stationary armature and cylindrical rotor, rated at 108 MVA, 13,800 volts, three-phase, 60 Hz, and 3,600 rpm. The generator output voltage is supplied to a main transformer for conditioning. This transformer also provides electrical power from the power grid when the turbine/generator set is not on line. The output power is interconnected on site to the transmission line to the grid.

Cooling-Water and Water Treatment Systems

The cooling-water, water treatment, heat rejection and waste-water discharge systems design will be site-specific.

Electrical System

The electrical equipment will be partially site-dependent, and consists of transformers, switchgear, motor control centers, cable bus ducts, DC electrical systems, UPS systems and instrumentation-and-control systems. System descriptions and ratings are general in nature and subject to change as a result of finalized utility requirements, fault calculations, and code and standard requirements. Typically the 80 MW SEGS plants in California delivered power to the grid at 230 kV.

Distributed Control System

Plant process control, indication and annunciation are handled by a computer-controlled distributed control system (DCS). Major subsystems of the DCS are devoted to the solar field, turbine-generator, fossil-fired HTF heater, and heat-transfer-fluid system. Operator interface occurs through cathode-ray tube (CRT) displays and panels in the control room. The DCS operates on a 120-VAC battery-backed power system.

The DCS is a unified control system comprised of individual control units. It provides control, monitoring, data acquisition and operator interface to the various plant systems. The DCS controls the HTF system and most significant systems with the balance-of-plant (BOP) and power block. It also communicates with the FSC to ensure that the HTF flow and solar field operation are fully coordinated. Systems with vendor-supplied controls, such as the turbine-generator and water treatment system, have control interfaces with the DCS to provide status reports and to receive instructions on mode of operation, setpoints and alarms.

COST ESTIMATE

The electricity costs of SEGS plants in California reduced steadily from their introduction in 1984 through the construction of SEGS IX due to a reduction in unit capital costs and an increase in output per dollar invested. Capital costs dropped from about $4500/kW to just over $3000/kW as the solar collector technology reached its third generation and plant sizes increased from 14 MW to 80 MW.

The capital cost estimates presented here are based on reference cost data for the SEGS plants and factors specific to an installation in Hawaii. The costs are generalized in that they are not developed for a specific site. These costs assume a turnkey project with a lead EPC (engineering, procurement and construction) contractor. Cost elements in the SEGS estimate include the following:

- Site Preparation: grading, roads, flood protection, and land
- Buildings/Fence: control and maintenance buildings, security fencing
- Solar Field Material: collector and foundation equipment
- Solar Field Installation: installation costs of solar field
- HTF System: pumps, headers, fluid
- Turbine/Generator: turbine/generator set
- Boiler/Heater: auxiliary fossil-fired steam source
- Other Power Block Equipment: major steam-water cycle equipment other than turbine-generator
- Electrical: electrical wiring, motor control centers, other
- BOP: balance-of-plant equipment (e.g., cooling towers and pumps, solar heat exchangers, diesel set, air compressors)
- Substation/interconnect: transformers, switchgear, breakers, tower interconnect to transmission line
- Indirects: field supervision, field engineering, miscellaneous construction facilities. Sales tax, interest during construction and profit are not included in the indirects.
- Other: engineering, start-up
- Contingency: reserve margin for estimated uncertainties @ 15%

SEGS cost data from the California plants have been adjusted for Hawaii conditions. A key source for the cost adjustments was the 1992 study by Black & Veatch for HECO on new generating facilities (Ref. III-1). Table III-3 compares cost assumptions for Hawaii compared to the reference SEGS plants, as well as showing other adjustment factors which were applied to all labor, materials and equipment cost. The final SEGS cost estimate resulting from the application of these adjustments to the reference SEGS costs is given in Table III-4. The total cost is $3845/kW, though this can vary considerably depending on site conditions. As an example, consider a site in which grading is not an issue (e.g., the Pearl Harbor Blast Zone area), land costs are $30,000 per acre, both transmission and water costs are one-half of the assumed cost, and a contingency of 10% is applied. In this case, the total cost reduces to $3080/kW. Though it is hard to accurately portray the range of costs that could be incurred over a broad spectrum of sites, it is our recommendation that an uncertainty band of 15% be applied to the reference plant cost, resulting in an estimated range of $3500/kW to $4200/kW for a reference 80-MW SEGS plant in Hawaii. Smaller plants will be more costly; as a rule of thumb from SEGS construction experience, the cost increment over 80-MW plant costs is about 15% for a 30 MW plant and 30% for a 15 MW plant.

Table III-3. Cost Adjustments for a SEGS Plant in Hawaii

Cost Element	Mojave SEGS	HECO Study	Hawaii SEGS
Grading/flood protection	--	--	3x higher
Land cost	$1000/acre	--	$40,000/acre
Water supply/treatment	$110/kW	$58/kW	$60/kW
Transmission/interconn	$55/kW	$480/kW	$110/kW
Excise taxes	--	4.16%	4.16%
Ocean freight	--	5%	5%
Labor wage rate adj	--	20-25%	20%
Labor productivity adj	--	15-25%	20%
Contingency	10%	10-30%	15%

Table III-4. Cost Estimate for Reference SEGS Plant in Hawaii (1992$)

Category		$/kW	Unit $/kW	Cost % of Direct
Site Preparation				
Grading			295	10
Flood Protection			180	6
Land			210	7
Other			235	8
	Subtotal	920		31
Solar Field				
Equipment			860	29
Installation			150	5
	Subtotal	1000		34
HTF System				
	Subtotal	415		14
Power Equipment				
Power Block			325	11
Fire/Water Systems			60	2
BOP			90	3
Electrical			30	1
	Subtotal	505		17
Substation/Interconnect				
	Subtotal	120		4
				% of Total
Total Direct Costs			2960	77
Total Indirect Costs			245	6
Total Other			50	2
Contingency			590	15
Total			3845	100

SEGS PERFORMANCE PROJECTION for HAWAII

Performance Model

The methods utilized to project the performance of the SEGS plants improved considerably over the period of SEGS development. Initially, the performance model utilized average monthly projections and incorporated relatively simple models which did not do justice to the complexity of a solar electric power plant, or deal adequately with the peaking characteristics of the operating strategy.

The complex interactions of a hybrid solar/fossil-fired electric power plant require an hour-by-hour method which accurately models the solar field, power block and fossil-fired HTF heater performance to project overall plant output. Such a model was developed for the SEGS plants based on similar performance models written by SERI and the University of Wisconsin. The current performance model used at the SEGS sites takes into account the relevant physical characteristics of the solar field, turbine/generator system, HTF piping and important BOP systems.

The performance model utilizes hourly solar radiation conditions to predict the performance of the solar field from fundamental information. For each hour, the direct radiation incident on the plane of the

collector aperture is computed from direct normal radiation data. From this and the performance characteristics of the collector, the energy delivered by the solar field to the heat transfer fluid is calculated. The production rate of solar steam is then determined for the appropriate solar steam conditions, after accounting for piping heat losses and heat exchanger losses. If the hour is in the daily start up or shutdown stage, transient thermal capacitance effects are also considered. At night, collector and piping heat losses are determined using standard quasi-steady state heat transfer methods. The model contains an operating strategy that determines whether a particular hour is to be a solar-only, fossil-only or hybrid operating mode. For Hawaii, calculations have been carried out for the solar-only mode.

The subroutine which treats the turbine-generator does not carry out a complete Rankine steam cycle analysis for each hour. Rather, it uses full-load or part-load turbine efficiencies for each mode as provided by the turbine manufacturer. For each hour, the percent load of the turbine is determined based on the steam inlet mass flow rate, and the gross electrical output is calculated using the appropriate turbine heat rate along with the inlet steam conditions. Electrical parasitics are calculated based on the operating mode. In the solar mode, heat transfer fluid pumping requirements, which are a function of the solar field performance, are an important contributor to the parasitics. Finally, the net electric power is determined for the hour. Comparisons between the model output and actual plant operating data were used to validate the model algorithms and input data. As discrepancies between the data and model were found, modifications were made to improve the ability of the model to more accurately project plant performance.

One important drawback in this model limits its accuracy for performance projections in Hawaii. While it is the best model available for solar thermal electric performance projections for a SEGS plant, it is deficient in its ability to deal with the intermittent cloudy conditions that are typical of Hawaii. This point will be explored in more detail below.

Insolation Data Base

The weather data base required for the SEGS performance model must contain hourly data on direct normal insolation (DNI), direct insolation incident on the plane of the collector array, the incidence angle of the sun to the earth, ambient air temperature and average wind speed. The second and third values are calculated knowing the date, time of day and DNI. While extensive radiation data bases exist for Hawaii, these normally contain only global horizontal radiation data. This quantity, which consists of the direct insolation falling on the horizontal surface of the earth plus diffuse (or scattered) radiation, is not sufficient for performance calculations with concentrating collectors. Hence, an important step towards estimating performance in Hawaii was to establish a data base for DNI. While it would have been possible to use recent insolation modeling techniques to estimate DNI from global horizontal insolation data, our preference was to locate actual measurements.

Fortunately, this became possible through Dr. Paul Eckern, formerly of the University of Hawaii at Manoa. With his assistance, a DNI hourly data base was assembled from NIP measurements (stands for Normal Incidence Pyroheliometer, which is an instrument that measures direct normal insolation) made from the roof of Holmes Hall at the University during the years 1979-1987. The year 1979 was chosen as a typical solar year for this evaluation. Other data are available that allow estimates of island-to-island variations. These variations are discussed in Appendix B. The ambient temperature and wind data, which have a lesser influence on the performance results, were generated from long-term averages of National Weather Service data from Honolulu. The magnitude of the variations in DNI between Holmes Hall and other locations of interest throughout Hawaii are discussed below.

Insolation Levels

Important characteristics of the NIP data are the average magnitude and the extent of hourly and daily variations in Hawaii compared to that experienced by the SEGS plants in California. The annual average of the DNI readings at Holmes Hall for 1979 is 5.01 kWh/m^2-day, compared to 7.44 in the Mojave desert.

The monthly ratios of average direct normal insolation values between the two locations are given in Table III-5.

While the performance of concentrating collectors is dependent on the direct normal radiation, the relationship is directly proportional only for point-focus systems (central receivers or parabolic dishes) that track in two axes and point directly at the sun. The performance of parabolic trough collectors, which track the sun on a single axis, correlates directly with the component of the direct normal insolation incident on the plane of the collector aperture. The ratio of the level of this radiation between Hawaii and the Mojave sites is given in Table III-6.

The positive effect of the lower latitude in Hawaii (Honolulu is at 21.3^{o}; SEGS sites are at 35.0^{o}) can be seen by comparing the two tables. The ratios are about the same in summer, when the sun is at comparable angles of incidence to the site. In winter, however, the sun is higher in the sky in Hawaii and the component incident on the plane of the collector is greater.

Table III-5. Comparison of Direct Normal Insolation (Ratio of Hawaii NIP/Mojave NIP)

Month	Ratio	Month	Ratio
January	0.646	July	0.624
February	0.463	August	0.728
March	0.746	September	0.815
April	0.661	October	0.695
May	0.578	November	0.822
June	0.479	December	0.985

Annual average ratio: 0.673

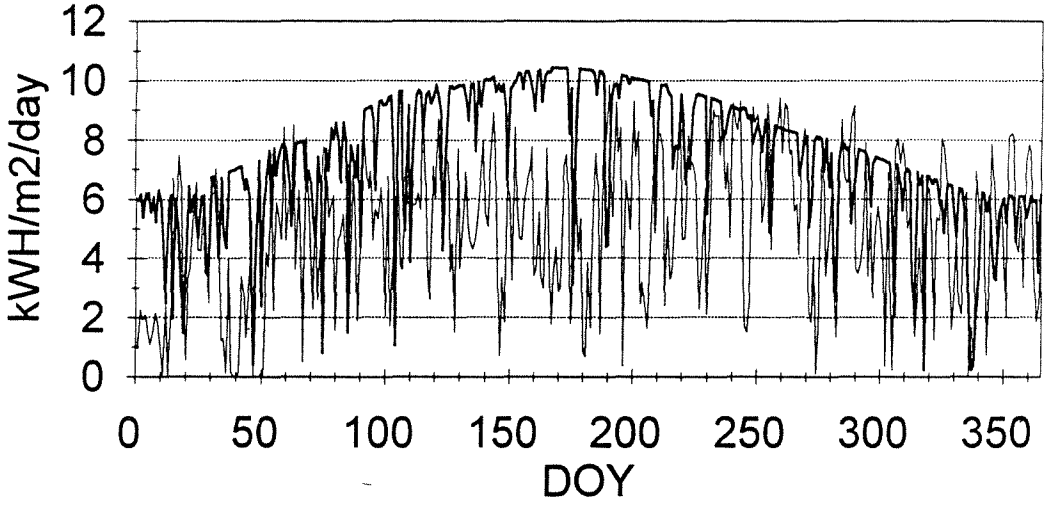
Table III-6. Comparison of Direct Insolation Incident on the Aperture Plane (Ratio of Hawaii/Mojave)

Month	Ratio	Month	Ratio
January	0.800	July	0.627
February	0.541	August	0.750
March	0.819	September	0.877
April	0.688	October	0.794
May	0.586	November	0.998
June	0.481	December	1.226

The magnitude of daily variations are shown in Figure III-7 for both the direct normal insolation and the direct insolation incident on the collector plane. Note that there is more daily variation in the Hawaii data, and that the differences in average levels diminish when the latitude effect is taken into account.

Of more importance is the hourly comparison. Figure III-8 shows data for hourly bins of insolation, which contain the number of hours for which the insolation is within a specified range. For example, the Daggett NIP was between 400 and 500 W/m^2 for 250 hours of the full year. The data show that there is a significantly greater occurrence of lower insolation in Hawaii and very few hours of high insolation (above 900 W/m^2).

a) Direct Normal Radiation



b) Direct Insolation Incident on Collector Plane

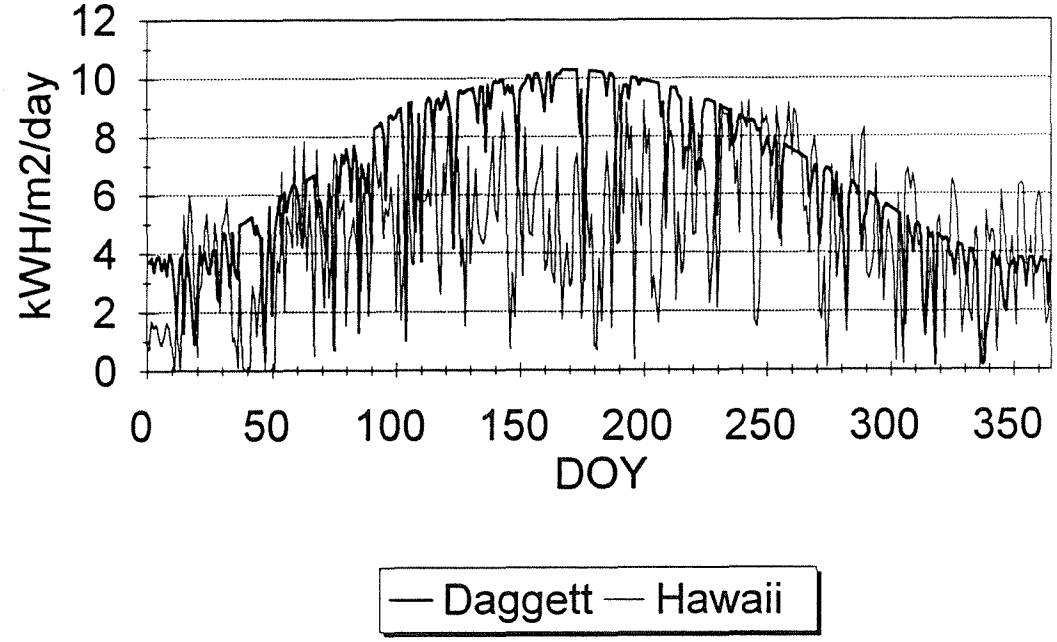


Fig. III-7. Daily Insolation Patterns in Hawaii and California (Mojave Desert)

Max Bin Value	Daggett NIP	Daggett NIP*cos()	Hawaii NIP	Hawaii NIP*cos()
0	4452	4479	4584	4584
100	547	546	867	907
200	213	219	446	459
300	126	149	340	379
400	184	282	330	334
500	250	426	320	355
600	307	536	332	402
700	284	435	393	447
800	461	539	421	412
900	794	778	580	443
1000	1142	371	147	38
	8760	8760	8760	8760

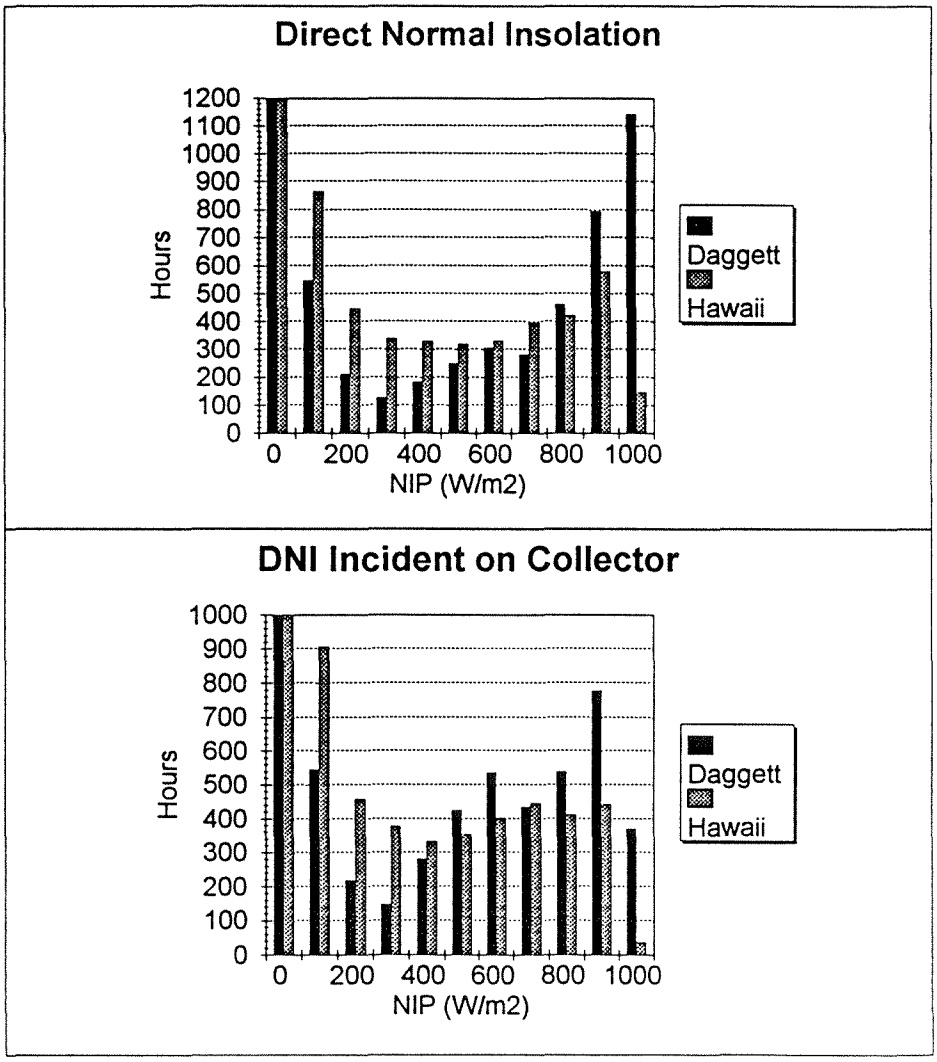


Fig. III-8. Comparison of Hourly Insolation Occurrences

Performance Projections

The insolation data were used in the SEGS performance model to project the performance of an 80-MW plant located at each site. The Mojave projection is useful as a reference for comparison. Figure III-9 shows the daily gross electrical output plotted against day of the year and also against the direct insolation incident on the plane of the collector. The latter plot shows the good correlation of electrical output as a function of daily planar insolation. The monthly electrical outputs for the Holmes Hall data are presented in Table III-7. The annual output of 119,119 MWh/year in Oahu compares to 180,520 MWh/year in the Mojave, or a reduction of 34%.

However, this result does not reflect the true impact of intermittent clouds on performance. The effects of clouds are greater than might be predicted simply from the reduction in average solar radiation. There are transient effects in the power block that magnify this impact. Consider a passing cloud bank of, say, 15 minutes duration. As the solar resource falls, HTF flow rate needs to be reduced by the control system. Steam flow rate will drop, and turbine load will fall off (decreasing turbine efficiency), possibly reaching the point that the turbine must come off line. If the HTF flow is maintained, solar field heat losses to the environment will continue, HTF parasitic pumping losses will continue, the turbine and PB/BOP will cool down, and heat collected by the solar field would need to be rejected to the environment (e.g., turbine steam bypass). When the insolation increases, heat will be required to warm up the PB/BOP until a startup condition is reached.

Table III-7. Performance Projections for 80-MW Plant using Holmes Hall Data

Month	MWh	Month	MWh
January	3393	July	13811
February	3870	August	15373
March	10216	September	14492
April	12534	October	9189
May	12484	November	7130
June	9903	December	6724

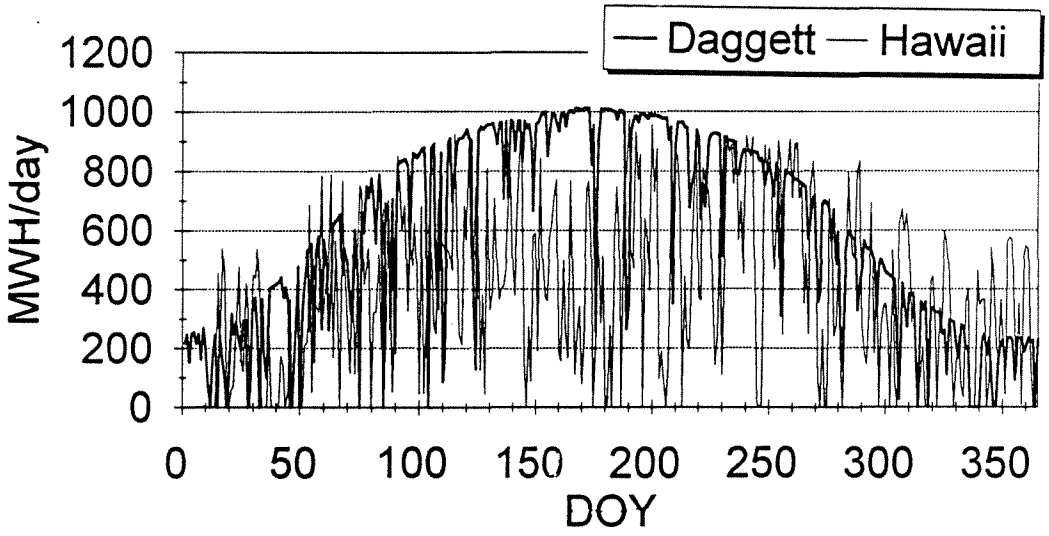
Annual Total: 119119 MWh

Another area of concern arises with respect to intermittent clouds. The transient effects discussed above can occur within minutes in a conventional SEGS configuration without storage. But the performance model only accepts hourly averages, masking the true extent of variations in insolation that may be occurring. For example, an average hourly insolation of 600 W/m^2 could be achieved with a steady insolation of this level over the hour or, say, by alternating 10-minute durations of 400 and 800 W/m^2. While using smaller time increments would be an improvement, the SEGS performance model does not have the appropriate modeling terms to properly account for these effects. Better modeling of such transient effects would increase the complexity of the model significantly, and was not an issue for SEGS plants in the Mojave where intermittent cloudy conditions are infrequent.

The effect of these deficiencies in the radiation data base and the model is to overproject performance, and hence the performance projections given above are assumed to be high. In our judgment, the projections are optimistic by a factor in the range of 10-20%. Hence, the performance of an 80-MW SEGS in Oahu might be expected to be about 60% of the performance of an identical plant in Southern California. At a 60% level, the annual output would be about 108,300 MWh (solar only), corresponding to a capacity factor of 15.4%. Supplementary firing could bring this level up to any desired capacity factor.

The DNI levels at the preferred sites on the other islands range up to 13% higher. This could result in a performance increase of about 15%, or an annual capacity factor of 17.8% in solar-only operation.

a) Daily Gross Electrical Outputs



b) Daily Electrical Output vs. Planar Insolation Level

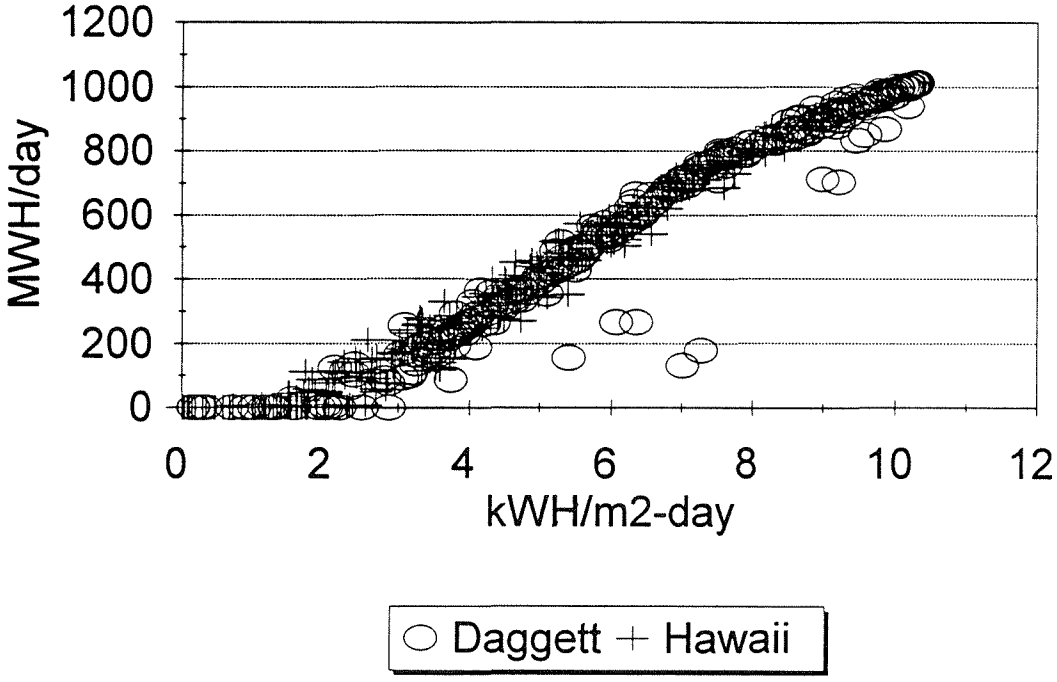


Fig. III-9. Electrical Output of 80-MW SEGS in Hawaii and California (Mojave Desert)

THERMAL ENERGY STORAGE AND BACK-UP OPTIONS

The electrical output of a solar thermal electric plant is inherently in a state of change, being dictated by both predictable and unpredictable variations - namely, the influences of time and weather. In either event, utility system needs may require a fully functional back-up system or buffer storage system to mitigate the changes in solar radiation. A back-up option can supplement a solar energy source with a reliable alternative source, providing greater control over the dispatch of the electricity delivered by the facility. The storage option can store energy for shifting its delivery to a later time, or for smoothing out the plant output during intermittently cloudy weather conditions. Possible storage or back-up options include short-term thermal energy storage, fossil-fired steam generators or heaters, chemical energy storage and electric battery storage. The fossil-fired systems have more flexibility but introduce the requirements of fuel availability and handling.

The SEGS plants in Southern California incorporate both limited sensible heat thermal storage (in the 15 MW_e SEGS I plant) and gas-fired back-up systems (in SEGS II-IX). In contrast to the perceived needs of a similar plant in Hawaii, these facilities are designed to meet strong peaking power demands of the utility and are situated in a region with few days of intermittent clouds. The local utility - Southern California Edison Company - has a high summer afternoon and evening peak due to air conditioning loads, and the goal of the plant supplementary energy systems is primarily to provide reliable capacity on summer afternoons and evenings. Since these are IPP's which sell electricity to the utility, the incentive to provide this capability is solely economic and is driven by the much higher electricity revenues in the peak periods. The SEGS plants after SEGS I utilized a gas-fired back-up system rather than storage because of the need for a more reliable and flexible means to meet summer peak demands, as well as estimated high storage system costs.

Need for Storage or Supplementary Back-up in Hawaii

Seasonal and diurnal system variations in Hawaii are relatively small, as discussed in section II. HECO's peak monthly demand, for example, varies by less than 15% over the entire year. Diurnal loads are quite flat from about 9 a.m. to 4 p.m., followed by peaks up to 11% in winter during the 5-7 p.m. period. Figure III-10 compares a typical solar output pattern to HECO's demand profiles. Assuming that a SEGS plant were part of the system supply mix, it appears unlikely that these small peaks would justify thermal energy storage or a fossil fuel or biomass fired back-up systems strictly for time-shifting of electrical production. For economic reasons, however, a fossil-fired back-up system could be desirable because it enables a much higher plant capacity factor with a fairly small additional expenditure in capital investment.

A buffer thermal energy storage (TES) system, on the other hand, can have a much more significant impact on the operation of a SEGS plant in Hawaii. Insolation changes due to intermittent weather conditions will - without a buffer TES system - directly affect the pattern and efficiency of electrical output. Put another way, the efficiency of electrical production will degrade with intermittent insolation, largely because the turbine-generator will frequently operate at partial load and in a transient mode. If regular and substantial cloudiness occurs over a short period, turbine steam conditions and/or flow can degrade enough to force turbine trips if there is no supplementary thermal source to "ride through" the disturbance.

In addition, other operational requirements of the solar plant could be supplied by the supplementary system. For example, some turbine systems need steam blanketing during night shutdown periods, which is a technique for controlling potential corrosion by preventing exposure of hot metal surfaces to oxygen. More importantly, morning start-up of a SEGS-type plant requires thermal energy to replace the heat losses that have occurred during the night, specifically to heat the solar field and power block systems to bring them back up to operating temperatures.

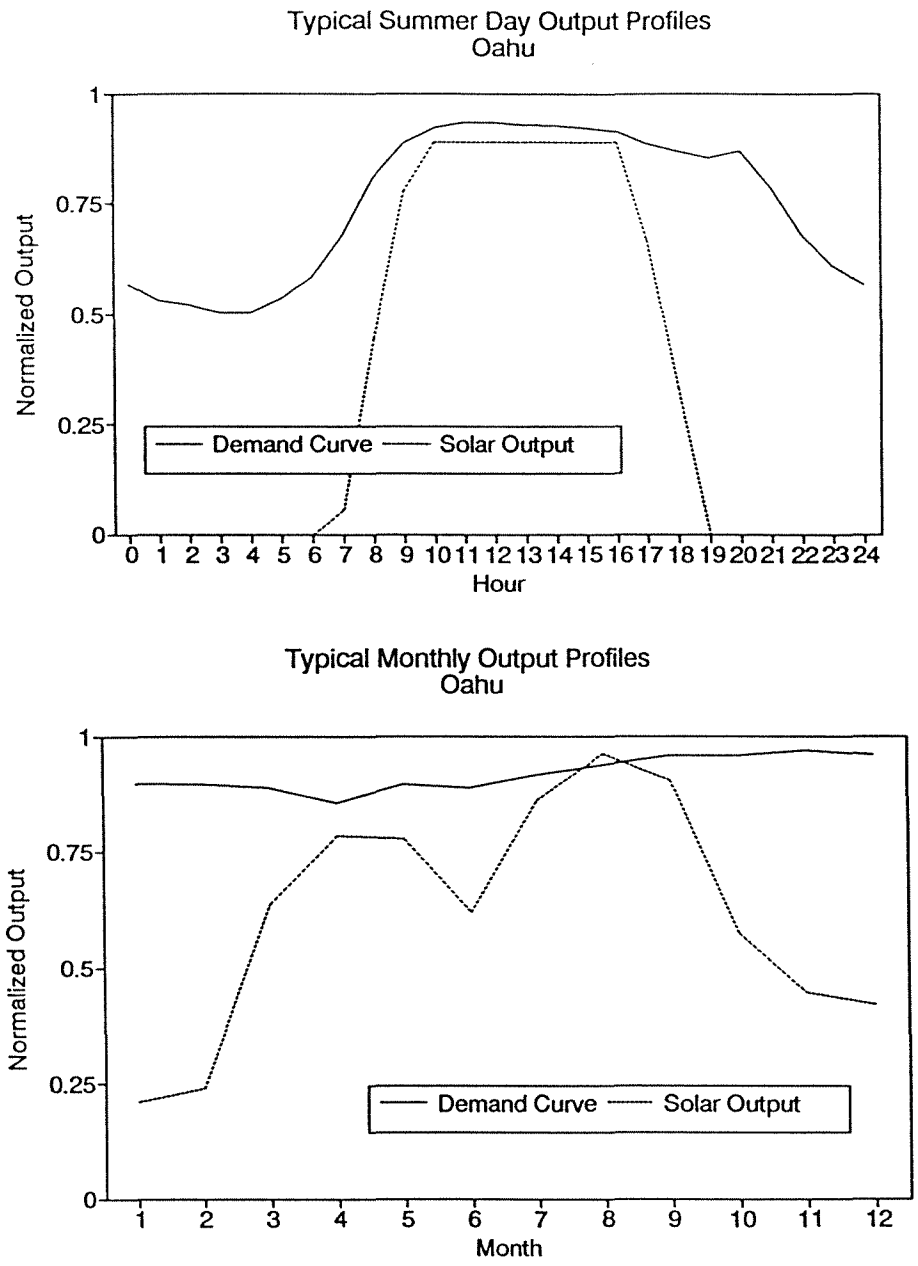


Fig. III-10. Typical Profiles of Electrical Demand and Solar Output

A key issue in the selection or design of a thermal energy storage system is its thermal capacity -- the amount of energy that it can store and provide. Experience suggests that buffer storage would be typically be chosen with capacity to provide full load for periods ranging from 1 to 3 hours. Definitive selection of storage capacity is site- and system-dependent; detailed statistical analysis of weather patterns at a given site along with a comprehensive economic tradeoff analysis would be required to select the storage capacity for a specific application.

Battery storage systems are more akin to a fossil-fired backup in that their main benefit is to shift electricity delivery to a later time of use. Batteries would have no ability to smooth the operation of the power cycle during intermittent cloudy weather, though they could partially serve to smooth the electrical output of the plant during such conditions.

Thermal Energy Storage Options

Thermal storage can utilize *sensible* heat or *latent* heat mechanisms. Sensible heat is the means of storing energy by increasing the temperature of a solid or liquid; latent heat, on the other hand, is the means of storing energy via the heat of transition from a solid to liquid state, e.g., molten salt has more energy per unit mass than solid salt.

Sensible Heat Storage

Table III-8 shows the characteristics of candidate solid and liquid sensible heat storage materials for a SEGS plant.For each material, the low and high temperature limits are given which, combined with the average mass density and heat capacity, lead to a volume-specific heat capacity in kWh_t per cubic meter. The table also presents the approximate costs of the storage media in dollars per kilogram, finally arriving at unit costs in $\$/kWh_t$.

Table III-8. Candidate Storage Media for SEGS Plants (Ref. III-2)

Storage Medium	Temperature Cold °C	Temperature Hot °C	Average density kg/m³	Average heat conductivity W/m°C	Average heat capacity kJ/kg°C	Volume specific heat capacity kWh_t/m^3	Media costs per kg $/kg	Media costs per kWh_t $/$kWh_t$
Solid media								
Sand-rock-oil	200	300	1,700	1	1.30	60	0.15	14
Reinforced concrete	200	400	2,200	1.5	0.85	100	0.05	1
NaCl (solid)	200	500	2,160	7	0.85	150	0.15	1.5
Cast iron	200	400	7,200	37	0.56	160	1.00	32
Cast steel	200	700	7,800	40	0.60	450	5.00	60
Silica fire bricks	200	700	1,820	1.5	1.00	150	1.00	7
Magnesia fire bricks	200	1,200	3,000	5	1.15	600	2.00	6
Liquid media								
Mineral oil	200	300	770	0.12	2.6	55	0.30	4.2
Synthetic oil	250	350	900	0.11	2.3	57	3.00	43
Silicone oil	300	400	900	0.10	2.1	52	5.00	80
Nitrite salts	250	450	1,825	0.57	1.5	152	1.00	12
Nitrate salts	265	565	1,870	0.52	1.6	250	0.70	5.2
Carbonate salts	450	850	2,100	2	1.8	430	2.40	11
Liquid sodium	270	530	850	71	1.3	80	2.00	21
Phase change media								
$NaNO_3$	308		2,257	0.5	200	125	0.20	3.6
KNO_3	333		2,110	0.5	267	156	0.30	4.1
KOH	380		2,044	0.5	150	85	1.00	24
Salt-ceramics (Na_2Co_3-$BaCO_3$/MgO)	500-850		2,600	5	420	300	2.00	17
NaCl	802		2,160	5	520	280	0.15	1.2
Na_2CO_3	854		2,533	2	276	194	0.20	2.6
K_2CO_3	897		2,290	2	236	150	0.60	9.1

For each material, the low and high temperature limits are given which, combined with the average mass density and heat capacity, lead to a volume-specific heat capacity in kWh_t per cubic meter. The table also presents the approximate costs of the storage media in dollars per kilogram, finally arriving at unit costs in $/kWh_t$.

The average thermal (heat) conductivity given in the table has a strong influence on the heat transfer design and heat transfer surface requirements of the storage system, particularly for solid media (high conductivities are preferable). High volumetric heat capacity is desirable because it leads to lower storage system size, reducing external piping and structural costs. Low unit cost leads, obviously, to lower overall costs for a given thermal capacity.

Solid Media:

The cold-to-hot temperature limits in Table III-8 are greater, in some cases, than could be utilized in a SEGS plant because parabolic trough solar fields are limited to maximum outlet temperatures of about 400°C. Imposing this limit on the storage medium temperature range, the unit heat capacities and media costs become:

Storage Medium	Heat Capacity kWh_t/m^3	Media Cost $/kWh_t
Sand-rock-oil	60	14
Reinforced concrete	100	1
NaCl (solid)	100	2
Cast iron	160	32
Cast steel	180	150
Silica fire bricks	60	18
Magnesia fire bricks	120	30

Using these values and judging the options against the guidelines discussed above, the sand-rock-oil combination is eliminated because it is limited to 300°C. Reinforced concrete and salt have low cost and acceptable heat capacity but very low thermal conductivities. Silica and magnesia fire bricks, usually identified with high temperature thermal storage, offer no advantages over concrete and salt at these lower temperatures. Cast steel is too expensive, but cast iron offers a very high heat capacity and thermal conductivity at moderate cost.

Liquid Media:

The heat transfer fluid in a SEGS plant operates between the temperatures of 300°C and 400°C, approximately. Applying these limitations on temperature, and dropping mineral oil because it cannot operate at the upper temperature requirement, we find:

Storage Medium	Heat Capacity kWh_t/m^3	Media Cost $/kWh_t
Synthetic oil	57	43
Silicone oil	52	80
Nitrite salts	76	24
Nitrate salts	83	16
Carbonate salts	108	44
Liquid sodium	31	55

Both the oils and salts are feasible, though the salts generally have a higher melting point and parasitic heating is required to keep them liquid at night, during low insolation periods, or during plant shutdowns. Silicone oil is quite expensive, though it does have environmental benefits in that the synthetic oils may be classified as hazardous materials. Nitrites in salts present potential corrosion problems, though these are probably acceptable at the temperatures required here (The U.S. Solar Two project has selected a eutectic of nitrate salts because of the corrosivity of nitrite salts at central receiver system temperature levels.)

Latent Heat Storage

Because the latent heat of fusion between the liquid and solid states of materials are high, storage systems utilizing phase change materials have the possibility of reduced size compared to single phase sensible heating. However, heat transfer design and media selection are more difficult, and experience with low temperature salts has shown that the performance of the materials can degrade after a moderate number of freeze-melt cycles. Extensive work has not been done on systems in the temperature range of interest to SEGS plants. Nevertheless, Luz International Ltd. proposed evaluation of a phase-change salt concept to the solar community which used a series of salts in a "cascade" design (to be discussed later in this section).

Table III-8 shows, for a number of potential salts, the temperature at which the phase change takes place as well as the heat capacity (heat of fusion). Data for the salts shown in the table that are applicable to SEGS plants are:

Storage Medium	Heat Capacity kWh_t/m^3	Media Cost $/kWh$_t$
$NaNO_3$	125	4
KNO_3	156	4
KOH	85	24

It can be seen that the heat capacities, at least for the nitrites, are high and unit costs are comparatively low.

Phase change salt systems suitable for this application have been postulated but not tested. Many questions remain with respect to heat transfer characteristics during charging and discharging cycles, media lifetime as a function of the number of charge/discharge cycles, and the detailed design of a TES system.

Existing TES Systems in Solar Thermal Plants

Of seven installed thermal energy storage systems in solar thermal electric plants, six have been of an experimental or prototype nature and one has been a commercial unit. Table III-9 gives the characteristics of the existing units. All have been sensible heat storage, with two single tank oil thermocline systems, three single medium two-tank system -- one with oil and two with salt -- and two dual medium single tank systems. To put the size of these systems in perspective, a 30 MW_e plant in Ouarzazate with a plant efficiency of 35% would require about 170 MW_t for a 2-hour storage capability. This is comparable to the two-tank storage installed at SEGS I (the commercial unit) and the oil-sand-stone system installed at the Solar One prototype central receiver facility.

All of these systems were successful to varying degrees, recognizing that most were development units which were expected to reveal design flaws or issues as a basis for future design improvements. Two important characterizations of storage systems are the "roundtrip efficiency" and the cost per unit of thermal energy delivery ($/kW$_t$). The roundtrip efficiency is, simply, the ratio of the useful energy recovered from the storage system to the amount of energy initially extracted from the heat source. This efficiency is affected by the laws of thermodynamics and by heat losses in the tanks, piping and heat

exchangers in the system; electric parasitic losses needed to circulate storage system fluids constitute additional losses.

Efficiency and cost experience from existing systems are informative but of limited relevancy to commercial plants since most of the existing facilities were one-of-a-kind development projects. Nevertheless, roundtrip efficiencies of over 90% were measured in many of the systems listed in Table III-9, though some systems were as low as 70%. Unit costs (extrapolated to 1992$ at 5% inflation) appear to have been in the range of $\$40\text{-}70/kW_t$. Both the oil systems and molten salt systems were shown to be technically feasible. While various problems arose due to mistakes in design, construction or operation, no fundamental issues surfaced for these approaches.

The SEGS I storage system cost $\$37/kW_t$ ($\$25/kW_t$ in 1984$), with the oil representing 42% of the investment cost. Since this system has a capacity of 120 MWh_t and a plant electrical output of 15 MW_e, the SEGS I system cost about $\$300/kW_e$ in 1992$. The SEGS I oil, an aliphatic hydrocarbon, is limited to operation at about 305°C. The oil used in the later SEGS plants for operation up to 400°C costs approximately 8 times more than the SEGS I oil. Extrapolating the SEGS I cost to a similar system for higher temperature operation with the more expensive oil but scaled equipment costs, we get a total estimate of close to $\$150/kW_t$, or $\$1200/kW_e$ installed. This is reason enough that a storage system similar to the SEGS I storage concept was not repeated in later SEGS plants, though there were other important considerations such as total system investment, very large tank size requirements, and inflexibility compared to a back-up system.

Table III-9. Existing TES Systems in the 200-450°C Temperature Range (Ref. III-3)

Project	Type	Storage Medium	Cooling Loop	Nominal Temperature cold °C	Nominal Temperature hot °C	Storage Concept	Tank Volume m^3	Thermal Capacity MWh_t
Irrigation pump Coolidge, AZ.	Central Receiver	Oil	Oil	200	228	1 Tank Thermocline	114	3
IEA-SSPS Almeria, SP	Parabolic trough	Oil	Oil	225	295	1 Tank Thermocline	200	5
SEGS I Daggett, CA	Parabolic trough	Oil	Oil	240	307	Cold-Tank Hot-Tank	4160 4540	120
IEA-SSPS Almeria, SP	Parabolic trough	Oil Cast Iron	Oil	225	295	1 Dual Medium Tank	100	4
Solar One Barstow, CA	Central Receiver	Oil/Sand/ Rock	Steam	224	304	1 Dual Medium Tank	3460	182
CESA-1 Almeria, SP	Central Receiver	Liquid Salt	Steam	220	340	Cold-Tank Hot-Tank	200 200	12
THEMIS Targasonne, FR	Central Receiver	Liquid Salt	Liquid Salt	250	450	Cold-Tank Hot-Tank	310 310	40

Design Concepts for Hawaii Plants

Two important evaluations (Refs. III-2,3) of thermal energy storage for large scale SEGS plants have been carried out and are relevant to plants in Hawaii. Out of these have come several systems with differing degrees of maturity and potential. Summary descriptions of six thermal storage concepts follow.

Design Conditions

The systems described here are designed to supply 200 MWh_t for an 80 MWe SEGS plant of the most recent design configuration and conditions. Table III-10 gives the relevant conditions for the reference solar plant and storage system. Figure III-11 gives a schematic diagram of a SEGS plant configuration

with storage. The relatively low temperature differences in a SEGS plant between solar field outlet temperature and solar field inlet (same as preheater outlet) drive up the size of a thermal storage system compared to a solar system with higher outlet temperatures available

Table III-10. Nominal SEGS TES System Design Parameters for 80 MW Plant

Nominal Solar Field Values	
Inlet temperature, °C	290
Outlet temperature, °C	390
Inlet pressure, Pa	25.5×10^5
Outlet pressure, Pa	14.8×10^5
Flow at full load, kg/s	1008
Full load operation, MW_t	240
Thermal Storage System	
Storage discharge capacity, MWh_t	200
HTF inlet temperature (charge), °C	390
Maximum HTF outlet temperature (charge), °C	315
Minimum HTF outlet temperature (discharge), °C	350
HTF inlet temperature (discharge), °C	265
Maximum storage pressure drop (@833 kg/s), Pa	15.9×10^5
Minimum oil pressure, Pa	10.3×10^5
Maximum HTF flow, kg/s	833
Nominal Power Block Conditions	
Turbine inlet temperature, °C	371
Turbine inlet pressure, Pa	100×10^5
Turbine inlet steam flow, kg/s	101
Net power plant output, MW	80

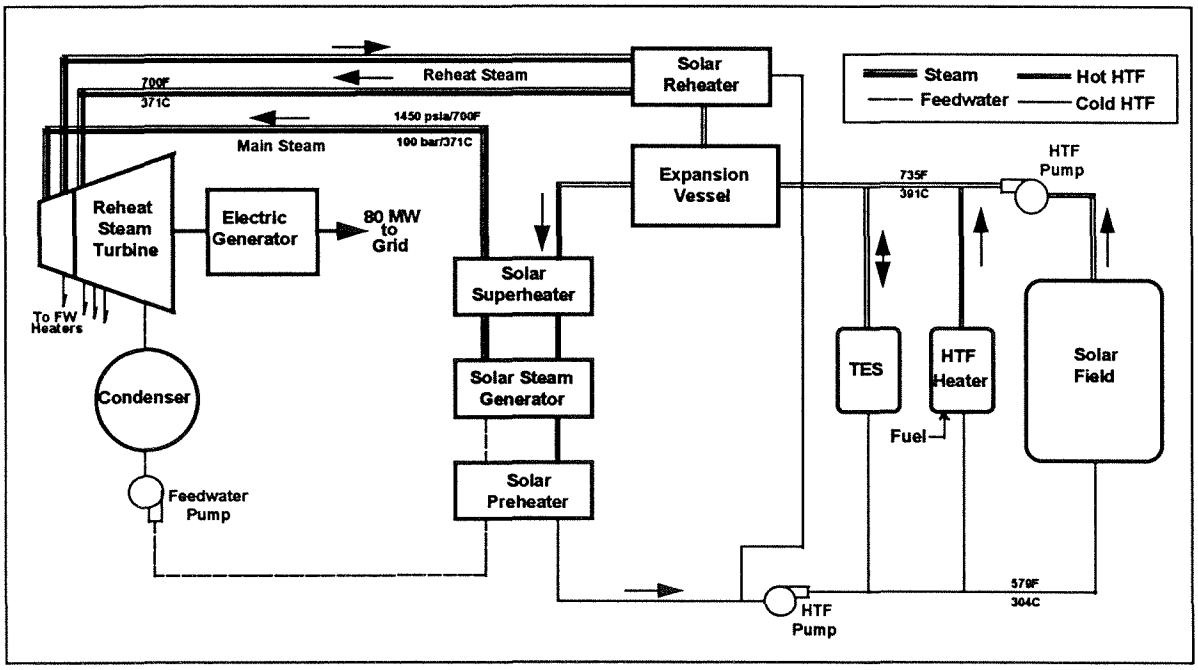


Fig. III-11. Schematic Diagram of a SEGS Plant with TES

Storage systems inherently introduce temperature degradations due to the nature of thermodynamic laws. Consider a solid storage medium (e.g., concrete, cast iron, or solid salts) which is charged or discharged by HTF flowing through a network of pipes or tubes imbedded in the storage material. If the charging HTF is 390°F, the storage medium might be heated to 380°F maximum, for example, because some temperature difference is thermodynamically necessary for heat transfer. Since the HTF will cool as it releases its energy while passing through the storage medium, there will be a temperature gradient along the storage medium itself. This is acceptable because, during discharge of the storage medium, the HTF to be heated will be circulated in a reverse flow (counterflow) and will pass out of the storage medium at the highest temperature region. However, a temperature difference for heat transfer is also required in this process, and the maximum HTF temperature out of the storage system during discharge of the storage energy might be, for example, 370°F. These design temperature differences for heat transfer can be reduced at the expense of adding more heat transfer surface allowing, in this example, discharge outlet temperatures closer to 375°F or higher. This tradeoff between heat transfer surface area and system performance is one of the typical economic design optimizations in the design of a thermal storage system. (Design considerations in two-tank liquid storage systems and phase change salt systems do not have all of the same heat transfer characteristics of solid media storage systems, but some of the same considerations are present.)

As energy is extracted from storage in the discharge mode, the entire temperature level will decrease and the HTF outlet temperature from storage will slowly decrease. Because there is a minimum steam condition allowable at the turbine inlet, a limitation is set on the minimum HTF storage outlet temperature which, in this design case, is 350°F.

One of the major potential advantages of phase change materials is that temperatures within the storage media do not suffer these large sensible heat temperature drops. For a SEGS plant using an HTF medium through the solar field, however, the solar side of the storage system will still be controlled by sensible heating characteristics.

Candidate TES Systems

Table III-11 shows the storage systems initially considered in the assessment described in Ref. III-3 Of these only a few survived the initial screening for cost and performance. The final systems were:

Dual medium sensible heat systems: Two single tank alternatives were analyzed, one in which HTF oil flows through a storage medium of concrete and another in which the storage medium is solid salt. Cast iron and cast steel were eliminated as storage media due to high cost, even though they offered thermodynamic advantages.

Sensible heat molten salt system: A two-tank system (similar to SEGS I) utilizing the HITEC salt was chosen. HITEC is a eutectic mixture of 40% $NaNO_2$, 7% $NaNO_3$ and 53% KNO_3 with a 142°C melt-freeze point.

Phase-change systems: These higher risk systems were judged to have high uncertainty in technical feasibility and cost, but were evaluated for their potential in this application. It is our conclusion that rather optimistic assumptions on performance and cost were used in the evaluation, and considerable development is required to prove these concepts. Three different phase-change concepts were evaluated. The first was a Luz design using five phase-change materials (PCMs) in a series, or cascade, design; the second was a design by the Spanish company INITEC which also used 5 PCMs but in a different heat exchanger configuration; the third design originated with the German companies Siempelkamp and Gertec (SGR) and used 3 commercially available PCM's along with concrete for the higher temperatures.

Table III-11. Candidate Storage Concepts for SEGS Plants (Ref. III-3)

TES Concepts	Storage Type	Status*	Assessment
Sensible Active	Two Tank Oil	T	Basic concept, state-of-the-art
	HITEC	T	2 variants analysed based on existing PSA/THEMIS designs
	Thermocline	T	Proved on pilot scale, no advantages over basic two tank system
Sensible DMS	Oil/Cast Iron	T	Proved on pilot scale, no advantages over basic two tank system
	Oil/Steel	LR	Used in chipboard presses
	Oil/Concrete	MR	Several variants analyzed
	Oil/Solid Salt	MR	Several variants analyzed
PCM	Oil/PC Salts	HR	Several cascade arangements analyzed
Chemical	Oil/Metal Hybrids	HR	Early state of development, no lead concepts, no cost data

* Nomenclature: T- Tested; LR- Low Risk; MR- Medium Risk; HR- High Risk

Results

Storage system designs for the SEGS conditions based on these five concepts were developed in Ref. III-3. Summary results are presented here giving overall system volume, thermal storage capacity and utilization, and specific costs in $\$/kWh_t$ of capacity.

The utilization measure is an interesting aspect of storage systems. Earlier discussion described some of the aspects of temperature differences within the HTF fluid and between the HTF and a solid storage medium. Another aspect of storage design is the temperature difference within the medium itself. In a two-tank liquid system, for example, the entire fluid is heated to a charged temperature and hence the entire storage medium is utilized. PCM systems theoretically also have very high utilization factors. In a solid system, however, temperature gradients required for thermal conduction through the media itself prevent full utilization of the material. In this case, 100% utilization would be achieved if the entire solid medium were heated to the full charging temperature. Hence, the "potential" storage capacity might be 2 or 3 times higher than the practical storage capacity. Detailed heat transfer calculations on specific designs provide this type of information.

Figures III-12 through III-14 give results on the total volume, storage capacity and utilization, and specific cost of the six candidate systems analyzed for SEGS plants. For comparison purposes, we will select the Initec PCM design as representative of the PCM class, with the qualifier that there is much more uncertainty and technical risk in the PCM results than in the sensible heat oil-solid systems or in the sensible heat Hitec molten salt system.

With regard to volume, the concrete and salt concepts are about 6,900 and 5,200 m^3 in overall size, respectively, whereas the molten salt and PCM system are 2,600 m^3. If the cross-sectional area perpendicular to the flow measured 13m by 13m, the length of the concrete system would be 41m compared to a 15m length for the PCM system. A major reason for the larger sizes of the concrete and solid salt systems is the poor volume utilization -- the concrete system, for example, is utilized at 36% of its full potential capacity. The molten salt and PCM systems, on the other hand, have utilization factors up to 100%. The concrete system does, however, have cost advantages due to the very low cost of concrete, which results in a low system cost even though there is more structure required for this larger volume system.

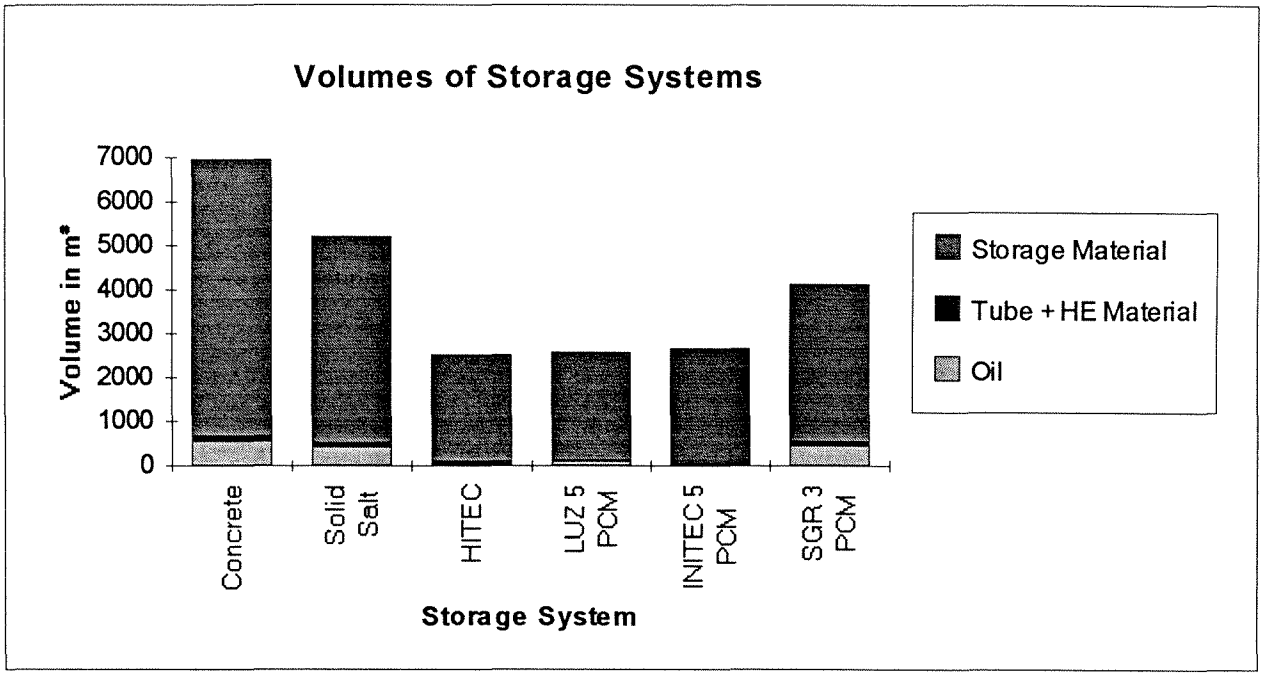


Figure III-12. Projected Storage Volumes for Reference SEGS Plant

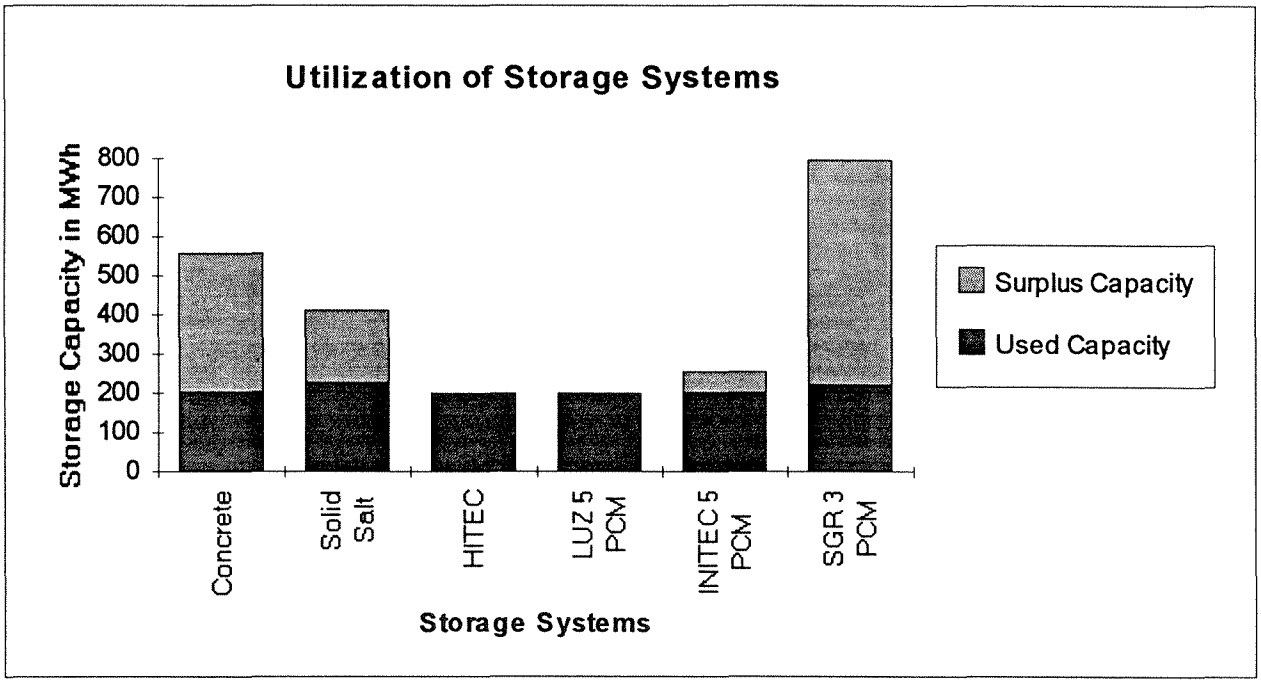


Figure III-13. Storage Utilization for Reference SEGS Plant

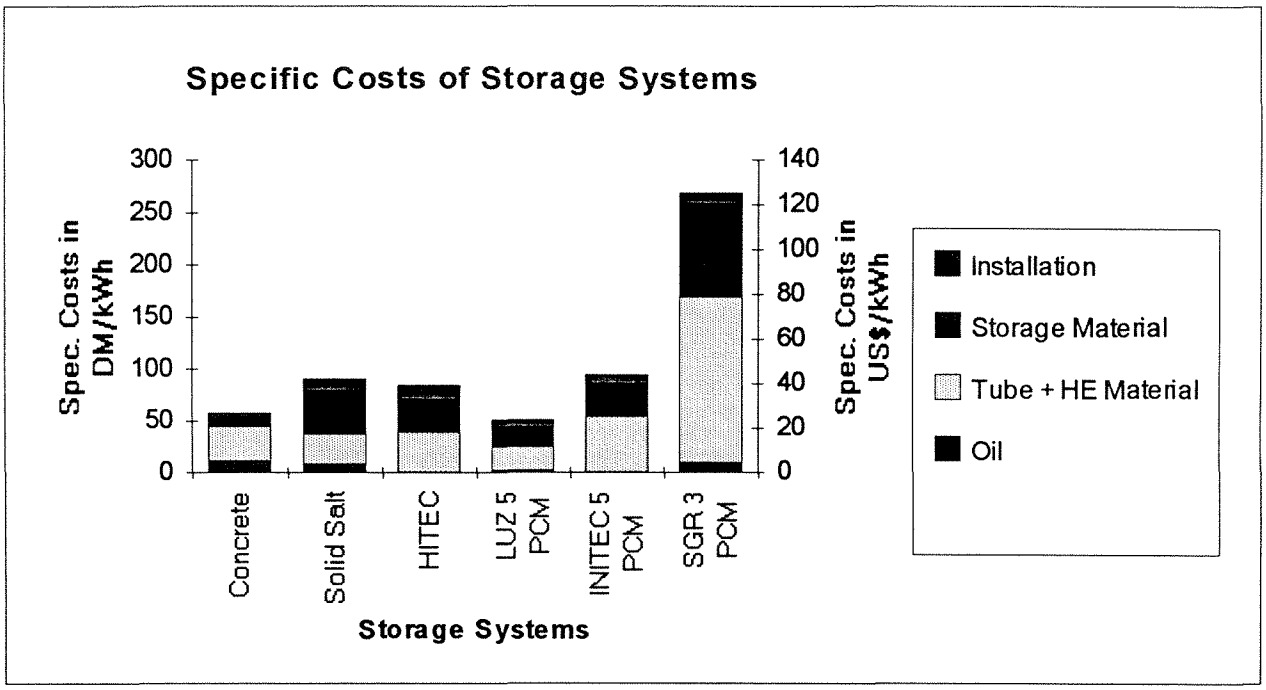


Figure III-14. Storage Costs for Reference SEGS Plant

Generally, the storage costs developed in this assessment vary from \$25-50/kWh$_t$ (on the order of \$65-130/kWh$_e$). At the low end, a TES unit of 200 MWh$_t$ capacity would have a capital cost of \$5M, or about \$63/kW$_e$ capital cost installed.

Value of Thermal Storage

Now let us look in preliminary fashion at the potential value of buffer thermal storage in this 80 MWe reference plant. Assuming that the value of the storage system is to reduce turbine shutdowns as well as the frequency of low part-low operation, we know that the overall efficiency of the solar electric power plant will be improved but the magnitude of the improvement is unknown. A much more sophisticated plant performance model than presently exists would be needed to quantify the gain in performance. Present experience with the SEGS plants and design knowledge of the plant configuration suggests that performance gains from 5-10% would be possible, and 20% might be achieved.

Given the value of the electricity, we can then calculate a savings due to the gain in performance resulting from use of the storage system. Table III-12 shows the savings using reasonable ranges for these factors.

For a 10% performance gain at an electricity rate of 10 cents/kWh, the annual savings would be \$1,800,000. At an cost of storage of \$7,500,000, the simple payback for the system would be just over 4 years. For the full range of cost and value parameters postulated here, simple paybacks would range from a low of just over 1 year to a high of 16.7 years.

Discussion

A symposium workshop (Ref. III-4) on TES systems for SEGS plants, held in 1989, discussed several of the options presented above. While the workshop focused on phase-change material concepts, both sensible heat storage and chemical storage were also included in the agenda. The more detailed evaluations reported in Ref. III-3 were completed subsequent to the workshop. However, we are unaware of any other relevant and significant work on this topic being carried out since then, and consequently the conclusions of the workshop remain current and valuable.

Table III-12. Estimated Value of Buffer Storage

Estimated Savings, $K [a]			
Electricity Value [b]	Performance Gain with TES [c], %		
	5	10	20
10	**600**	**1200**	**2400**
15	**900**	**1800**	**3600**
20	**1200**	**2400**	**4800**

Notes: a) Based on plant performance without TES of 120,000 MWh_e/yr
b) Value of electricity in cents/kWh_e
c) Parametric range of potential improvement

With respect to sensible heat storage, the workshop concluded that this approach could result in a cost-effective system. While no new research would be required, thorough and careful engineering development and small-scale testing would be necessary. Issues such as thermal expansion, potential leakage, heat transfer configuration and heat exchange optimization require more detailed design within the context of a design concept.

Latent heat (or phase-change) storage was considered to be in a more primitive state of development. While promising, considerable research, system development and proof-of-concept testing would be required. Concerns on heat transfer characteristics and heat exchange configuration were expressed. Of several possible configurations, it was concluded that both shell-and-tube heat exchangers and a system of encapsulated particles of phase-change salts were worthy of exploration, with the latter approach having both more potential for cost-effectiveness and a lower probability of success.

Other Storage Options

Battery Storage

Storage of electricity in utility-scale battery systems would be in wider use today were the technology commercially available and economic (Ref. III-5). Lead-acid batteries are the most developed but suffer from low energy and power density, high capital costs on the order of \$150-250/kWh_e, and return trip DC/DC energy efficiencies in the 75-85% range. Lead-acid batteries have been tested in prototype projects up to a capacity of 40 MWh at discharge rates of 10 MW. Other issues under evaluation are lifetime (number of cycles), environmental impact, and maintenance requirements.

Other battery types have been proposed for utility-scale application, but need development and extensive testing. Candidate technologies include the zinc-bromide battery, sodium-sulfur battery, metal-fuel/metal-air systems. Each presents certain advantages and disadvantages, and none is close to commercial deployment.

Hence, this technology does not offer a viable option for storage for a solar thermal electric plant in the near-term.

Chemical Storage

Chemical storage systems have been proposed for energy storage at high density and efficiency. These systems potentially offer particular advantages at elevated temperatures and for longer-term storage compared to sensible and latent-heat storage (Ref. III-2,4). At this point in time, however, chemical storage is not a viable option as no operating systems or prototypes exist, and it is premature to expect valid projections on cost and efficiency.

Chemical storage systems generally require completely reversible chemical reactions at an equilibrium temperature which matches the charge/discharge temperature of the application. Reactions could be gas-gas, solid-gas or liquid-gas. Solid-gas systems have the advantages of high energy density and ease of component separation. Metal hydrides, particularly magnesium hydrides, have been examined for point-focus solar technologies.

The decomposition of metal hydroxides (mainly magnesium and calcium hydroxide) have also been proposed. A recent study at Batelle's Pacific Northwest Laboratory made preliminary estimates on the efficiency and cost of a metal hydroxide system for a SEGS application (Ref. III-6). The PNL system is based on the reversible reaction, $CaO + H_2O = Ca(OH)_2$. During the charging process, thermal energy drives an endothermic reaction creating calcium oxide and water from calcium hydroxide. The reverse occurs on discharge when calcium oxide and water combine in an exothermic reaction to produce calcium hydroxide and release thermal energy. The study concluded that such a storage system could be technically and economically feasible at initial cost estimates of about $\$45/kWh_t$. There were a number of technical and economic questions left unresolved in the evaluation, however, and projected costs should be considered to be very preliminary.

Back-up Options

Fossil Fuel Boilers/HTF Heaters

The current SEGS plants after SEGS I use gas-fired equipment to supplement solar energy in periods of low insolation. SEGS II-VII incorporate conventional gas-fired boilers which supply steam to augment solar-generated steam. In the later plants, both the gas-fired and solar systems provided turbine inlet steam at 1450 psi. Superheat temperatures were 700°F for solar and 950°F for gas-firing; reheat steam temperature was 700°F for both resources.

For operational reasons, the SEGS design evolved away from the gas-fired boiler to a gas-fired heat transfer fluid (HTF) heater placed in parallel with the solar field. Hence, thermal energy is supplied to the HTF by either the solar field or the heater, or a combination of both. The efficiency of the gas-fired heater was 83% on a higher heating value basis; cost of the unit was about $165/kW, or approximately 10% of the total system direct costs. One of the advantages of the HTF heater is that it was configured as four units, each of which supplied 25% of full load capacity. Hence, part-load operation was particularly efficient; for example, at 50% load two of the heater units would be operating at full-load efficiency and the other two would be shut down.

In the SEGS plants, the purpose of the fossil back-up is primarily to provide peak load demand if solar energy is not available. As independent power producers, the SEGS plants have power purchase agreements which make electricity sales particularly valuable during summer afternoons and evenings, and the bulk of the fossil back-up is used in those periods. About 30% of the annual output of a SEGS plant is derived from natural gas, a limit which is imposed by rules of the Federal Energy Regulatory Commission.

In Hawaii a back-up HTF heater could also be used with a SEGS plant, though peak demand supply would not be the goal. Rather, it is more likely that a back-up heater would be used to maintain the turbine at a given output level during cloudy periods, reducing turbine cycling and temporary turbine shut-downs. System design optimization of this configuration could result in a back-up system with, say, 50% of full-load capacity.

Since the HTF heater fulfills a conventional function of generating steam or heating a process fluid, other fuel options could be used with the appropriate modifications in burners, fuel delivery and handling systems, and environmental controls. Costs of these systems would be dependent on the rating and anticipated capacity factor of the unit. While costs for an oil-fired or coal-fired heater would be higher

than a gas-fired unit, it is still expected that such a unit would be a small fraction of the total direct cost of the plant.

Biomass-Fired Units

Biomass fuel for an auxiliary-fired boiler or HTF heater using bagasse is a possible option in Hawaii. Specific issues for any given project would be in the areas of the availability and reliability of the bagasse feedstock and the combustion technology.

Every sugar company in Hawaii today has a power sales agreement with a major utility (Ref. III-7) to supply electricity from the combustion of bagasse. The terms of the agreements vary widely with respect to the firmness of the obligation to deliver energy and capacity, and the specifics of the payments for electricity. Firm power commitments usually come with substantial penalties for failure to meet obligations. The sugar industry in Hawaii is facing uncertainties on costs and profits, and the eventual outcome of these pressures cannot be predicted. It seems unlikely that bagasse can be targeted as an expected resource to supplement a solar thermal electric plant.

If this resource were available, however, it is expected that bagasse-fired units could be available for this application with relatively straightforward modifications of existing technology.

Higher heating value efficiencies of bagasse boilers average about 65%, with performance up to 70% possible with full heat recovery in the form of economizers, air preheaters and flue-gas bagasse dryers (Ref. III-8). Biomass is typically burned in conventional steam generation equipment equipped with specialized combustors to produce steam from 400 psig and 750°F for 25 MW_e units to 1250 psig and 950°F for larger systems (Ref. III-9), which match SEGS requirements well. The low density and low heating value of biomass relative to coal require that the combustion area be somewhat oversized. Direct combustion technologies include stationary and traveling grate combustors, and atmospheric fluidized-bed combustors (bubbling-bed or circulating bed). Compliance with emissions requirements on opacity and particulates continues to be a major challenge with biomass combustion technology. Capital costs for biomass steam generation units are expected to be about 25% higher than the gas-fired equipment currently used on SEGS plants, contributing a small addition to overall plant cost.

Summary Conclusions

Solar system performance in a climate of intermittent radiation will suffer markedly from transient effects and possibly frequent turbine shutdowns, leading to the conclusion that buffer thermal storage could provide an important enhancement to overall performance. Back-up systems would be much less efficient in this regard, and are of more benefit in providing electricity in peak periods when solar radiation is low. Typical electrical demand periods in Hawaii do not suggest that back-up systems are desirable.

Several evaluation have been made of energy storage for SEGS plants. Of the possible energy storage options, sensible heat thermal storage using molten salt or a liquid-solid media are feasible from both technical and economic aspects, though uncertainties exist in each area. Rough calculations indicate that such storage systems could add \$65-130/kW_e, possibly with attractive economics.

OPERATION AND MAINTENANCE COSTS

Operation and maintenance (O&M) costs include labor, spare parts, consumables and normal maintenance equipment requirements. For a SEGS plant, spare parts and consumables are needed for the solar field, power block, and other BOP equipment, including pumps, water treatment chemicals, electrical, instrumentation and control, and extensive mechanical equipment.

The SEGS O&M cost estimate is based on a 22-25 person crew per 80-MW plant, as well as support from a central administrative and maintenance organization. Experience at the SEGS plants shows that O&M

costs are high, but are reducing as improved O&M practices are developed. A value of $81/kW-yr for the fixed O&M, with a negligible value for variable O&M costs, was taken for an 80 MW SEGS plant.

REFERENCES

III-1. HECO Generating Facility Siting Study: Preferred and Alternate Site Technology Report, Hawaiian Electric Company, Inc., Black & Veatch, August 1992.

III-2. M. A. Geyer, "Thermal Storage for Solar Power Plants", Ch. 6 of C.-J. Winter, R.L. Sizmann, L.L. Vant-Hull (Eds.), Solar Power Plants, Springer-Verlag, New York, 1991.

III-3. F. Dinter, M. Geyer and R. Tammer (Eds.), Thermal Energy Storage for Commercial Applications, Springer-Verlag, New York, 1990.

III-4. Phase-Change Thermal Energy Storage, SERI/STR-250-3516, Solar Energy Research Institute, November 1989.

III-5. D. R. Brown and J. A. Russel, A Review of Storage Battery System Cost Estimates, Report PNL-5741 (Batelle Pacific Northwest Laboratory), Richland, WA, 1986.

III-6. D. R. Brown, et al., Chemical Energy Storage System for SEGS Solar Thermal Power Plant, Report PNL-7799 (Batelle Pacific Northwest Laboratory), Richland, WA, 1991.

III-7. C. M. Kinoshita, "Cogeneration in the Hawaii Sugar Industry", Bioresource Technology, Vol.35, pp 231-237, 1991.

III-8. Personal communication with C. M. Kinoshita, Hawaii Natural Energy Institute, Honolulu, Hawaii.

III-9. Electricity from Biomass, Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, U.S. Dept. of Energy, DOE/CH10093-152, 1992.

IV. SITE EVALUATION AND SELECTION

SCOPE AND PURPOSE OF SITE SELECTION EVALUATION

As the populated islands of Hawaii are electrically isolated from one another, it is currently necessary to match electric generation to electric load on an island-by-island basis. Given that SEGS are inherently large, utility-scale systems, opportunities can be deemed realistic only where projects exceed 15 MW in size. The prospects of inter-island electric transmission add considerable flexibility to siting considerations and are considered in this study as a possible, future consideration. We assume that a solar thermal electric plant could take advantage of an inter-island electric grid should future comprehensive planning lead to such a development.

Section II considered electric utility requirements in Hawaii, concluding that the five larger islands are worthy of additional evaluation for potentially supporting SEGS development. The islands identified are Oahu, Hawaii, Kauai, Maui, and Molokai. Envisioned SEGS plant sizes are 80 MW on Oahu and 15-30 MW on Kauai, Maui, and Hawaii. Assuming an inter-island electric transmission cable were feasible, SEGS opportunities would be enhanced, particularly on the island of Molokai. With adequate transmission capability and a satisfactory handling of perceived social hurdles, an 80-200 MW SEGS project in western Molokai may prove well suited to exporting power to Oahu and/or Maui. It is noted that Lanai was eliminated as a potential SEGS site due to the island's small local electric load and the relative advantage exhibited by Molokai's proximity to the electric load centers on Oahu.

This siting evaluation endeavors to identify locations throughout the Hawaiian Islands which appear best suited for the development of SEGS power plants. To this end, several general candidate areas have been identified based principally upon general topography, direct insolation, and current land use. These candidate sites are then evaluated according to several critical siting issues. The bulk of the information contained in this report was gathered during site visits in September 1990 and January 1991. Some additional information has been acquired and included.

This section first discusses the pertinent siting criteria which determine the viability of a prospective SEGS site. After a description of the overall site evaluation methodology, each siting factor is discussed with respect to its general relevance to a hypothetical SEGS project and the specific evaluation criteria which are used to assign raw scores to each candidate site. The next subsection identifies the candidate SEGS sites considered in this study. A synopsis discussion of salient siting criteria affecting potential SEGS development is presented for each candidate site. This material includes general comments about the site as well as scoring assignments and summary discussion for each primary siting factor.

The results of the evaluation process are then presented in a site evaluation matrix. This matrix summarizes the raw scoring and weightings which were assigned to each siting factor for every candidate site. Each site is also categorized as to its relative potential for SEGS development, that is, the sites are classified as either preferred, acceptable, or not recommended.

To conclude the section, comments are made on the scope of the likely permitting requirements for a SEGS plants in Hawaii.

A listing of various reports, maps, data and other significant sources which were utilized in the siting assessment is presented in Appendix C.

METHODOLOGY AND DISCUSSION OF SITING ISSUES

Siting Factors for SEGS

The feasibility of pursuing SEGS facilities in Hawaii is contingent upon the identification of sites well suited to the technology. Desirable physical characteristics of a favorable SEGS site include high direct (beam) insolation, flat topography, suitable water supply and waste water discharge availability, access to nearby electric transmission facilities, and availability of auxiliary fuel supplies. Additionally, socio-political issues such as existing land use and cost, potential environmental and cultural impacts, and local public acceptance can strongly influence the feasibility of a SEGS project. Many of these characteristics are identical to those of conventional power plants, with the prominent exceptions of solar radiation levels, extensive land area needs, and the much reduced importance of air emissions, fuel delivery, and fuel and waste handling. If a SEGS plant design incorporates thermal storage rather than auxiliary fuel back-up, concerns over fuel related siting characteristics can be eliminated altogether.

Based on the experience of developing and evaluating numerous sites for SEGS plants over the past decade, siting issues can be put in categories of relative concern. Table IV-1 presents fifteen (15) siting factors, categorized into three distinct levels of importance, as guidelines in screening potential sites for SEGS-type development in Hawaii. These groupings are based on *technical* potential. Characterization of these factors on some other basis—for instance, political or environmental potential—would probably lead to a reclassification of the relative importance of some siting factors.

This overall set of siting factors would be of general relevance for SEGS projects anywhere on the globe; however, the relative influence of individual siting factors may be rearranged. For example, land use and cost, which are not of great significance for remote desert sites on the mainland, are unquestionably primary issues on the Hawaiian Islands. In a detailed comparative siting analysis focused on a small number of sites, economic values would be assigned to all of the siting factors, where possible, and a quantitative trade-off study would be carried out. In a broader, more preliminary assessment of this type, the evaluation of potential sites using these siting criteria lean more heavily on subjective judgment developed from the extensive SEGS experience supplemented, to the extent possible, by site visits and cost estimates specific to Hawaii.

Few, if any, areas in Hawaii embody every desirable characteristic for a solar thermal electric plant at a single site. Hence, the evaluation of siting criteria is an important yet sensitive step in the assessment of SEGS potential in Hawaii.

Table IV-1. Siting Factors for SEGS Power Plants in Hawaii

Primary	Secondary	Tertiary
Insolation	Back-up/Storage	Accessibility
Topography/Geology	Natural/Military Hazards	Labor Pool
Water/Waste water	Surface Hydrology	Legal Issues
Land Use/Cost	Air Quality	Political Issues
Electric Transmission	Biology	
	Corrosion	

(Note: Groupings are based on authors' assessment of *technical* impact; different criteria or local input incorporating a diverse spectrum of interests may lead to reclassification of some siting factors.)

Site Evaluation Methodology

As discussed earlier, the evaluation of utility requirements resulted in the selection of the islands of Oahu, Hawaii, Kauai, Maui, and Molokai for further consideration as potential sites for SEGS power plants. In order to compare the relative merits of various sites on five different islands, the site evaluation methodology has been structured and prioritized such that each siting factor reflects its relative economic impact on the cost and performance of a hypothetical project.

The initial step in the site selection procedure was a preliminary screening process which identified several general candidate areas on each of the five islands under consideration. The screening was principally based on solar radiation level, topography, and incompatible land use. The next step entailed evaluation of the candidate sites over the broad range of siting issues listed in Table IV-1. For each site, relative scores were assigned to each siting factor. The scores ranged from 1 (worst) to 5 (best). A score of zero (0) indicates that the particular siting issue was regarded as a fatal flaw.

Appropriate weighting factors were developed based on the perceived importance of each siting factor with respect to economic impact. The relative impact of the three categories of siting criteria were arbitrarily assigned relative weightings of 75 for all primary factors, 15 for all secondary factors, and 10 for all tertiary factors. The sum of all weighting factors is 100. The weighting factors for primary siting criteria were rooted in actual costs for mainland SEGS projects then adjusted, to the extent possible, to reflect Hawaiian conditions. Secondary and tertiary factor weightings resulted from our best judgment of their relative technial importance. Assigned weightings may differ if based on local opinion.

The product of the weighting factor and siting factor raw score yielded a weighted score for each of the siting criteria. By summing the weighted siting factor scores, a cumulative relative score was obtained for each site. Since the final scores are strongly influenced by subjective judgments, their absolute values are less important than their use in showing the relative attractiveness of the sites. Hence, the results of the evaluation have been used to classify the sites into three general categories: preferred, acceptable, and not recommended.

The siting criteria relevant to SEGS projects in Hawaii are discussed next. Each factor is considered with respect to its relative significance to a hypothetical SEGS plant. Additional discussion details the evaluation criteria utilized to determine the raw scores (1-5) assigned to each candidate site. For primary, secondary, and tertiary siting factors, information presented below in the discussions of evaluation criteria serve as the basis for the value assignments applied subsequently, and as the key to details and abbreviations contained in the site evaluation matrix.

PRIMARY SITE EVALUATION CRITERIA (Total Weighting = 75)

Insolation

General Discussion: Sunshine is the raw fuel for a any solar electric device. The performance of a concentrating solar thermal electric power plant is directly tied to the available direct normal insolation, measured in kWh/m^2. For a solar performance goal of a stated level of annual electrical output, a location which embodies relatively less annual direct insolation requires a proportionately larger solar array field. On the other hand, the maximum short-term direct normal insolation flux (usually expressed in W/m^2), while influenced by site elevation and local atmospheric turbidity, is not expected to vary significantly throughout Hawaii. Accordingly, maximum electrical output per unit area of SEGS solar field (kW/m^2) should be quite similar for any low elevation site in Hawaii. Because site insolation level is the most important factor determining the solar field acreage required for a specific SEGS development, it has a major impact on both initial capital cost as well as operating revenues.

Another important insolation issue which is expected to impact performance in Hawaii is the frequency of cloud transients. Cloud-free days in Hawaii are rare. Typical sky conditions for the majority of Hawaii

exhibit numerous small, broken clouds which block the sun's rays as they drift with the prevailing breezes. Thermal power plants must maintain certain minimum heat input conditions to warrant operation of their steam cycle. For SEGS plants, this condition translates to a threshold direct insolation flux of approximately 400 W/m^2. In general, an increase in frequency of cloud transients results in a higher frequency of plant cycling, thereby reducing SEGS net performance. Section III discussed the use of thermal energy storage and/or an auxiliary fueled back-up system to deal with this situation.

Weighting: 40 (out of a total for all factors of 100)

Evaluation Criteria: The best long-term measured direct normal insolation data base in Hawaii is the ten-year record from Holmes Hall at the University of Hawaii at Manoa. Raw scores for insolation are based on the estimated percentage higher (+) or lower (-) than the typical annual direct normal insolation data for the Manoa campus (5.0 kWh/m^2/year). By comparison, the existing SEGS facilities around Daggett, California would compare as a +48% (7.4 kWh/m^2/year). For additional information on insolation in Hawaii, refer to Appendix B of this report.

Value	Insolation
5	>=+15%
4	5% to 15%
3	-5% to +5%
2	-15% to -5%
1	<= -15%

Geology/Topography

General Discussion: Due to the diffuse nature of solar energy, solar power plants require a large land area to collect an appreciable amount of energy. The extensive solar collector fields of the Mojave Desert SEGS installations were graded into several adjacent level terraces. Numerous benefits accrue from construction on level terrain; these include uniformity of fabrication and assembly of parts, simplified construction techniques, and ease of maintenance. Site preparation costs associated with grading, digging pylon foundations, slab designs, and road construction are a function of soil conditions (geology) and site surface characteristics (topography). These costs are affected by the effort and expense required to grade a particular soil type (i.e. loose sand versus lava) as well as the engineering requirements, dictated by soil conditions, for slabs, footings, and roads.

Weighting: 15

Evaluation Criteria Scoring for topography is based on the typical percent grade in the siting area, using the lower value when ranges are provided. Geological information provides a secondary influence on scoring. In the site evaluation matrix, geological information is included parenthetically. This information, if included, identifies the typical soil type (lava, clay, loam, sedm = sedimentary) and/or special terrain features making SEGS site preparation more difficult (stony, erod = eroded, mud flat, sogy = high water table).

Value	Geology/Topography
5	< 0.5% grade (no gullies, sedimentary geology)
4	0.5 to 2% grade
3	2 to 3.5% grade *or* 0.5 to 3% grade (lava), mud flats
2	3.5 to 5% grade *or* >=3% grade (eroded and stony) *or* >=3% grade (lava)
1	5 to10% grade
0	>=10% grade

Waste Water Disposal/Water Supply

General Discussion: Rankine cycle steam power plants, such as SEGS plants, require water for cooling, feed water makeup, and plant service needs. In addition, a SEGS plant uses water for periodic washing of the collector field mirrors. The single largest water requirement of typical SEGS installations is for cooling water used by wet cooling towers. In California, SEGS annual water requirements are approximately 10 acre-feet per MWe net (about 3.25 acre-feet/GWh net), with about 80% used for cooling, 15% of feedwater makeup, and 5% for mirror washing. Dry cooling towers, which blow ambient air across dry heat exchanger surfaces, would eliminate the cooling water requirement of the plant, but at slightly higher capital and operating costs and with some reduction in plant performance. Mirror washing requirements in Hawaii would be considerably less due to the more frequent and abundant rainfall in Hawaii. Mojave desert SEGS plants experience only about 4 inches of rainfall per year, most of which comes in a few heavy storms during the winter months.

Waste water disposal may be a more difficult requirement in Hawaii than securing an adequate water supply. With wet cooling towers, some of the water used to wet the tower heat exchanger surfaces will evaporate as pure water and be lost as drift. Typically, cooling water will continue to be re-used until the increasing concentration of impurities renders the water quality unsuitable. SEGS facilities in California dispose of the plant waste water from the cooling tower and the power system by discharging to a lined evaporation pond, which is best suited to hot, low humidity desert conditions. Other waste water discharge methods include injection wells and treatment and release to a reservoir or ocean.

The most likely waste water disposal method in Hawaii is by underground injection well. In areas where there is a danger of injected fluids contaminating good quality ground water resources, such wells are prohibited. The Hawaii Department of Health maintains maps for the entire state which delineate Underground Injection Control (UIC) Lines. These maps clearly designate the areas in which UIC wells are permitted and where they are prohibited. Due to sea water intrusion, all coastal areas permit UIC wells. Only limited information was secured during this study pertaining to the precise location of UIC lines in each siting area. Some potential sites are known to be in locations which permit injection wells (UIC), other sites are thought to permit UIC wells in the general vicinity, but off-site (oUIC).

Coastal areas offer the opportunity for once through cooling, where large volumes of water, perhaps 125 acre-feet/GWh net, are pumped through the plant condenser and returned directly to the sea. These systems are desirable from a plant performance standpoint, but are expensive and difficult to permit due to the thermal characteristics of the discharge. The Keahole Pt. area offers the unique opportunity to utilize deep ocean cooling water from the Natural Energy Laboratory of Hawaii (NELH), without the expense and permitting concerns of constructing a dedicated ocean outfall. Areas designated as Ground Water Resource Zones (GWRZ) have restricted water resources which pose special concerns for both supply and discharge. Generally, any type of water well will be shallower, and therefore cheaper to construct, in coastal areas.

Weighting: 4

Evaluation Criteria: The scoring for this factor is based principally on the methods available for waste water disposal at the site. When included, the parenthetic abbreviation pertains to water supply.

Abbreviations

UIC	=	Underground Injection Control wells permitted on site
oUIC	=	off-site injection wells permissible in general area near site; or, location of UIC line unknown
re-use	=	potential to re-use effluent from other facilities
NELH	=	deep ocean sea water for cooling from the Natural Energy Laboratory of Hawaii
GWRZ	=	potential Ground Water Resource Zones: area with restricted water resources.
Dry	=	Dry cooling only due to lack of local water supply.

Value	Waste Water Disposal/Water Supply
5	UIC permitted & plentiful fresh water supply
4	UIC permitted in area & brackish/sea water supply
3	UIC possible in area & brackish/sea water supply
2	UIC possible in area & questionable supply of any quality
1	UIC not allowed & questionable water supply of any quality

Land Use/Land Costs

General Discussion: An 80 MW SEGS plant in the Mojave desert requires approximately 400 acres of land (general rule-of-thumb: 5 acres/MWe). This land requirement in California is a significant and important issue, though it is generally not critical due to the combination of relatively low land costs and reasonably high availability. The land requirement of a SEGS is a function of available insolation levels. Due to the lower insolation prevailing in Hawaii, it is expected that the land need for Hawaiian sites will be at least 6 acres/MWe.

Hence, 30 and 80 MWe plants in Hawaii would require approximately 180 and 480 acres, respectively. Industrial tracts of that size are not commonly available in the State. Furthermore, suitable tracts which embody favorable SEGS siting characteristics are even rarer. The apparent shortage of suitable land tracts, coupled with prevailing high land values in Hawaii, elevates the importance of land use and land cost to the status of a primary siting factor.

There are a very limited number of land owners possessing tracts potentially suitable for SEGS development in Hawaii. These owners include various private, state government, and federal government entities. Most tracts under consideration as SEGS sites are currently designated for use as agriculture or conservation. The willingness and interest of current property owners to make land available for solar thermal electric development has not been investigated within the scope of this assessment.

Weighting: 10

Evaluation Criteria Scores are based on estimated land costs and expected land use. The prices assigned for sites reflect a high uncertainty at this time, and expected land use is based on our best judgment from limited information. Rough estimates of land costs are provided in $/acre (i.e. 40K = $40,000 /acre). In many areas, no tracts are expected to be for sale. In some cases, major land owners are noted according to the key below. A site contained wholly within a National Park is regarded as a fatal flaw, and is assigned a value of zero. Due to the high land values in Hawaii, leasing land for a SEGS facility is considered a likely option.

	Purchase ($)	Key for Land Ownership Abbreviations	
5	<=10K	HH	Hawaiian Homelands
4	10K to 20K	HI	State of Hawaii
3	20K to 50K	USN	United States Navy
2	50K to 100K	USA	United States Army
1	>100K	USNP	US National Park (= 0)

Electric Transmission

General Discussion: Electric generating facilities are connected to the load via transmission lines. A new power plant requires a substation and connecting transmission lines to tap into the existing utility transmission network. In addition, a large capacity addition often has other far reaching impacts on the network, generally requiring down-line transmission line or system improvements. However, if added at the appropriate part of the network, additional capacity can improve the reliability and quality of the utility transmission system. In summary, electrical transmission inter-connection requirements are very specific to the MW size and location of a proposed project, and must be considered in the context of the existing transmission system.

A few sites are in load growth areas and would be highly desirable locations for generation additions. This benefit may be included in higher capacity and energy valuation from the utility as well as minimizing required transmission line additions. Other areas will require substantial transmission line upgrades. It should be noted, however, that some of the siting regions considered in this assessment (especially on Hawaii) are quite large and do not permit good estimates of likely transmission needs or costs. The possibility of an inter-island electric transmission cable is considered for Molokai, which may be the best opportunity for a large scale (greater than 80 MW) SEGS project in Hawaii.

Weighting: 6

Evaluation Criteria: The relative rating of the desirability to the host utility of a site location for the addition of electric generating capacity is given as: Good, OK, or Poor. The assumed miles of electric transmission line required to inter-tie a proposed SEGS plant with the local electric transmission grid are given parenthetically in the matrix. Sites which require an undersea electric transmission cable are indicated by: cable.

Value	Electric Transmission
5	Existing substation/adequate transmission on site
4	Good area for capacity & <10 miles of transmission required
3	OK area for capacity & <10 miles of transmission required
2	>10 miles of transmission required
1	Inter-island cable; major transmission project required

SECONDARY SITE EVALUATION CRITERIA (Total Weighting = 15)

Back-Up/Storage

General Discussion: To improve reliability, SEGS plants in California utilize natural gas as a back-up fuel. Since the power block of a SEGS plant includes a conventional steam turbine, its configuration lends itself to a relatively inexpensive addition of a back-up system. Although there is no natural gas in Hawaii, there are numerous other alternatives including diesel, fuel oil, synthetic natural gas, and various biomass fuels. Another method of improving plant reliability is by adding thermal storage capacity to the plant. For instance, if a SEGS plant could store up two hours of thermal energy, the plant would still be able to operate continuously through brief cloud or rain conditions. The issue of SEGS back-up systems, including both back-up fuel and storage scenarios, was treated in section III.

Weighting: 3

Evaluation Criteria: Thermal storage capacity is not a site-specific issue, but a back-up fuel option has site-specific implications associated with transport distances and/or biomass and pipeline gas availability. Scoring for this siting factor is based on fuel transportation and storage charges. Additional weight was given areas which may be served by pipeline.

Natural/Military Hazards

General Discussion: The state of Hawaii is subject to a great variety of natural disasters. Among these are active volcanoes, earthquakes, tsunamis, hurricanes, floods, and high winds. In all but the most severe cases, power plant components can be engineered to survive these conditions. However, over-designing plant systems for severe condition survivability would increase the capital cost of a SEGS project. Hence, the increased costs must be weighed against the relative risk imposed by each of these natural disasters.

Several tracts considered as SEGS sites are near or on military reservations. The close proximity of a SEGS plant to military facilities increases the risks of plant damage due to acts of war. Peacetime and wartime military accidents also introduce the potential for negatively impacting a nearby SEGS project. Risks posed by military mishaps and acts of war, no matter how remote the chances of occurrence, may make use of military reservation property for a civilian SEGS project extremely difficult.

Weighting: 3

Evaluation Criteria: The scoring for this factor considered the potential for natural hazards, including hurricanes, tsunamis, volcanic eruptions, and earthquakes, as well as perceived land use availability in areas where hazards due to military accidents or acts of wars are expected. Value assignments for natural hazards are based on historical events. It should be noted that any site could be vulnerable to military hazards and certain natural hazards even if there has been no history of such an event in that area.

Value	Natural/Military Hazards
4	Non-coastal areas which are considered to be exposed to lower risks than average
3	Typical site with no history of hazard events
2	Historical demonstrated hazard in part of the siting region or some exposure to military risks
1	High military hazard risk (blast zone)

Surface Hydrology

General Discussion: Surface hydrology pertains to the way in which the topography, geology, and vegetation of a particular site and its surroundings contribute to water runoff during rainfall events and floods. Given the large area covered by a SEGS power plant, large storm water runoff handling systems which require extensive dyking and drainage canals impact the capital cost of a SEGS project. Plant components which are engineered to survive flooding conditions will also result in increased costs.

Weighting: Surface hydrology is not considered in the evaluation matrix.

Evaluation Criteria: This factor is not explicitly considered in the evaluation matrix, as it would require analysis of a broad region surrounding a specific site. To some extent, certain aspects of this factor are reflected within the consideration of Topography/Geology.

Air Quality

General Discussion: Environmental regulations designed to insure local air quality standards impact the design, operation, and performance of all large power plants which utilize combustion processes. For a SEGS plant, air quality is an issue if a conventional fueled or biomass back-up system is to be incorporated into the solar power plant design. The level of emissions depends entirely on the fuel type and operating scenario for the supplementary thermal source. Additionally, there are lesser emissions considerations associated with the heat transfer fluid utilized in the solar field heat transport system.

The most significant air quality considerations pertain to regulated constituents of combustion such as oxides of nitrogen (NOx), oxides of sulfur (SOx), volatile organic compounds (VOC), and particulate

matter. In some cases, expensive pollution control equipment can be required to comply with environmental regulations. It is important to note that air quality is a very dynamic discipline, and future changes in air quality requirements which could potentially impact the operation of both existing and future power plants should be considered when evaluating future generating options.

Weighting: 3

Evaluation Criteria: Air quality standards are the same for all sites under consideration, although the permitting process may be somewhat more involved for certain sites. Different air basins have different ambient qualities, and some are more susceptible to exceeding allowable concentration limits than others. Site-specific air quality monitoring would likely be a prerequisite to approval of air permits in most areas. The rudimentary air quality scoring in this analysis is based on the generalization that ambient air quality will be worse in developed areas, especially if there are know point source emission facilities, and if the local topography inhibits dispersion.

Value	Air Quality
4	Predominantly undeveloped areas & modestly developed areas with high winds
3	Typical site
2	Area with heavy industrial development (southeast Oahu)

Corrosion

General Discussion: As with any power plant, many of the materials utilized in a SEGS installation are subject to potential degradation in their natural environment. Among the principle degradation concerns is corrosion of metal parts throughout the power plant, which can vary significantly in severity between different sites. Sites exhibiting windblown salts or caustic emissions from volcanoes are expected to be higher corrosion risks resulting in an accelerated replacement schedule (higher operating costs) for components subject to degradation.

Weighting: 3

Evaluation Criteria: Quantifying this factor at all sites would be an extensive undertaking and is dealt with in a cursory fashion for this evaluation. In addition to consideration of wind-borne debris and salt corrosion along the coastline, areas in the lee of Mauna Loa and Kilauea may risk corrosion from acids vented from these active volcanoes. Relative corrosion hazards have been estimated by considering the proximity to the coast, wind environment, and elevation of each prospective SEGS site.

Value	Corrosion
4	High altitude site (Saddle Road)
3	Typical Hawaiian site
2	Windy coastal areas *or* area immediately downwind from active volcano

Biology

General Discussion: Due to the large tracts of land which are required for solar power plants, potential impacts from SEGS construction and operation can pose significant impacts on the natural environment. For this reason, an Environmental Impact Statement (EIS) will generally be required to minimize the environmental impacts of the development, and, in the case of listed endangered plant and animal life, ensure that there will be no adverse impacts. The EIS is a time consuming process, expensive, and can potentially stop a project if unacceptable potential impacts are determined.

Weighting: 3

Evaluation Criteria: Scoring is based on the assumption that developed areas are unlikely to contain sensitive flora or fauna. Sites with large undeveloped areas are more likely to host sensitive species. When protected species are known to be affected by a prospective SEGS site, mitigating procedures to assure that no adverse impacts occur will be required. Hawaii's listed endangered species are primarily concentrated in forest areas, none of which are thought to be directly affected by any of the potential SEGS sites. Projects involving an undersea cable will require a thorough EIS due to the numerous protected marine species in Hawaiian waters.

Value	Biology
4	Highly developed areas with unlikelihood of undisturbed flora or fauna *or* barren lava field
3	Typical Hawaiian site
2	Sites known to have endangered species *or* sites requiring cable with potential marine impacts
1	Site on National Park land, EIS required, impacts judged closely

TERTIARY SITE EVALUATION CRITERIA (Total Weighting = 10)

Accessibility

General Discussion: Construction of a SEGS plant entails the mobilization of hundreds of workers and the delivery of large amounts of materials and equipment. If a site has restricted access, the higher delivery cost of each plant component will reflect in the total capital cost of the project.

Weighting: 2

Evaluation Criteria: The simplified scoring utilized in this evaluation considers the distance of each site from the nearest seaport to infer relative land transportation costs. Practically all sites are easily accessible, requiring less than one hour of overland transportation from the nearest harbor.

Value	Accessibility
4	Southeast Oahu sites near deep draft harbor
3	Maui, Hawaii, Kauai, Molokai and north Oahu sites

Labor Pool

General Discussion: The peak manpower requirements for the construction schedule utilized to complete 80-MW SEGS projects in California in less than 12 months was about 1000 workers. A smaller plant or longer construction period would reduce this requirement. If construction is in a remote site, the local labor pool will likely be insufficient to provide the necessary trades. If workers must be brought in and housed near a site, there must be consideration given to the social impacts of this size work force on the local community.

Weighting: 2

Evaluation Criteria: With the extensive resort development in Hawaii, skilled construction workers are plentiful. However, during growth periods labor may be in high demand and less available. A large project on Molokai (total population 6,000), would be expected to require labor from other islands. The available labor pool is not perceived to be a major problem at any of the other sites, particularly not on Oahu.

Value	Labor Pool
4	Oahu sites
3	Maui, Hawaii, Kauai sites
2	Molokai sites

Legal Issues and Political Issues

General Discussion: Although these categories can be critically important siting factors, they are also the most broad and variable. This category includes many state and local concerns with energy planning, land use, and energy resource management. Strong utility and government support will, of course, ease the path for a project of this nature. Examples of these issues include such items as applicability of solar tax credits for SEGS plants and the granting of land use permits.

Weighting: 6 (Legal Issues = 3 and Political Issues = 3)

Evaluation Criteria: Since these issues are potentially very important but defy definition and prediction at this stage, they are considered to be of tertiary importance in the matrix. Unlike geological characteristics, these issues can and often do change rapidly. Scores for these factors are considered collectively based on general perceptions regarding public acceptance and political enthusiasm.

Value	Legal Issues and Political Issue
4	Site in which government enthusiasm was perceived (e.g., old airport site on Maui)
3	Typical Hawaiian sites
2	Military reservation sites *or* sites with perceived difficulty with public acceptance
1	Use of National Park land, likely legal hurdles

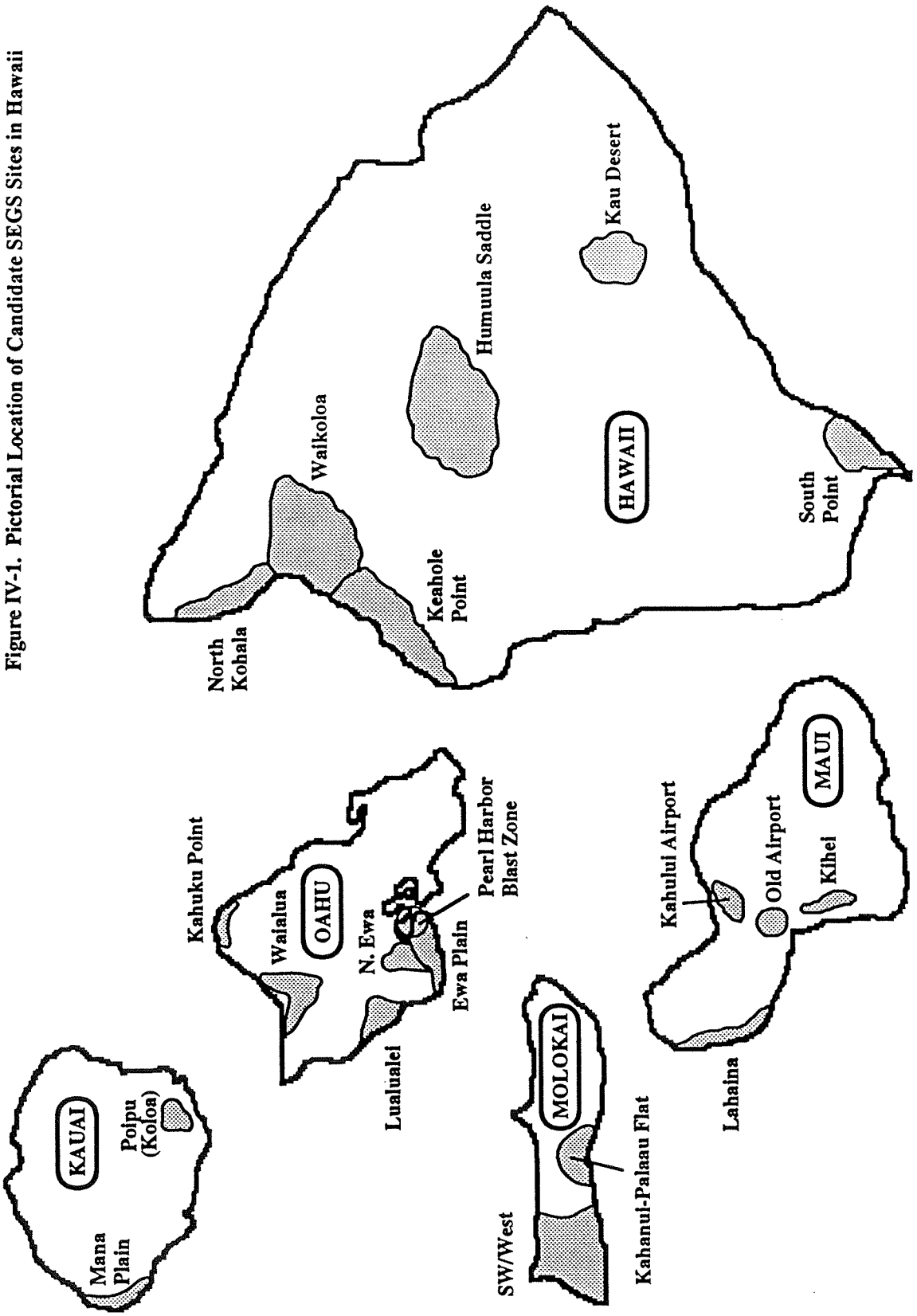


Figure IV-1. Pictorial Location of Candidate SEGS Sites in Hawaii

DISCUSSION OF CANDIDATE SITES

Selection of Candidate Sites

As described earlier, the site selection methodology begins with an initial screening of all islands in Hawaii and progresses with the assimilation of detailed information pertaining to a broad range of siting criteria for each identified candidate site. This initial step incorporated direct insolation, topography, and existing land use as its screens. First, areas suspected of having relatively good direct insolation were identified. Generally, this focused attention to the southwestern side of islands and mountains, in the lee of Hawaii's northwesterly trade winds. Secondly, USGS topography maps were analyzed to determine the flatter areas within these sunny regions. Thirdly, land use and land ownership maps contained within the *Atlas of Hawaii* were consulted to determine if some of the previously identified areas could be excluded. Uses such as urban development, park land, and military facilities were generally considered to be incompatible with use as a SEGS power plant. This method produced candidate SEGS sites on each of the islands.

The general siting areas which passed the initial site screening process are identified geographically on the candidate site map, Figure IV-1. Examination of this map shows that areas under consideration are generally on the leeward side of mountains. A few areas are on windy island points which may be relatively clearer than their surroundings if cloud formation typically occurs downwind from their location. The Humuula Saddle on the Big Island, at elevation 6,500 feet, was selected based on the premise that it may be high enough to escape most of the cloud and other obscuring phenomena which occur in the atmosphere's trade wind inversion layer. Each of these sites is evaluated with regard to specific siting factors according to the evaluation criteria outlined in the previous section, and the results integrated in a site evaluation matrix.

Description of Candidate Sites

Discussion of the candidate sites is organized by island. Material presented for each prospective site begins with a general description identifying the site's location in brief narrative form. The general description may also discuss exceptional characteristics which distinguish the site from others on the island. The next block of material evaluates the site with respect to the primary siting factors of direct insolation, topography/geology, water supply/waste water discharge, land use/cost, and electric transmission. For sites which exhibit noteworthy secondary or tertiary siting factors, additional material is appended to the site descriptions pertaining to these factors. Site-specific information is judged against the evaluation criteria to determine a raw score for each siting factor. The scoring assignments appear to the right, immediately before the narrative discussion of each siting criterion. Scores range from 1 to 5, with 5 being the best and 1 being the worst. A score of zero (0) indicates that the factor is regarded as a fatal flaw.

OAHU SITES (assumes 80 MW SEGS sites)

OAHU: 1) Pearl Harbor Blast Zone Area

general The blast zone is a restricted use buffer region extending 7,405 feet radially around the munitions magazines located on the West Loch of Pearl Harbor. Undeveloped tracts within the blast zone include approximately 1000 acres in sugar cane fields (zoned for agriculture) on the west side of West Loch (Honouliuli area) and about 1000 acres on the Waipio Peninsula to the northeast of West Loch. The principal appeal of locating a SEGS here is that there are very few other sufficiently large tracts which may be economically available for this use on Oahu. Quite simply, an expansive SEGS solar field would appear to be a lower value use than most competing development projects in southwestern Oahu. Furthermore, the blast zone area is physically an excellent site. The blast zone has very limited potential uses since the Navy prohibits occupied civilian structures within this area. With few competing land uses for this tract, it is *assumed* that the Navy may be receptive to allowing a large solar field within the blast zone. Any occupied structures, such as the power plant control building, would have to be located outside the blast zone on adjacent property. It is noted that HECO is investigating the Waipio Peninsula as a preferred location for a future baseload generating plant of up to 800 MW. Additionally, the Navy is interested in developing the blast zone for limited base recreational facilities. Thus far, the US. Navy's position regarding the potential use of the blast zone for SEGS use has not been ascertained. Clearly, the potential risk of catastrophic damage to the solar collector field from a munitions explosion would have to be carefully evaluated.

insolation-4 Annual direct insolation is estimated to be 5% higher than Manoa—probably as high as any site on Oahu.

topo/geology-5 Entire area is nearly level—slope is on the order of 0.2%. Site elevation is predominantly about 20 feet MSL. A thin layer (8-20 inches) of stony silty clay loam soils over coral limestone, with occasional coral outcrops, prevail over the entire site. Some areas have been converted to cultivation by covering with fill material.

water-4 Salt water and brackish water are readily available. Injection wells are permissible on site.

land-3 Most of area is owned or controlled by the U.S. Navy. Adjacent land owners include the Campbell Estate and small land owners in the Honouliuli area, and various federal entities, including the FCC, on the Waipio Peninsula. Cultivated land is currently leased to Oahu Sugar for about $350/acre/year. In addition to naval facilities, land uses in the immediate vicinity include the Ted Makalena Golf Course on the Waipio peninsula.

transmission-4 The site is relatively closer to the majority of HECO's load than the bulk of HECO's existing generation facilities. In the Honouliuli area, there are 46 kV transmission lines on the tract and several 46 kV substations within 3 miles of the site. On the Waipio peninsula, there are three 46 kV substations in Waipahu which are only about 1 mile away.

back-up-4 Fuel delivery via pipeline is probable since there are existing petroleum products and synthetic gas pipelines just north of the site. Overland fuel transportation, if required, should be relatively inexpensive. Trucking charges would add only about 0.5% to the cost of delivered diesel.

OAHU: ***2) Sugar Fields Inland (Mauka) from Ewa***

general This region encompasses the sugar fields north of Ewa, particularly those north of Highway H1 along Highway 750. Going in the direction away from the ocean (mauka), most physical characteristics deteriorate with regard to their potential as SEGS sites, but the land becomes cheaper and more likely to be available. Although Hawaii would like to insure that some farm lands endure in order to preserve the state's historical agricultural character, the future status of the sugar industry in Hawaii is unknown.

insolation-3 Annual direct insolation is estimated to be 3% lower than Manoa for the bulk of the site. Direct normal is expected to deteriorate in the mauka direction due to orographic clouds associated with the Honouliuli Mountains. Near Ewa, direct normal is comparable or perhaps slightly better than Manoa.

topo/geology-3 North of Highway H1, slope ranges from 2-5%. The sugar fields northwest of Ewa are more level (slope 1-2%) but less likely to be available for SEGS development. Site elevation ranges from 60 feet to perhaps 700 feet MSL. Principle soil types are silty clay and silty clay loams underlain by igneous rock and alluvial gravel. Near Ewa, sticky, plastic clay soils with high shrink-swell potential prevail.

water-3 Water suitable for irrigation is generally available, however, wells are relatively deep -- scaling approximately with elevation above MSL. Waste water injection wells are not thought to be permissible on site. In some cases, waste water may have to be piped a few miles to a UIC region, discharged to a municipal system, or reduced through use of dry cooling towers.

land-3 Most of lands in these areas are owned by the Campbell Estate and the state of Hawaii. In the purely agriculture areas, land prices are roughly $30,000/acre; lease rates range from $300-1500/acre/year. Some sources have reported that the state has a strong desire to keep these areas in agricultural production.

transmission-3 There are a few 46 kV substations scattered about the general site area, most of which spur off of a single 46 kV transmission line. Several 138 kV lines cut through the site, however, splicing into some for an intermediate substation between Kahe and Waiau may be impractical.

OAHU: **3) Ewa Plain**

general This site region stretches from Barber's Point toward the east over the entire Ewa Plain. Physically, this is the best area on Oahu: best direct insolation, flat, transmission access, only area with fuel pipelines, and most accessible to shipping. The one drawback, likely fatal, is the expected unwillingness/ impracticality of the Campbell Estate to sell or lease enough land for this comparatively low-value use. Massive development is planned and currently underway for the entire southwestern corner of Oahu.

insolation-4 Annual direct insolation is estimated to be 5% higher than Manoa for the bulk of the site. Portions of this region are thought to experience the highest direct insolation on Oahu.

topo/geology-4 Entire region is quite flat with slopes of less than 1%. Site elevation ranges from sea level to about 60 feet MSL. Principle soil types are coral outcrops near coast; elsewhere, coral which is thinly covered by stony silty clay loam soils.

wate-4 Water supply by sea water or brackish water wells (50 feet deep) and waste water disposal by underground injection well (100+ feet deep) are readily available for most of the region.

land-1 Nearly the entire region is owned by the Campbell Estate and the U.S. Navy. Massive development is planned and currently underway for the region. Purchasing an unimproved tract in the Campbell Industrial Complex currently starts at about $200,000 per acre. A 30 year lease term for a SEGS power plant is expected to be perceived as an unreasonably long commitment by the Campbell Estate. When the entire Ewa plain is considered, there may be a compatible tract which could be acceptably permitted for SEGS use. If found, acquiring use of this site is expected to be expensive.

transmission-3 This area is a well developed section of HECO's 46 kV transmission network. There are numerous substations and several generating facilities, particularly in the Campbell Industrial Complex. Additional generation in the area is possible but not desirable since there is already over 1000 MW of generation in this corner of the island.

OAHU: 4) Lualualei

general The Lualualei valley is a large flat valley situated to the west of the Honouliuli Mountains in southwestern Oahu. The valley penetrates several miles inland and is bounded at the coast by Nanakuli to the south and Waianae to the north. The only extensive sites (400 contiguous acres) are located on federally-owned Navy Radio Transmission Facility property. The current land ownership is perceived to be a serious conflict.

insolation-3 Annual direct insolation is estimated to be about the same as Manoa. In some areas, there may be a limited horizon to the east due to the Honouliuli Mountains.

topo/geology-4 The better areas within the region are relatively flat, with slopes ranging from 0.5% to 1%. Most of the area is vegetated with small scrubby trees. Site elevation ranges from 20 feet to perhaps 400 feet MSL. Principle soils are stony silty clay loam and sticky, plastic clay exhibiting high shrink-swell potential; underlying material below 4 feet is coral, gravel, sand, or clay.

wate-3 Salt water and brackish water are readily available near the coast. Deeper into the valley, fresh water resources may be adequate. Waste water injection wells near the coast are probable. In some cases, waste water may have to be piped a few miles toward the coast to a UIC region. It is noted that the existing facilities and conceptual baseload additions at Kahe utilize once-through cooling with an ocean outfall.

land-1 The bulk of the property in the valley is controlled by the Naval Radio Station. Much of the coastal property is owned by the State of Hawaii and Hawaiian Homelands. It is assumed that the Navy would not be receptive to a private power plant located within the Naval Facility. A project utilizing Hawaiian Homeland property may be possible after extensive negotiation.

transmission-2 The area has little electric load and is only a few miles north of the Kahe power plant -- the largest electric generating facility in Hawaii. There are currently four 46 kV substations located in the Lualualei valley, although new generation here is expected to necessitate some transmission line additions. With the Honouliuli Mountains separating the valley from Hawaii's major loads, transmission line construction would be significantly more expensive than over level terrain.

OAHU: 5) Waialua Area

general The Waialua area stretches inland from Dillingham Air Force Base to Kawailoa. Some of the site's drawbacks include low insolation, wind and corrosion hazards, and very limited existing electric transmission.

insolation-2 Annual direct insolation is estimated to be 10% lower than Manoa.

topo/geolog-3 Areas near the coast have slopes of less than 1%. Sugar cane fields inland from Waialua are sloped from 2-5%. Site elevation ranges from sea level to perhaps 600 feet MSL. Principle soils are clay over muck near shore and silty clay inland.

water-3 Water suitable for irrigation is generally available; sea water and brackish water are available near the coast. Waste water injection wells are not thought to be permissible on site, except near the coastline. In most cases, waste water may have to be piped a few miles to a UIC region.

land-3 The majority of the area is moderately sloped sugar fields owned by Castle & Cooke. Land prices are estimated at $40,000 per acre. Lease rates are approximately $900 per acre per year.

transmission-2 The area has modest electric load and modest electric transmission facilities. There is currently only one 46 kV substation located in the entire Waialua area. New generation in this area would likely necessitate lengthy transmission line additions.

OAHU: 6) Kahuku Point

general This region includes the coastal flats in the immediate vicinity of Kahuku Point. The area has several serious drawbacks including high winds, high corrosion potential, high water table, tsunami hazards, and probable land use conflicts.

insolation-1 Annual direct insolation is estimated to be 15% lower than Manoa, although there is some suspicious data which suggest considerably higher values for isolated portions of the region.

topo/geology-4 The coastal areas comprising this region are relatively flat, with slopes ranging from less than 0.5% to 1%. Site elevation ranges from sea level to about 30 feet MSL. Primary soils are sand and coral outcrops near shoreline, clay over muck, and silty clay inland.

water-4 Saltwater, brackish, and fresh water are readily available. Injection wells are thought to be permissible on or near the site.

land-2 The Campbell Estate owns the entire area. Although generally undeveloped, the Campbell Estate's master plan envisions much of the area as park land and tourism-related development. Due to nearby development and potential future plans, real estate prices reflect a premium and may be available for about $75,000 per acre.

transmission-2 There is a single 46 kV corridor which circles the island adjacent to this area. This area is perhaps the most remote part of HECO's entire transmission grid. A few existing substations in the area connect with wind projects in the vicinity. Additional small generation in this area may be desirable. A sizable new generating facility, however, would likely require quite a few miles of new circuit.

HAWAII SITES (assumes 30 MW SEGS site)

HAWAII: 1) Waikoloa Area

general This broad region includes the Waikoloa general vicinity from Lahuipuaa to Kawaihae along the coast and inland toward Waimea. The better sites are toward the coast. These lands, however, are expected to be much more expensive and draw more opposition for industrial power plant use. Further inland, physical site characteristics deteriorate, yet projects should have less impacts and may be more feasible.

insolation-4 Annual direct insolation is estimated to be 10% higher than Manoa. Insolation resources are expected to improve at the lower elevations toward the coast and to the northwest, with the best areas in the vicinity of Kawaihae (perhaps 20% higher than Manoa). There is a non-precipitating sea breeze cloud which frequently stagnates in the general Waikoloa area. The typical nature of this cloud could have significant impacts on direct insolation throughout the area and would have to be thoroughly investigated prior to siting a SEGS facility in this vicinity.

topo/geology-3 Typical slopes are 3 to 5% mauka from Highway 19. Toward Waimea some lands have less slope (2%) but likely have less sunshine and are more expensive. South of Kawaihae between Highway 19 and the coastline, some parcels are nearly level. This flat coastal portion, however, is prime real estate. Site elevation ranges from sea level to 2500 feet MSL. The primary soil is very stony (50% of surface layer) fine sandy loam, underlain by lava at a depth of 20-40 inches. Other areas are extensive lava fields with little or no soil covering.

water-3 Fresh ground water is available but relatively deep. Near the coast, sea water and brackish water are readily available. Injection wells would have to be located toward the coast, which may entail piping waste water from higher elevation sites.

land-3 Prominent land owners in the area are the Parker Ranch, Transcontinental Development Corporation, and the State of Hawaii. Some tracts may be available for about $25,000 per acre. Parcels near Waimea and along the highways are likely to be much higher. Tracts along the coast are likely to be very expensive. Undeveloped state lands near the coast may eventually be designated for use as parks.

transmission-4 New generation on the west side of Hawaii would be highly desirable due to significant load growth in the region over the past ten years. HELCO is planning additions in the Kawaihae area in the immediate future. There are several 69 kV transmission lines and substations within the general area. From a transmission standpoint, this area is currently the most desirable location on the island in which to add capacity.

HAWAII: 2) North Kohala

general This area stretches along and above Highway 270 north of Highway 19, from Kawaihae to Mahukona. The region is thought to have the highest insolation of any site under consideration, however, it is also the steepest land being considered in the assessment. Although the site scores favorably in the evaluation process, the prevailing slope of 10% must be construed as a fatal flaw for this region. The current SEGS technology is not designed for installation in such terrain. It is expected that the necessary solar field design modifications and/or site grading costs would be prohibitive.

insolation-5 Annual direct insolation in better areas is estimated to be 20% higher than Manoa. With the high mountain peaks excepted, areas in the lee of the Kohala Mountains are thought to experience the highest annual direct insolation in the state. Available global horizontal data collaborates this area's claim to the highest insolation of any low elevation site in the state.

topo/geology-0 The entire region is steep, with slopes of about 10%. Site elevation ranges from sea level to about 1000 feet MSL. The characteristic soil is stony loam with numerous gullies and rocky outcrops. Much of the area has scrubby vegetation including numerous kiawe (mesquite) trees up to 20 feet tall. The slopes in this region are considered excessive, resulting in a fatal flaw.

water-3 Water suitable for irrigation is available in some areas; sea water and brackish water are available near the coast. There is a proposal to divert water from the east side of the Kohala Mountains to the dry western side, introducing a potential fresh water at the northern end of the siting region. Waste water injection wells are not thought to be permissible on site, except near the coastline. In most cases, waste water may have to be piped a few miles to a UIC region.

land-3 A large portion of the region is owned by the state of Hawaii and Hawaiian Homelands. Large private landowners include the Kohala Ranch, Parker

Ranch, and the Queen's Medical Center. The area is mostly undeveloped, although a number of hotel and housing projects have been initiated in recent years. There may be resistance to large power plant development in the area from hotels and residents for visual aesthetic reasons.

transmission-4 New generation on the west side of Hawaii would be highly desirable due to significant load growth in the region over the past ten years. HELCO is planning additions in the Kawaihae area in the immediate future. The 69 kV transmission system currently terminates at the Kohala Ranch substation about 8 miles south of Mahukona.

HAWAII: 3) Keahole Point Area

general This area stretches from north of Kona near the Keahole Airport, across the lava fields toward Waikoloa. The Host Park-Natural Energy Laboratory of Hawaii is a specific site within this broad region which has many favorable siting characteristics. As of 1991, Host Park had adequate industrially zoned acreage for a 30 MW SEGS plant, although NELH may soon secure commitments from tenants which would render the site unavailable. Immediately adjacent properties may also be earmarked for development or unavailable because of airport expansion plans. Barren lava fields to the northeast may prove to be suitable.

insolation-4 Annual direct insolation is estimated to be 13% higher than Manoa. Unlike most of the other sites under consideration, there is a long period record of measured global horizontal and diffuse horizontal insolation from the NELH.

topo/geology-3 Some areas near the coastline are nearly level, while many areas to the northeast have slopes less than 0.5%. The region is almost entirely comprised of unvegetated Aa and Pahoehoe lava fields, with occasional patches with thin soil less than 6 inches deep. Site elevation ranges from sea level to perhaps 600 feet MSL. Grading work on the flat lava fields at the NELH was reported to cost approximately $50,000 per acre.

water-4 Sea water and brackish water are available along the coast. The NELH site, which performs ocean thermal energy conversion (OTEC) research, has the unique option of providing 43°F sea water for cooling. NELH currently charges water users $3.50 per gpm per month. Waste water injection wells should be permissible on site. It is noted that sea water from the NELH is currently discharged directly onto the lava.

land-4 Nearly the entire area consists of barren lava fields owned by the state. It is assumed that land could be leased for this project, particularly near the NELH, given that the site is already dedicated to the utilization and study of natural energy in Hawaii.

transmission-4 New generation on the west side of Hawaii would be highly desirable due to significant load growth in the region over the past ten years. A 69 kV transmission line parallels Highway 19 through the area, interconnecting with an existing HELCO power plant about 6 miles south of the NELH.

HAWAII: 4) South Point

general The area under consideration is the southeast corner of the intersection of South Point Road and Highway 11. The extreme southeastern portion should have the best insolation. Drawbacks include questionable insolation, likely electric transmission upgrade requirements, a windy and corrosive environment, and the archeological importance of the area.

insolation-2 Annual direct insolation is estimated to be 10% lower than Manoa. The reliability of insolation in the area is questionable. The extreme south point is thought to be generally sunny. Yet, only 10 miles north on the southern Kau slopes of Mauna Loa, reports suggest that there is less sunshine than in Hilo, which is about 30% lower than Manoa.

topo/geology-3 The South Point area consists of clear grasslands of 2-5% uniform slope. Site elevation ranges from sea level to perhaps 1,000 feet MSL. Soils are a mixture of deep (> 4 feet) fine sandy loam and extremely stony loamy sand about 20-30 inches deep, underlain by Aa lava.

water-4 Water suitable for irrigation is generally available; sea water and brackish water are available near the coast. Waste water injection wells are thought to be permissible on site near the coastline.

land-3 The preferred extreme southern section of the region is owned by Hawaiian Homelands. The northern part has various private landowners. Much of the land is utilized as pasture. The area is significant for its archeological sites and for being the southernmost point in the United States.

transmission-2 The area is a long way from load centers and already contains a wind turbine farm. Substantial transmission upgrading would likely be required for an additional 30 MW of generation at this site.

HAWAII: 5) Kau Desert

general Desert area in the lee of the Kilauea Crater in Hawaii Volcanoes National Park. The entire desert is on National Park territory and hence not expected to be available for SEGS development.

insolation-4 Annual direct insolation is estimated to be 10% higher than Manoa. The insolation environment in this general area is thought to be very site specific.

topo/geolog-2 The prevailing grade of the desert is about 3%, sloping to the south-southwest; some areas to the south and east are much steeper. Site elevation ranges roughly from 2,000-4,000 feet MSL. The desert is a lava ramp consisting of sparsely vegetated pahoehoe and aa flows, with occasional bedrock outcroppings and surface crevices.

water-2 Water resources in the area were not investigated. Waste water disposal would likely be very difficult.

land-0 The Kau Desert is totally contained within the Hawaii Volcanoes National Park. A private power plant serving the general electrical needs of the island is

considered an incompatible land use with a National Park. In this case, land ownership is considered a fatal flaw.

transmission-2 Electric transmission lines parallel Highway 11 in the volcanoes region. Although HELCO's load growth is primarily on the Kona side of the island, electrical interconnection at this site should be straightforward from a technical stand point. However, permitting overland electric transmission lines within the Kau Desert would be highly restricted if not actually prohibited (Conservation District, Subzone P (Protective)).

HAWAII: 6) Humuula Saddle

general This high altitude site includes the land near the summit of the Saddle Road (Highway 200). Some of the site's drawbacks include water supply and waste water disposal uncertainties, current land use as army base, endangered species (birds) in the area, and volcanic hazards.

insolation-2 Annual direct insolation is estimated to be 5% lower than Manoa. This site should have peak instantaneous direct normal insolation that is slightly higher, perhaps by 5-15%, than any of the other sites considered in the study due to the thinner air mass through which sunlight must travel. The site encounters prevailing afternoon upslope clouds from both the east and the west.

topo/geology-3 Typical slopes in the saddle area are about 2-3%. Site elevation ranges from about 5,500 to 7,000 feet MSL. Principle soils are deep alkaline loamy sand intermixed with lava fields.

water-1 There is no known local water supply other than water catchment. The Army base trucks in all of its water requirements for up to 3,000 troops per day. Dry cooling towers and perhaps evaporation ponds may be required, since waste water disposal by UIC is not an option at this site.

land-2 All lands in the region are either federally owned or state owned and leased long-term to the Army. The only major land use in the area is the army base near the crest of the saddle.

transmission-3 The site is transected by one 69 kV line, with a single substation at the army base, and a 138 kV transmission line which has no substations in the area.

MAUI SITES (assumes 30 MW SEGS site)

MAUI: 1) Old Airport Site

general This site is the immediate vicinity of the old Maui airport, approximately 4 miles due south of Kahului. The State is coordinating with Maui county officials to perform master planning for the 1000 acre site. The site is envisioned to contain a wide variety of land use areas, including some industrial. A new county waste water treatment facility is one potential user that may integrate well with a potential SEGS by providing the option of waste water effluent re-use for power plant cooling purposes. A SEGS in this area may prove feasible, particularly if incorporated into the site's master plan.

topo/geology-4 Sugar cane fields inland from the coast are sloped from 1-3%. Site elevation ranges from sea level to perhaps 150 feet MSL. Principle soils are silty clay loam soils underlain by gravel.

water-3 Water suitable for irrigation is generally available; sea water and brackish water are available near the coast. Waste water injection wells are permissible near the coastline. In some cases, waste water may have to be piped a short distance to a UIC region.

land-3 The majority of the area is moderately sloped sugar fields owned by Alexander & Baldwin. The immediate vicinity of the Kahului Airport is owned by the state of Hawaii, and closer to Kahului there are various small land owners. Agriculture lease rates are estimated at $900 per acre per year.

transmission-3 There are several 69 kV and 23 kV transmission circuits adjacent to the site due to the proximity of the Kahului power plant, which is only about 2 miles from much of the siting region. This area is considered to be acceptable but not favorable for new capacity additions.

KAUAI SITES (assumes 15 MW SEGS site)

KAUAI: 1) Mana Plain

general This area includes the entire Mana Plain, but especially near Kekaha. The area is a very flat sedimentary plain on the sunny side of the island.

insolation-3 Current estimates of annual direct insolation are about the same as Manoa. The limited measured data for the area, however, suggest that annual direct normal may possibly be 10% higher than Manoa.

topo/geology-5 The majority of the Mana Plain is very flat, with slope of less than 0.2%. Tracts adjoining the foothills of the Wiamea Mountains have somewhat more grade. Site elevation is generally less than 20 feet, particularly near Kekaha, but ranges up to perhaps 80 feet MSL in areas to the north. Primary soils are clay, silty clay, fill land, and loamy fine sand in some areas along the coast. The loamy sand is highly erodible with vegetation removed and is not generally utilized for crops. Much of the area is a natural swamp with a high water table (less than 2 feet in most areas). Even with the area's extensive sugar cultivation, 15,000 gpm (= 22 mgd) is continuously drained from the area and pumped to sea. If the sugar industry pulled out of the area, the water table would rise and some areas would revert to swamp. The high water table and soft soil would be a major consideration for footing and foundation design in this area.

water-4 Fresh water resources in the area are abundant if not excessive. The area has sufficient fresh water supply to utilize once through cooling. Thermal impacts of the discharge stream may make this option difficult to permit. A 15 MW SEGS plant would need about 5 mgd for once through cooling, based on an 18 degree F temperature rise. Given the region's immediate proximity to the coast, waste water injection wells should be permissible on site.

land-3 A 10 mile long strip of coastal property in extreme western Kauai is federally owned and utilized as the Barking Sands Pacific Missile Range Facility (PMRF). Practically all other property in the area is owned by the State of Hawaii and leased for sugar cultivation. Lease rates are estimated at approximately $900 per acre per year.

transmission-2 One 69 kV transmission line, currently energized at 57 kV, runs through the area to the PMRF. There has been essentially no load growth in the area resulting in about 5-10 MW of transmission capacity available in the area's 69 kV line (based on pre-Iniki information). Wheeling a sizable amount of power to the eastern developed side of the Kauai would likely require 12-15 miles of new transmission line to Port Allen, where it could then interface with a major 138 kV transmission upgrade from Port Allen to Lihue. The new Port Allen-Lihue upgrade was originally expected in 1995. Hurricane Iniki devastated the island's transmission and distribution network. It has been estimated that it may take up to 6 months to restore service throughout the island. At this time, comments pertaining to transmission availability in Kauai must be considered in the context of the post-hurricane situation.

hazards-2 Hurricanes are uncommon in Hawaii. Yet, of the three damaging hurricanes in Hawaii's modern recorded history, all three delivered the brunt of their fury on the island of Kauai. Given the relatively tight grouping of the Hawaiian islands and the unpredictable nature of hurricanes, this circumstance is considered to be more of a statistical anomaly than a demonstrated pattern. Nevertheless, Hurricane Iwa (1982) and Hurricane Iniki (1992) both produced wind gusts exceeding 100 mph on the Mana Plain as well as significant storm surge along the area's coastline. Almost certainly, a SEGS facility located near Kekaha would have suffered major damage, particularly during Hurricane Iniki. Additionally, the low elevation and flat topography of the region make the coastal areas potentially susceptible to tsunami damage.

KAUAI: 2) Poipu

general The area under consideration is the vicinity around the McBryde Mill (Koloa Mill) fanning out toward the coast. The luxury resort developments along Poipu Beach are among the most expensive in Hawaii. The area has suffered extensive hurricane damage, particularly along the beaches, during both Iwa (1982) and Iniki (1992).

insolation-2 Annual direct insolation is estimated to be 10% lower than Manoa. Direct normal near the beach should be higher.

topo/geology-3 The better tracts in the area are of modest slope (2-3%). Site elevation ranges from about 40 to 200 feet MSL. Principle soils are shallow stony silty clay over hard pahoehoe rock. There are some outcrops of the substratum rock.

water-3 Water suitable for irrigation is generally available; sea water and brackish water are available near the coast. Waste water injection wells may have to be located off-site, nearer to the coastline.

land-3 The majority of the area is moderately sloped sugar fields owned by the Grove Farm Co. Immediately inland from the coastal resort development are a few golf courses. Land prices are estimated at $40,000 per acre and lease rates are

approximately $900 per acre per year. In areas where there is development pressure for other uses, land will be much more expensive.

transmission-4 The area is a desirable location for additional electrical generation. There is currently one 57 kV substation located at the Koloa Mill, which delivers between 16-28 GWh of bagasse fueled non-firm electricity to Kauai Electric every year.

MOLOKAI SITES (assumed 80-200 MW SEGS site)

MOLOKAI: 1) Kahanui-Palaau Flat

general This area spans from south of the Molokai airport to the coast. The primary appeal of Molokai is the availability of large tracts of undeveloped land. Any project envisioned here, however, must utilize inter-island electric transmission. It is expected that there would be significant social hurdles to clear in order to pursue a project on Molokai.

insolation-3 Annual direct insolation is estimated to be about the same as Manoa. During trade wind conditions, it is typical for afternoon clouds to form in the wake of the tall east Molokai mountains. The exact position of the wake cloud is a function of the trade wind direction and strength. It is expected that direct normal insolation should be best near the coast.

topo/geology-3 The ocean coast is banded through this region by mangrove marshes several hundred feet wide. Surrounding the coastal marshes are salty silty loam mud flats which have a slope of less than 1% and elevation of less than 30 feet MSL. Flooding and ponding after heavy rains are common; when dry, the area suffers high wind erosion. The brackish water table in this vicinity is only 12-40 inches deep. Easily compacted silty clay soils often adjoin the mud flats. Toward Kaunakakai, in the Kahanui region, undulating terrain is vegetated with brush and small trees; overall slopes are less than 2%. Further inland, typical soils are very stony, eroded silty loams which slope up toward the airport area to an elevation of almost 400 feet at an average grade of 3-4%.

water-4 Water suitable for irrigation is available in some areas; sea water and brackish water are available near the coast. There are fresh water supplies less than 5 miles away, but they are not necessarily politically available. Waste water injection wells are thought to be permissible over much of the siting area, particularly near the coastline.

land-5 The majority of the area is owned by Molokai Ranch and Hawaiian Homelands. Development of the Hawaiian Homelands for other than its intended use may be a sensitive issue. Land prices are estimated at $10,000 per acre and agriculture leases run $250-350 per acre per year.

transmission-1 Molokai has insufficient load to warrant consideration of a SEGS facility solely for its own use. A SEGS here can only be feasible in conjunction with an inter-island transmission cable to export the bulk of the electricity from the project to either Oahu or Maui County. MECO recently considered a tri-island cable project for Maui County which had a cost of $100 million ($1,250/kW). A

recent HECO study performed by Black & Veatch evaluated Molokai as a prospective site for a 720 MW baseload power plant. Estimated transmission costs from this project came in at $320 million ($444/kW). It is noted that the evaluation methodology used in this study will not adequately reflect the economic impact of undersea cable transmission. In addition to the economic considerations, any project requiring inter-island electric transmission will have to contend with social and environmental hurdles.

MOLOKAI: 2) Southwestern/Western Molokai

general This area includes all of western Molokai; particularly areas southwest of Maunaloa. Areas to the northwest include a few isolated flatter areas which are extremely windy, of limited size, and possibly less insolation. Any project envisioned here must utilize inter-island electric transmission to Oahu or Maui. It is expected that there would be significant social hurdles to clear in order to pursue a project on Molokai.

insolation-3 Annual direct insolation is estimated to be 3% less than Manoa. During trade wind conditions, it is typical for afternoon clouds to form in the wake of the tall east Molokai mountains. The exact position of the wake cloud is a function of the trade wind direction and strength. Its usual position over western Molokai would have to be resolved prior to pursuing this area as a SEGS site. Based on preliminary information, it is expected that direct normal insolation should be best along the southern edge of the region, near the Hale O Lono Harbor, and to the extreme northwest, around Ilio Point. The higher elevations around Maunaloa are expected to be much worse.

topo/geology-2 Most of the region has slopes of 3 to 5%. The higher elevation areas, up to 1000 feet, are somewhat flatter and either clear pasture or grasslands with few trees, consisting of silty loam and silty clay loam soils 4-7 feet thick. In areas which were previously cultivated in pineapple, the surface soil layer will be strongly acidic. The lower elevations in Southwestern Molokai are steeper, rougher, and forested with 12-25' kiawe trees. Soils are thin (generally less than 2 feet to bedrock), very stony (50-75% of surface are stones and boulders), and eroded with gullies.

water-4 Fresh water resources in western Molokai are very limited. The only water currently available is quite brackish (perhaps 9,000 ppm chlorides). This is the primary factor inhibiting conventional development in the area. Sea water and brackish water are available near the coast. Waste water injection wells are thought to be permissible over much of the siting area.

land-5 The majority of the area is owned by Molokai Ranch, Kalua Koi Corp., and Alpha USA. There is a federally owned Coast Guard reservation at the extreme northwest at Ilio Point. The entire region is almost completely devoid of development, except for the small resort community at Kepuhi. Land prices are estimated at $10,000 per acre and agriculture leases at $250-350 per acre per year.

transmission-1 Comments identical to those above for Kahanui-Palaau Flat.

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Table IV-2. Evaluation Matrix for Candidate SEGS Sites in Hawaii

		PRIMARY FACTORS														SECONDARY FACTORS					TERTIARY FACTORS			
CANDIDATE SEGS SITE	TOTAL RELATIVE SCORE	Insolation Weight: 40		Topography/ Geology 15		Water Supply/ Waste Water 4		Land Use/Cost 10		Electric Transmission 6		SUB-TOTAL 75				Back Up 3	Air Qual 3	Hazrd 3	Corsn 3	Biolg 3	Access 2	Labor Pool 2	Legal/ Political 6	SUB-TOTAL 25	
OAHU																									
Pearl HBZ	375	+5%	4	<.5%(sedm)	5	UIC	4	40K;USN	3	good(<5)	4	305				4	2	1	3	4	4	4	2	70	
N. Ewa Plai	304	-3%	3	2-5%(clay)	3	oUIC	3	30K	3	ok(<5)	3	225				4	3	4	3	3	4	4	2	79	
Ewa Plain	366	+5%	4	<1%(sedm)	4	UIC	4	40K	3	ok(<5)	3	284				4	2	3	3	4	4	4	3	82	
Lualualei	280	same	3	1%(clay)	4	oUIC	3	USN&HH	1	poor(10)	2	214				3	3	2	3	3	3	3	2	66	
Waialua	248	-10%	2	2-5%(clay)	3	oUIC	3	30K	3	ok(12)	2	179				3	3	2	2	3	3	3	3	69	
Kahuku Pt.	230	-15%	1	<1%(sedm&clay)	4	UIC	4	40K	3	ok(20)	2	158				3	4	2	2	3	3	3	3	72	
HAWAII																									
Waikoloa	350	+10%	4	2-5%(lava)	3	oUIC	3	10K	4	good(<5)	4	281				2	3	2	3	3	3	3	3	69	
N. Kohala	332	+20%	5	10% (erod&stony	0	oUIC	3	40K	3	good(<5)	4	266				2	3	3	3	3	3	3	2	66	
Keahole Pt.	347	+13%	4	0.5-5%(lava)	3	UIC(NELH)	4	40K;HI	3	good(<8)	4	275				2	3	2	3	4	3	3	3	72	
South Pt.	266	-10%	2	2-5%(loam&lava)	3	UIC	4	5K;HH	5	poor(>25)	2	203				2	4	2	2	3	3	3	2	63	
Kau Desert	261	+10%	4	3%(lava)	2	oUIC	2	USNP	0	ok(<5)	2	210				2	4	2	2	1	3	3	1	51	
Saddle Rd.	233	-5%	2	2-3%(loam&lava)	3	(Dry)	1	USA&HI	2	ok(18)	3	167				2	4	2	4	2	3	3	2	66	
MAUI																									
Old Airport	331	same	3	1-2%(loam)	4	UIC(re-use)	4	40K;HI	3	ok(<4)	3	244				3	3	4	3	4	3	3	4	87	
Kihei	304	+3%	3	3-10%(stony clay	2	oUIC	3	10K	4	good(4)	4	226				3	3	4	3	3	3	3	3	78	
Lihaina	266	+3%	3	6%(stony clay)	1	oUIC(GWR	2	35K	3	good(<4)	4	197				3	3	4	2	3	3	3	2	69	
Kahului	312	-3%	3	1-3%(loam)	4	oUIC	3	45K	3	ok(<5)	3	240				3	3	3	3	2	3	3	3	72	
KAUAI																									
Mana Plain	345	same	3	<.5%(sedm/sogy	5	UIC	4	7K;HI	5	poor(14)	2	273				3	4	2	2	3	3	3	3	72	
Poipu	269	-10%	2	2-3%(clay&lava)	3	oUIC(GWR	2	10K	4	good(<4)	4	197				3	3	2	3	3	3	3	3	72	
MOLOKAI																									
Palaau Flat	298	same	3	1-5%(mud flats)	3	UIC	4	7K	5	cable	1	237				3	4	2	2	2	3	2	2	61	
SW/W	292	-3%	3	3-5%(erod&stony	2	UIC	4	5K	5	cable	1	222				3	4	4	3	2	3	2	2	70	

RESULTS OF PRELIMINARY SITE SELECTION

Matrix Evaluation of Candidate Sites

The matrix presented in Table IV-2 summarizes the results of the site selection. The matrix contains a unique line for each candidate site. The number immediately following the site name is the total relative score. Each line also contains value assignments for each primary, secondary, and tertiary siting factor. The weighting for each siting issue is included at the top of each column, immediately below the siting factor heading. The total relative score is obtained by summing all of the weighted siting factor scores for a particular site. The matrix also contains sub-totals for the cumulative impact of all primary siting factors, and a sub-total for the collective impact of all secondary and tertiary siting factors.

Since the maximum raw score is 5 in all cases, and the total siting factor weighting is 100, a hypothetical site which embodies exceptional qualities for each siting factor would produce a perfect total relative score of 500. An average site, that is a site which had typical characteristics of a candidate SEGS site scored as 3's for every siting factor, would produce a total relative score of 300 (3 x 100). Any site which includes a zero (0 = fatal flaw) as a score for any siting factor in the matrix is dropped from further consideration as a SEGS site.

The importance of the results of this site selection process is the organization of sites into several groups, rather than a sequential ranking of absolute scores. We emphasize that the techniques employed in this assessment rely more on subjective judgment based on experience than detailed site-specific information. The results of the matrix have been grouped into three categories Preferred, Acceptable, and Not Recommended. The breakpoints chosen for these classifications are:

Preferred	Total score >= 325
Acceptable	275 < Total score < 325
Not Recommended	Total score <= 275.

Applying the grouping breakpoints to the candidate sites which were considered yields the recommendations contained in Table IV-3 and shown in Figure IV-2.

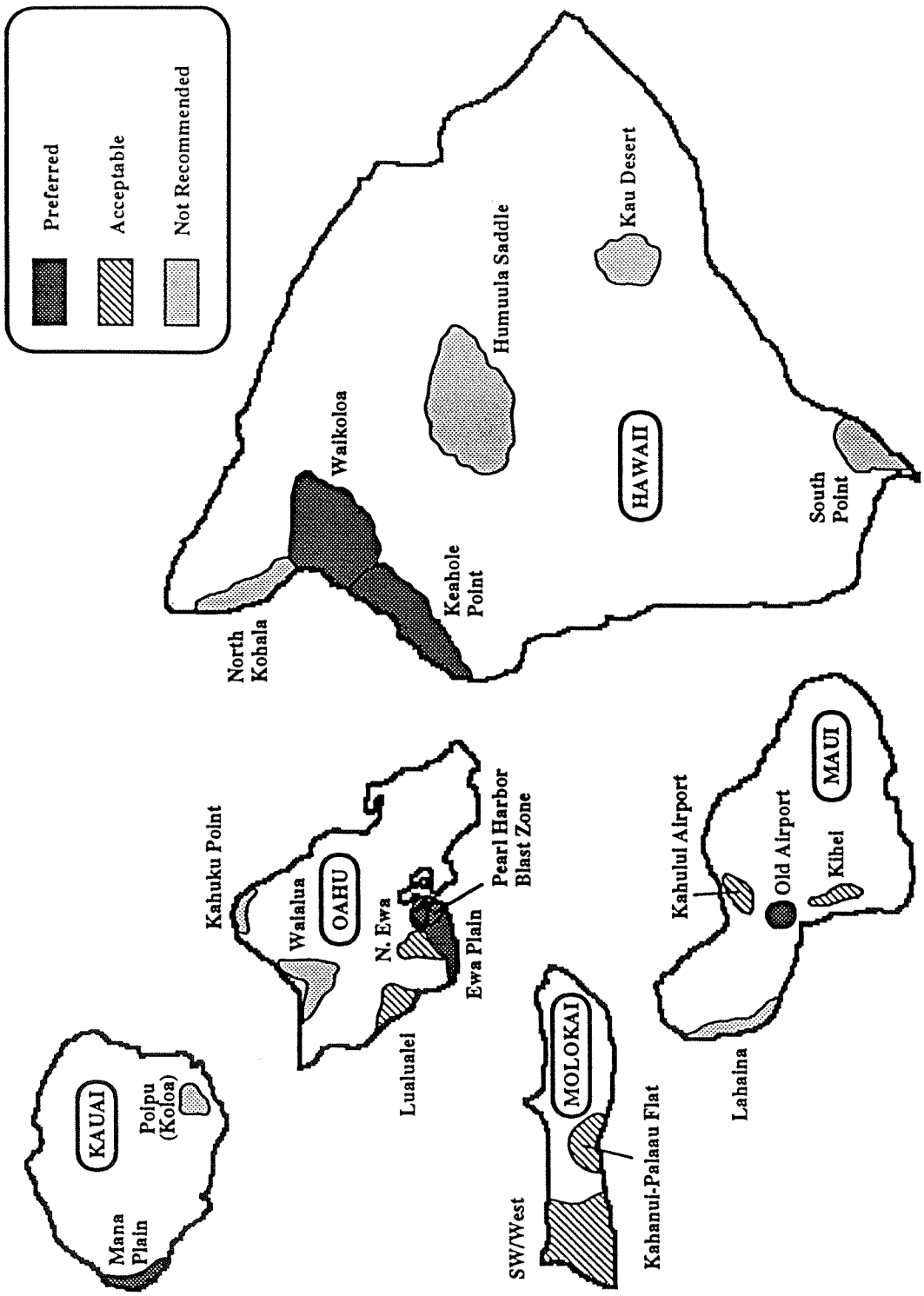
Table IV-3. Site Selection Results

Preferred	Acceptable	Not Recommended
Pearl Harbor Blast Zone (Oahu)	North Ewa Plain (Oahu)	Wailua (Oahu)
Ewa Plain (Oahu)	Lualualei (Oahu)	Kahuku Point (Oahu)
Waikaloa (Hawaii)	Kihei (Maui)	South Point (Hawaii)
Keahole Point (Hawaii)	Kahului (Maui)	Saddle Road (Hawaii)
Old Airport (Maui)	Palaau Flat (Molokai)	Lahaina (Maui)
Mana Plain (Kauai)	SW/W Molokai (Molokai)	Poipu (Kauai)
		North Kohala (Hawaii)
		Kau Desert (Hawaii)

Discussion of Site Selections

Under the strict application of the grouping breakpoints, the North Kohala site on Hawaii would be a preferred site. However, due to the excessive slope (10%) at that site, topography was judged to be a fatal flaw. The Kau Desert site, also on Hawaii, was dropped from consideration since we believe that the siting of a SEGS power plant in a National Park would be unacceptable.

Figure IV-2. Representative Map showing Site Evaluation Results for SEGS Plants in Hawaii



The levelized cost of electricity from a SEGS plant is determined from, among other contributions, the projected performance and estimated capital cost of the facility. An important element affecting both of these is the economy of scale improvements associated with increasing the size of the plant. Larger plants lead to lower unit costs and have higher turbine efficiencies than smaller plants. The envisioned plants located on both Oahu (80 MW) and Molokai (80-200 MW, assuming an Oahu-Molokai transmission cable) will benefit from the economy of scale factor relative to the smaller facilities which are envisioned for sites on Kauai, Maui, and Hawaii. This impact has not been reflected in the site selection process.

PERMITTING ISSUES

Introduction

As with any major industrial development, permitting is a major component of turning a project into reality. The objective of this discussion is to examine the permitting environment in Hawaii as it applies to SEGS power plants in order to provide a general guideline based on current requirements. Discussion of primary permitting steps will be the focus here, although a general listing of permits which may be required for a SEGS development by federal, state, and county permitting agencies will also be included. Among the major permitting processes examined are those required for land use and those designed to limit adverse environmental impacts. A rough cost estimate for the effort needed to obtain the major permits most likely required for a Hawaiian SEGS project is also included.
This report draws heavily from DBED-sponsored assessments on the permitting of geothermal and photovoltaic developments. Particularly in the area of geothermal power, recent analyses of permitting regimes and requirements has been quite thorough. Since there is considerable overlap in the permitting requirements of SEGS and geothermal developments, a more detailed investigation into the specific requirements of particular permits may be available through the reports on geothermal permitting. Sources of information used to create this report, both published sources and state agency contacts, are included as the final section of this report.

In California's Mojave Desert, an 80 MW SEGS plant requires about 400 acres of land and has an annual consumptive water use of approximately 900 acre-feet (560 gpm; 0.8 mgd). Most of the water is used in the plant's wet cooling towers. A smaller portion is used for blowdown, make-up feedwater, and mirror cleaning. Wastewater is disposed of in evaporation ponds. The hot, dry desert climate minimizes the acreage required for the disposal ponds. To reduce installation costs of the solar field, a SEGS site is graded into level terraces during the initial phase of construction. Also worthy of note is the fact that Mojave Desert SEGS plants are located adjacent to natural gas pipelines, thus eliminating the need for on-site auxiliary fuel storage facilities.

Numerous possible permits are described and listed in this report. The potential applicability of each for a SEGS power plant will be project and site specific. The air quality permits mentioned herein would only be necessary if an auxiliary fuel were to be used. Numerous other permits are contingent upon the necessity of electric transmission expansion/additions, especially via an inter-island underwater cable. The size of a SEGS project would also have some bearing on the requirements of certain permits. In the following sections, the applicability of specific permits will be described in the context of a SEGS project.

Discussion of Permitting Considerations

Land Use

As dictated by Hawaii Revised Statues, Chapter 205, all lands in the state of Hawaii are designated by the State Land Use Commission into four land-use classifications: 1) agricultural, 2) rural, 3) conservation, and 4) urban. The state retains regulatory authority for all conservation district lands, while the respective county governments have sole jurisdiction over zoning on lands in urban districts. Agriculture and rural district lands are managed jointly by the state and counties. Most areas identified as potential SEGS development sites are in agricultural districts; a few are in conservation districts. Required electric

transmission upgrades could involve all four land use districts. The following section presents an overview of the permitting procedure for development in each of the land use districts likely to be encountered.

There is no precedent in Hawaii for land use permitting of solar power plants. It is not known with certainty what zoning would be required for a SEGS development. While zoning laws vary from county to county, it is presumed a SEGS power plant would require Urban-Industrial zoning. Vacant, multi-hundred acre tracts of Urban-Industrial zoned land are uncommon in Hawaii. Furthermore, it is critically important to select a SEGS site based on favorable siting factors (insolation, topography, etc.) in order to minimize construction and operational costs and to maximize plant performance. Only the Keahole Point area on the Big Island combines favorable siting criteria with industrial zoning. All other potential SEGS sites in the state would likely require special action.

Informal discussions with the State Land Use Commission were inconclusive in identifying the most likely scenarios for permitting SEGS projects in the various land use districts. If agriculture lands were prohibited from development, the number of potential SEGS sites in Hawaii would be significantly diminished. The clarification of which land use districts are SEGS-compatible, and the procedure required for development of these lands, will have important ramifications for the prospects of SEGS in Hawaii. Due to this uncertainty, three possible alternatives are discussed below: 1) legislative action permitting solar development on agriculture district lands, 2) specific land use permits, and 3) re-designating land to zoning allowing SEGS development.

Legislative Action

State land use legislation was amended in 1976 to list wind energy production as a permitted agricultural use. It is possible that this same action could establish solar thermal electricity production as a permitted use for agriculture district lands as well. It should be noted, however, that wind turbine machines, perched high above the ground on widely-spaced pedestal towers, do not greatly impact the agricultural potential of the land below them. A SEGS development, on the other hand, would be consumptive of the entire footprint that the power plant would occupy. No agricultural use—not even livestock grazing—would be practical within the solar field. While the state of Hawaii is interested in promoting alternative energy development, it is also committed to preserving productive agricultural lands. It is conceivable that SEGS might only be permissible on less productive agricultural lands. Since such legislation, if enacted, would greatly expand the development opportunities within the state, legislative action to allow permitting of SEGS power plants in agriculture districts is a potentially important issue.

Specific Land Use Permits

If considered a non-permitted use, a SEGS plant would require a special permit allowing use in that district. State law provides for special use permits to facilitate "unusual and reasonable" uses of lands permitted for other uses. If SEGS were not considered a reasonable use for a particular land use district, a more complicated District Boundary Amendment/Change of Zoning procedure would be required.

For allowable but non-permitted development, the type of land use district dictates the required permitting process. On conservation district land, a Conservation District Use Permit (CDUP) issued by the Department of Land and Natural Resources (DLNR) is required. A SEGS project in either agriculture or rural districts would require a Special Permit. If the site is less than 15 acres, approval is granted solely by the County Planning Department. If greater than 15 acres (which would be the case for a SEGS plant), the Special Permit is issued by the State Land Use Commission contingent upon concurrence with the recommendation of the County Planning Department. Permitting use on Urban District tracts which are not zoned compatibly for SEGS power plants is achieved through a Change of Zoning procedure to create SEGS-compatible urban zoning.

The CDUP and Special Permit generally define numerous special conditions which must be satisfied in order to proceed with development at a specific site. These permits will stipulate the requirement for such items as an Archaeological Review, Cultural Resource Assessment, and Environmental Assessment. The listing of special conditions can include numerous environmental and engineering disciplines affecting the construction and operation of the project.

With respect to land use permitting for electric transmission lines, a CDUP would be required for routing over conservation district land in all subzones except Subzone P (Protective), in which case power line corridors are not allowed. On agriculture, rural, and urban district land, electric transmission lines are a permitted use. On Oahu, proposed transmission lines rated at 38 kV and above require an amendment to the Development Plan for Public Facilities Map prior to construction.

District Boundary Amendment/Change of Zoning Procedure

The State Land Use Commission (LUC), County Planning Commission, or the DLNR may determine that a SEGS power plant is not a reasonable use within an agriculture or conservation district. An alternate path for securing permission to develop, in these cases, may be to obtain a District Boundary Amendment from the LUC and subsequently a Change of Zoning from the County. Under this scenario, agriculture or conservation land could be re-defined as Urban by the LUC. This "new" Urban land would necessitate amendments to the appropriate County General Plan and/or Community Development Plan if not already reflected in these documents. Finally, the "new" Urban land would be zoned by the County suitably for a SEGS plant (most likely as industrial zoning). Additionally, this process would almost certainly trigger the Environmental Impact Statement. The time needed to complete the requisite actions would likely total several years. Due to the relative complexity and time element involved, the District Boundary Amendment/Change of Zoning Procedure is the least desirable of the three alternatives presented in this section.

Environmental Impact Statement

The Environmental Impact Statement (EIS) process is a multi-step review designed to prevent significant environmental degradation. The Office of Environmental Quality Control (OEQC) is responsible for implementing the state's EIS Law. The initial step in the EIS review process is the Environmental Assessment (EA), which is prepared by the government agency who receives the initial request for project approval. The EA is submitted to the OEQC informing of either a Negative Declaration—signifying that the project will not have adverse environmental impacts—or the need for a more detailed Environmental Impact Statement. The current opinion of the OEQC is that a SEGS project, due to its extensive scale, would lead to a full EIS if the review process is triggered.

Hawaii's EIS Law, HRS Chapter 343, is applicable to any proposed project which fulfills any of the following criteria:

- Uses State or County lands or funds
- Is in a State conservation district
- Is the reclassification of conservation district land
- Is in a shoreline setback area (20 to 40 feet from the shore)
- Is located in Waikiki
- Is within a listed historic site
- Requires an amendment to a County land use plan
- Is the construction or modification of helicopter facilities.

Certain additional criteria can trigger environmental reviews other than the state EIS. If federal lands or funds are used for the project, the more stringent NEPA (federal) EIS procedure is required. Final approval for the federal EIS is by the U.S. Environmental Protection Agency (EPA) and, if federal lands are involved, the federal Department owning the land. If the project involves coastal lands designated as

Special Management Areas (SMA's) — generally all coastal areas within 100 yards of the shoreline — an SMA Permit is required from the county's SMA permitting authority. Although the procedures vary somewhat from county to county, one component of the SMA Permit procedure is an environmental review process similar to the state EIS review. In some instances, the county's SMA authority can require the preparation of an OEQC EIS. If multiple environmental reviews are required, for instance both state and federal EIS's, efforts are made to reduce duplication of requirements.

Department of Health/EPA Permits

The State of Hawaii's Department of Health (DOH) and the U.S. Environmental Protection Agency (EPA) share permitting responsibility for all air emissions and hazardous and non-hazardous waste disposal from a proposed facility. Primary DOH permits are Authority to Construct, Prevention of Significant Deterioration, Permit to Operate,Underground Injection Control, and the National Pollution Discharge Elimination System. The EPA currently has permitting primacy for hazardous waste activity. The state's DOH is currently in the process of shifting primary responsibility for hazardous waste activity from the EPA to their Solids and Hazardous Waste Branch.

Authority to Construct, Prevention of Significant Deterioration, and Permit to Operate

Although SEGS plants can function without supplemental fuel, utilities find the reliability and flexibility of a supplemental fuel configuration very attractive. In Hawaii, the most likely candidate back-up fuels are diesel, fuel oil, and biomass. Even though the majority of the SEGS plant's electricity comes from sunshine, if the plant was equipped with the capability to burn an auxiliary fuel, air quality regulations would be applicable. The DOH, Clean Air Branch administers numerous regulations designed to limit the adverse impacts of development on air quality. These include the Authority to Construct, Prevention of Significant Deterioration, and Permit to Operate permits. While the air quality control measures associated with combustion are the major concern of this section, the DOH would also require fugitive dust control measures during construction.

In addition to compliance with National Ambient Air Quality Standards, SEGS power plants would be liable to regulations promulgated by the federal Standards of Performance for New Stationary Sources (NSPS) for steam generators (Subpart D). Specific regulations are dependent on boiler size. Additional, more stringent air pollution control requirements arise from the Ambient Air Quality Standards and the Air Pollution Control Regulations of the State of Hawaii. The DOH, Clean Air Branch administers all regulations specified in the sources listed above. For any air emissions unit other than those specifically excluded in the Hawaii Air Pollution Control Regulations, the DOH ensures compliance with air quality standards through the issue of the Authority to Construct (ATC) and Permit to Operate (PTO) permits. The application for Authority to Construct consists of a detailed description of the project, including proposed use of Best Available Control Technology (BACT) for pollutants subject to limitation, and, in some cases, results of source emission testing and ambient air quality monitoring.

The Prevention of Significant Deterioration (PSD) review are additional requirements needed to evaluate the application for Authority to Construct for certain significant air pollution sources. The PSD applies to major stationary sources and major modifications which would emit any pollutant subject to regulation by the Clean Air Act, or such facilities in an area designated as attainment or unclassifiable. The PSD review contains additional requirements for BACT and analysis of ambient air quality at the proposed site. This analysis must include at least one year of continuous air quality monitoring data. The PSD requires both DOH and EPA approval. If the project is within 100 kilometers of a National Park, the National Park Service (NPS) will also be included in the PSD review process. The stipulation for NPS involvement will affect all sites on the Big Island, Maui, and the eastern two-thirds of Molokai.

A "major stationary source" is, by legal definition, any air pollution source which has the potential to emit one hundred tons per year (100 tpy) or more of any pollutant subject to regulation under the Clean Air Act. The definition specifically includes any fossil-fuel fired steam electric plant with more than two

hundred fifty million British Thermal Units per hour (250 MMBTU/hr) heat input. This definition would apply to proposed SEGS plants rated for approximately 25 MW and higher. The exact value would depend on fuel type and boiler design (the smallest unit ever classified as "major" in Hawaii was a 7 MW diesel unit). This distinction is significant in that a non-major stationary source is not subject to the PSD review process. A very small SEGS plant which was not liable to NSPS regulations and burned a clean, gaseous fossil fuel would additionally be exempt from the requirements of the Authority to Construct and Permit to Operate.

The Permit to Operate is issued after construction is completed, contingent upon the approval of the DOH. This permit authorizes the operation of the plant according to the provisions of the PTO. The permit is valid for five (5) years.

Underground Injection Control, National Pollution Discharge Elimination System

The wastewater generated by a SEGS power plant can be disposed of by underground injection, discharge to a surface water body, or by an evaporation pond. Underground injection, where allowed, is the most practical disposal method in Hawaii.

Underground Injection Control (UIC) regulations are designed to protect drinking water quality aquifers from contamination by agricultural and industrial wastes. The DOH, Safe Drinking Water Branch oversees compliance with UIC laws. Maps have been developed which identify the UIC Line—a legal boundary delineating areas in which underground injection is allowed and prohibited. Since ocean water intrusion deteriorates fresh water quality in coastal areas, underground waste injection is usually allowed near the coast. The UIC Line generally parallels the shoreline and, in most areas, is within 1/4 to 2 miles of the shoreline. Occasionally, the UIC Line will penetrate inland to engulf interior island regions which have only poor quality aquifer resources. Although provisions are in place to request approval for underground inject outside the approved UIC zones, such a request for an industrial well would almost certainly be denied.

Underground injection wells must operate in compliance with state regulations. If the waste constituents are not consistent with state requirements, a neutralization basin or some other means of compliance would be necessitated. If a site was in an area where underground injection was prohibited, a pipeline could be installed to carry the waste stream to an injection well on the appropriate side of the UIC line. Easement and trenching costs would mount quickly. If a site were too far away from the UIC line to make a pipeline feasible, a lined evaporation pond may be the only alternative available for wastewater disposal. Evaporation ponds, however, are not well suited to conditions in Hawaii. Due to the relatively mild temperatures and high humidity, an evaporation pond in Hawaii would be much, much larger than its counterpart in the Mojave Desert. A SEGS plant at such a site would likely utilize dry cooling to minimize the amount of wastewater disposed.

Coastal sites present the opportunity for the thermodynamically attractive option of utilizing ocean water for condenser cooling. Several of the major electric power plants in Hawaii take advantage of this option. Increasing environmental concern over the impacts of ocean outfalls have made this practice more difficult to permit. The permit required for an ocean outfall is the National Pollution Discharge Elimination System (NPDES), which is issued by the DOH, Clean Water Branch.

Ocean waters in Hawaii are classified as either Class AA protected waters or Class A open waters. SEGS plants at sites along Class A waters would be allowed to construct an ocean outfall if able to satisfy the state's strict water quality requirements. The DOH sets allowable trace concentration limits for chemicals in the discharge stream and defines the maximum allowable temperature rise, discharge compared to ambient, of one degree Celsius (1°C). If a higher thermal gain is desired, a Zone of Mixing approval is required to comply with the NPDES. The Zone of Mixing is a limited area around the outfall where the discharge concentration levels are allowed to exceed the state standards. In order to obtain Zone of

Mixing approval, the applicant generally must implement control techniques (such as a holding pond) and perform an EIS.

Hazardous Waste Activity

Hazardous waste activity in Hawaii is permitted by the EPA. By the end of 1991, the DOH, Solid and Hazardous Waste Branch is expected to have permitting primacy for hazardous waste activity. The most probable permit which could be required of a SEGS plant is a hazardous waste storage permit from the Hazardous Waste Treatment, Storage, and Disposal (TSD) permit group. SEGS components which are classified as hazardous are certain chemicals used for water treatment and corrosion prevention. The synthetic heat transfer fluid (HTF) used in current SEGS designs would not be classified as hazardous in Hawaii. Contaminated soil from HTF spills and leaks would only be regarded as hazardous if any characteristic constituent exceeded federal limits. It is noted that there are no hazardous waste treatment facilities in the state of Hawaii. Contaminated materials would have to be neutralized on site (requiring a treatment TSD permit) or shipped back to the mainland for proper disposal. Regardless of whether or not a SEGS project would require TSD permits, the power plant should secure an EPA hazardous waste generator number as a contingency.

Other responsibilities of the DOH, Solid and Hazardous Waste Branch are the permitting of solid waste disposal and the administration of the Underground Storage Tank (UST) program. There is a critical shortage of landfill space in Hawaii. Disposal of wastes generated during construction and operation could be unexpectedly difficult. California SEGS sites require UST permits for tanks designed to contain spills from HTF expansion vessels. In Hawaii, UST permits may also be necessary.

Department of Land and Natural Resources

The State of Hawaii's Department of Land and Natural Resources (DLNR) is charged with the task of managing and preserving the land and water resources of the state. The DLNR administers numerous permits pertaining to state-owned lands and state protected areas. Actions affecting any surface or underground water source in the state would also require the permission of the DLNR. The following section highlights permits which may be required by the DLNR for SEGS projects in Hawaii.

All water well activity, whether for supply or disposal, would require a Well Drilling or Modification Permit. If in an area designated as a Groundwater Control Area, the well permit process would require a public hearing. DLNR approval of GCA wells would be discretionary. If a SEGS design dictated the need for a reservoir, DLNR would have to grant Dams and Reservoirs Construction Approval.

Numerous prospective SEGS sites include state-owned tracts. Due to the high real estate values in Hawaii, leasing state-owned tracts is considered a favorable option for securing the land needs of a SEGS power plant. The use of any state lands would require the approval of DLNR through the issue of an Easement for Use of State Lands. If a SEGS project impacts state protected areas, certain other DLNR permits could be applicable. These permits—which would not likely be necessary unless required for electric transmission line corridors—include the Forest Reserve Special Permit, Entrance to Wildlife Sanctuary Permit, and Permit to Enter a Closed Watershed. In areas where development may impact a listed historic site, a Historic Site Review would have to be submitted to the DLNR Historic Preservation Division. A Stream Alteration Permit would be required if any aspect of a SEGS project were to affect a perennial or intermittent stream. Routing a power line across an intermittent stream is sufficient action to necessitate the Stream Alteration Permit. If an underwater cable landing is constructed, a DLNR Ocean Waters Construction Permit would be required.

Other State Permits

The State Public Utilities Commission (PUC) regulations pertaining to above ground electric transmission lines may be applicable if transmission additions are required in conjunction with a SEGS project. While

the authority of the PUC is limited to publicly-owned utilities, Qualifying Facilities (QF) which enter into purchase power agreements with public utilities must also adhere to certain PUC rules. Typically, power lines additions required for a purchase power agreement are constructed by the utility, while the costs are borne by the QF. For such a case, all desired exemptions to existing PUC regulations would require formal PUC approval. If any transmission line is to be located within a State highway right-of-way, a Permit to Construct Within a State Highway would have to be obtained from the State Department of Transportation, Highways Division.

Federal Permits

In addition to the involvement of the U.S. Environmental Protection Agency described above, several other federal entities could have permitting responsibilities for SEGS power plants in Hawaii. The U.S. Fish and Wildlife Service (USFWS) oversees compliance with the Endangered Species Act. The Hawaiian Islands' unique collection of plant and animal life includes a vast number of rare, endemic species—many of which are listed, or are soon to be listed, as endangered. Consequently, prospective SEGS sites in Hawaii may require an Endangered Species Review by the U.S. Fish and Wildlife Service.

The U.S. Army Corps of Engineers' Section 404 permit is required for any activity involving dredging or excavation which affects waters of the United States. Any SEGS project in which the site is graded into level terraces, thereby altering the natural drainage of the site, would require a Section 404 permit.

If an underwater electric transmission cable were to be installed in conjunction with a SEGS power plant—a likely scenario for SEGS sites on Molokai—several federal permits could be required. For the construction of underwater cable landing facilities, the U.S. Army Corps of Engineers' Section 9 and 10 permits for work in navigable waters, as well as a Section 103 permit to dispose of dredged material, may be applicable. The Department of Transportation-U.S. Coast Guard would require notification of laying operations for a submerged cable. Additional approvals for an underwater electric transmission cable would likely be needed from the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the U.S. Navy.

A few potential sites in Hawaii could involve lands owned by branches of the U.S. military services. The U.S Department of Defense would review SEGS projects on or adjacent to their facilities to ensure that there would be no interference with military operations. Other agencies which could be involved under certain circumstances are the Federal Aviation Administration (if within an air interference zone), the Council of Environmental Quality (if federal EIS), and the National Park Service (if PSD required for a site within the 100 kilometer zone of influence of a National Park).

County Permits

Hawaiian Counties have jurisdiction over certain land use permits as previously described under the land use section of this report. Additionally, the counties are responsible for permits pertaining to the actual construction of a project. County required construction permits are issued by the Department of Public Works and include Grading, Grubbing, Excavation, Stockpiling, Building, Electrical, and Plumbing Permits. While the counties' construction permits are procedural in nature, it is prudent to notify the Department of Public Works of planned activity early during a project. This often is done during the County Planning Department's review process for a land use permit.

Current application fees for major State permits range in the hundreds of dollars. On the other hand, county construction permit fees based on the value of construction can be significant. For instance, the Maui County Department of Public Works charges approximately one quarter of one percent (0.25%) of the proposed construction value for a building permit fee and plan check fee. On a $40,000,000 construction project, total building permit fees would amount to about $100,000. Additional fees would be required for all other applicable county permits as well.

Preliminary Cost Estimates

Preliminary cost estimates for various permitting actions are offered in Table IV-4. These values are rough estimates for a typical 200 MW SEGS power plant based on the permitting experience of Luz in California. The permitting costs should not vary greatly for a smaller project.

The cost estimates assume that if both NEPA EIS and State EIS are required, only one (1) document will be necessary. Furthermore, the estimates do not include permit fees or mitigation costs resulting from permit conditions

Table IV-4. Preliminary Permitting Cost Estimates.

FEDERAL	
Environmental Protection Agency	100,000
Army Corps of Engineers	50,000
EIS / Fish and Wildlife Service	300,000
STATE	
State Land Use	50,000
Department of Health	100,000
Other State	50,000
COUNTY	
Planning	40,000
Public Works	100,000

Summmary of Possible Permits

The following list includes numerous permitting agencies which may require permits or approvals for SEGS projects in Hawaii. Potential applicability to a SEGS project is described parenthetically. This is not a comprehensive listing, but it should include the agencies requiring major permits for a typical SEGS project in Hawaii.

FEDERAL

Environmental Protection Agency
Hazardous Waste Generator
Hazardous Waste Treatment, Storage, and Disposal (TSD) Permits
Prevention of Significant Deterioration (PSD)
NEPA Environmental Impact Statement (EIS)

U.S. Army Corps of Engineers
Section 404 Permit (potential alteration of drainage)
Section 9 and Section 10 Permits (construction affecting navigable waters)
Section 103 Permit (dumping dredged material)

U.S. Fish & Wildlife Service
Endangered Species Review

National Marine Fisheries Service
Clean Water Act Review
Marine Mammal Protection Act Exemption
Endangered Species Act Consultation

Council of Environmental Quality
National Environmental Policy Act (NEPA) Compliance: Environmental Impact Statement

National Park Service
Prevention of Significant Deterioration (if within 100 km of a National Park)

Department of the Navy
Notification of Surface and Subsurface Plans

Department of Transportation - U.S. Coast Guard
Notice of Submerged Cable
Notification of Cable Laying Operations

Federal Aviation Administration
Notice of Proposed Construction (if within air interference zone)

Federal Highway Administration
Approval for work to be performed on a Federal Highway (if road repairs performed in conjunction with project)

STATE OF HAWAII

State Land Use Commission
Special Permit (required for development/use of Agricultural and Rural District lands when project site is greater than 15 acres)
District Boundary Amendment

Department of Land and Natural Resources
Conservation District Use Permit
Easement for Use of State Lands
Well Drilling or Modification Permit
Permit to Withdrawal/Supply Water within Groundwater Control Area
Stream Channel Alteration Permit
Historic Sites Review (if in listed historic area)
Forest Reserve Special Permit (if traverse State Forests)
Entrance to Wildlife Sanctuary Permit
Permit to Enter a Closed Watershed
Ocean Waters Construction Permit
Dams and Reservoir Construction Approval

Department of Health
Authority to Construct (ATC)
Prevention of Significant Deterioration (PSD)
Permit to Operate (PTO)
Underground Injection Control (UIC) Permit
Underground Storage Tank (UST) Permit
Hazardous Waste Treatment, Storage, and Disposal (TSD) Permits
SARA, Title III Reporting Requirements
Community Noise Permit for Construction Activities

Public Utility Commission
Approval for Electric Transmission Line in a Residential Area
(for above ground electric transmission lines 46 kV or higher)
Exemption from General Order No. 6 requirements relating to conflicting lines
(if transmission lines intersect or could otherwise physically contact if overturned)
General Order No. 7 Authorization (necessary if capital cost is over $500,000)

Department of Transportation, Highway Division
Overload and Overweight Approvals
Permit to Construct within a State Highway (if transmission line routing is along state highway right-of-way)

Department of Labor and Industrial Relations
Pressure Vessels/Boilers Permits

Environmental Quality Commission & Office of Environmental Quality Control
Environmental Impact Statement

Office of State Planning
Coastal Zone Management (CZM) Program Consistency

COUNTY

Department of Planning
Special Permit (project less than 15 acres on Agricultural or Rural District Lands)
Special Management Areas (SMA) Use Permits (under CZM program)
Shoreline Setback Variance (SSV) (transmission located within 40' of shoreline)
Subdivision of Land Permit

Department of Public Works
Grading, Grubbing, Excavation, Stockpiling Permits
Building, Electrical, Plumbing Permits
Permit to Construct Within a County Roadway
County Roadway Use/Modification Permit
Driveway Construction

Other County Permits
Zoning Waiver (Height Variance)
Outdoor Lighting
Sign Permits

V. ECONOMIC EVALUATION

INTRODUCTION

A major consideration in the assessment of the SEGS viability in Hawaii is the analysis of the cost of energy or electricity produced by the system. Comparing the electricity costs of various generating systems is not as simple as it might first appear. To perform a meaningful comparison of SEGS system cost to that of conventional (or even non-conventional) alternatives, we must not only specify the assumptions in a detailed way, but we must also specify the type of analysis to be used. It is in this last area that confusion often arises.

For purposes of this section of the report, we will use levelized nominal bus bar power costs. Our analysis includes the following basic assumptions:

- It is assumed that the project is owned by the utility and not by an independent third party owner or Independent Power Producer (IPP). This has financial implications (affecting the cost of debt and equity and choice of discount rate among others) and tax implications (since utilities are not eligible for the Federal Business Energy Tax Credit or accelerated depreciation).

- The comparisons are made using a constant capacity factor of 35% for both the SEGS and the conventional system. It is assumed that the SEGS would achieve the 35% capacity factor by burning additional fossil fuels and that the conventional system would be dispatched to achieve 35% capacity factor.

This comparison is not meant to be the kind of detailed analysis that a utility would use before making a final decision on a power plant (such an evaluation would include use of a sophisticated production cost simulation model, for example); rather, it is a screening analysis of the type that a utility would use as a first cut determination. The approach is to first determine the assumptions that would place SEGS in the range of economic competitiveness and then to do more detailed analysis if appropriate.

Economic Model

The analysis was carried out with a simple spreadsheet model that calculates the levelized bus bar electricity costs (bus bar refers to the fact that we are assessing the cost of power at the plant's bus bar as contrasted to the cost of power delivered to any specific point on a utility system). The input consists of key technical characteristics and economic assumptions pertinent to the utility. The model performs a year-by-year analysis for both a SEGS and a fossil fueled plant, calculating a bus bar cost of electricity in each year. A single annual cost of electricity is then determined which has the same net present value as the escalating stream of annual revenue requirements. This is the levelized bus bar electricity cost. Sample output of the model can be found in Appendix D. The following is a list of key input variables:

- Unit size in kW
- Capital cost in 1992 $/kW
- Annual capacity factor (fuel + solar)
- Fixed and variable Operations and Maintenance costs in $/kW-yr. and mills/kWh respectively
- Fuel cost in 1992 $/MMBTU
- Fuel cost escalation rate in nominal percent per year
- Full load heat rate in BTU/kWh using higher heating values of fuel
- Utility's fixed charge rate (before tax cost of money)
- Discount rate used for present value analysis
- Property tax and insurance rate

- State Energy Tax Credit rate
- Utility's federal tax bracket (relevant since state taxes are deductible for federal purposes and the state tax credit savings actually increases federal tax liability)
- Solar capacity factor which determines how much fuel must be used in order to reach the 35% overall capacity factor
- Federal Energy Tax Credit rate

The economic analysis assumptions that are common to all the cases considered are given in Table V-1, using data supplied by HECO. The relatively high diesel fuel cost is only strictly applicable to the islands other than Oahu, where diesel fuel is the incremental fuel source. These values were used for all cases, however, to see if SEGS would be competitive under such favorable (for solar) assumptions. Additional assumptions for the particular solar and fossil cases that were run are presented in Table V-2. Information on the fossil cases was supplied by HECO.

ECONOMIC RESULTS

Table V-2 presents the base case results for the analysis. As shown, the lowest cost SEGS configuration (the 80 MW SEGS with a cost of $0.254/kWh) is about 28% higher in cost that the highest cost fossil configuration (the Combustion Turbine with SCR at $0.198/kWh). A more realistic comparison (for Oahu) would contrast an 80 MW SEGS with a 56 MW Combined Cycle, revealing the SEGS to be some 68% more expensive. Or, for a neighbor island, one could compare a 30 MW SEGS with a 20 MW CT/SCR, with the SEGS being some 44% more expensive. Given that these results do not appear to be promising for SEGS, a series of sensitivity analyses were run to determine if any reasonable change in the assumptions would alter this result.

The parameters used in the sensitivity analysis were fuel price, fuel escalation rate, Federal energy tax credit, property tax exemption for solar facilities, a penalty on the fossil fueled options due to an assessment on environmental externalities, SEGS cost and SEGS performance.

Figures V-1 and V-2 present, respectively, levelized electricity cost as a function of fuel price and a comparison of levelized electricity costs for SEGS and conventional options as a function of fuel price escalation rate, holding the fuel price constant at $4.99/MMBTU. With regard to fuel price, the results indicate that a fuel price of $13/MMBTU (or about $78/barrel) would be required for the 80 MW SEGS to be competitive with the 70 MW CT. Alternatively, we would estimate that a SEGS capital cost of $1,600/kW would be required for the SEGS to be competitive under base case assumptions. Figure V-2 indicates that a fuel price escalation rate of 12% or more would be required for an 80 MW SEGS to be competitive with the smallest and most expensive combustion turbine option. These rates are in contrast to our most recent history of zero growth (and even decline) in oil prices, and would be some 7% above assumed inflation.

Figures V-3 and V-4 present this same structure for analysis but add consideration of various incentives. (Fig. V-3 presents the comparison for systems that would be relevant to Oahu; while Fig. V-4 gives a comparison of smaller systems that would be applicable to the neighbor islands.) Perhaps the most controversial of the incentives is that of environmental externalities wherein we have incorporated a net 1¢/kWh penalty for the fossil fueled options. This value was selected for a number of reasons:

- The appropriate value for environmental externalities, where they have been applied, has been deemed to vary with pollutant (e.g., NO_X, SO_2 and CO_2 — which in turn varies with fuel type and efficiency), and with location (e.g., within or outside an air quality non-compliance region). By using a 1 ¢/kWh figure, we can easily extrapolate to other values.

- Using this fairly small figure reflects the fact that the SEGS power output will have some degree of externality contribution since a substantial amount of fossil fuel will be burned.

It should be noted that inclusion of this analysis is not an endorsement of the concept of environmental externalities or of any specific value for an externality.

These Figures also present the impact of making the 10% Federal Energy Tax Credit available to utilities. The impact of the Federal ETC is relatively small since, by accounting conventions, the amount of the credit would be credited against rates by allocating it over the 30 year life of the plant. Also shown is the impact of exempting the plant from property taxes (solar plants are currently exempt from property taxes in California and Nevada, but not currently in Hawaii).

Several observations can be made from these results. Adding consideration of environmental externalities adds about a 1.5¢/kWh increase in the levelized cost of the fossil fired options relative to the SEGS option. The property tax exemption substantially improves the economics of SEGS, subtracting approximately 2.5-3.0¢/kWh from the levelized cost of SEGS electricity. For an Oahu application, a SEGS would still not appear to be competitive with a combined cycle plant for reasonable values of fuel price escalation (we calculate that a fuel price escalation rate of about 16% would be required to make the 56 MW Combined Cycle plant more expensive than the 80 MW SEGS including the impact of all externalities and tax benefits). For a neighbor island plant, inclusion of environmental externalities and a property tax exemption would appear to make the 30 MW SEGS plant competitive with the 20 MW CT/SCR assuming a fuel cost escalation rate of about 11%.

Figure V-5 provides further insight into the impact of various incentives by presenting the levelized cost of electricity as a function of fuel price escalation for an 80 MW SEGS under the following incentives scenarios (reading the curves from top to bottom):

- *80 MW SEGS without Hawaii ETC:* assumes removal of the current 35% state energy tax credit
- *80 MW SEGS:* the base case
- *80 MW SEGS + Federal ETC:* assumes that the federal 10% ETC would be extended to utilities
- *80 MW SEGS + Prop. Tax Exemption:* assumes that Hawaii would enact a property tax exemption for SEGS
- *80 MW SEGS + Federal ETC + Prop. Tax Exemption:* assumes both of the above tax benefits

Finally, Figure V-6 presents the levelized bus bar electricity costs for an 80 MW SEGS (under the current incentives law) as a function of SEGS capital cost (in $/kW) and as a function of solar capacity factor. The 25% solar capacity factor represents good performance for a SEGS plant located in the California desert. A typical Hawaiian site might yield a 15% capacity factor, with 20 % being a likely upper limit.

As an example of the impact of the various incentives on an 80 MW SEGS, at a fuel escalation rate of 8%, the effects on the levelized cost of electricity were found to be:

Without Hawaii ETC:	$0.281/kWh
Base Case	0.271
With Federal ETC:	0.267
With Property Tax Exemption:	0.246
With both Fed ETC + Prop Tax Exemption:	0.242

Figure V-6 is useful to examine plausible ranges for the cost of electricity due to significant variations in capital cost and performance (reflected by the capacity factor) of the SEGS plant. One scenario of possible combinations, for example, is:

Capital Cost	Capacity Factor	Levelized Electricity Cost
$2,000/kW	0.25	$0.16/kWh
5,000	0.15	0.31

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Capital Cost	Capacity Factor	Levelized Electricity Cost
$2,000/kW	0.25	$0.16/kWh
5,000	0.15	0.31

The 25% capacity factor represents the best that could be achieved in the California desert without thermal storage. In Hawaii, a 20 % capacity factor would be excellent without thermal storage, while higher values might be achieved with storage, but at a higher capital cost. While some scenarios for future advances in SEGS plants have had a goal of $2000/kW, this is a very difficult target, particularly with the cost adders for a plant constructed in Hawaii.

Impact of Hawaii ETC

Comparison of Figures V-5 and V-6 shows that the impact of a reduction in SEGS capital cost is more significant than an "equivalent" reduction due to the Hawaii ETC. Take, for example, a SEGS capital cost of $4000/kW. A 35% reduction in capital cost drops the price to $3076/kW and results in a levelized electricity cost of 0.226 $/kWh. This compares to a much higher levelized electricity cost of 0.258 $/kWh for a 35% ETC at the $4000/kW price.

The ETC is worth substantially less than a similar price reduction for several reasons. The accounting methodology used here for a utility-owned plant to calculate revenue requirements (or cost to the rate payers) spreads out the tax credit over 30 years, negating the up-front impact that such a tax credit would have for an IPP or other third party owner. The direct price reduction, on the other hand, reduces capital charges, depreciation, property taxes and insurance, all with significant up-front effects. Hence, annual revenues requirements are markedly reduced for the direct price reduction case, particularly in the early years. These factors lead to the final 3 cent advantage for the direct price reduction.

Summary

Summary conclusions of the economic analysis are included in the Conclusions section of this report.

Table V-1. Economic Assumptions Common to All Cases

Fixed Utility Parameters (same values used for all base case analyses)	
Fuel Cost (1992 Value, $/MMBtu)	4.99 (diesel)
Fuel Cost Escalation Rate, %	5.50
O&M Cost Escalation Rate, %	5.00
Fixed Charge Rate (Before Tax Cost of Capital), %	10.48
Discount Rate, %	10.48
Property Tax + Insurance Rate, %	3.00
Utility's Federal Income Tax Bracket, %	34.00

Table V-2. Economic Analysis Assumptions and Base Case Results

Parameter	CT20	CT20 w/ SCR	CT70	CC56	SEGS15	SEGS30	SEGS80	SEGS200[d]
Unit Size (MW)	20	20	70	56	15	30	80	200
Capital Cost (1992 $/kW)	1300	1710	710	1375	5000	4420	3845	4870
Solar Output (MWh/yr)	0	0	0	0	19710	45990	126145	331130
Annual Capacity Factor (%)	35	35	35	35	35	35	35	35
Solar Capacity Factor (%)	0	0	0	0	15	17.5	18	18.9
Fuel Capacity Factor (%)	35	35	35	35	20	17.5	17	16.1
Full Load Heat Rate (Btu/kWh)	10970	10970	13045	8070	13800	11800	11500	10950
Fixed O&M Costs (mills/kWh)	23.86	31.41	12.29	32.59	99.33	90.00	81.13	76.60
Variable O&M Costs (mills/kWh)	4.06	8.28	7.33	3.04	0	0	0	0
State Solar Energy Tax Credit (%)	0	0	0	0	35	35	35	35
Levelized Bus Bar Electricity Cost[e] ($/kWh)	**0.169**	**0.198**	**0.158**	**0.151**	**0.333**	**0.286**	**0.254**	**0.292**

Notes:
a) CT - combustion turbine
b) SCR - selective catalytic combustion
c) CC - combined cycle
d) SEGS 200 case includes $320 million ($1600/kWh) for Molokai to Oahu cable. Without this full cable cost, the levelized bus bar electricity cost would be $0.223/kWh.
e) These results include the Hawaii state ETC for the SEGS cases. Without this credit, the levelized bus bar electricity costs would be approximately 1 cent higher for the SEGS cases.

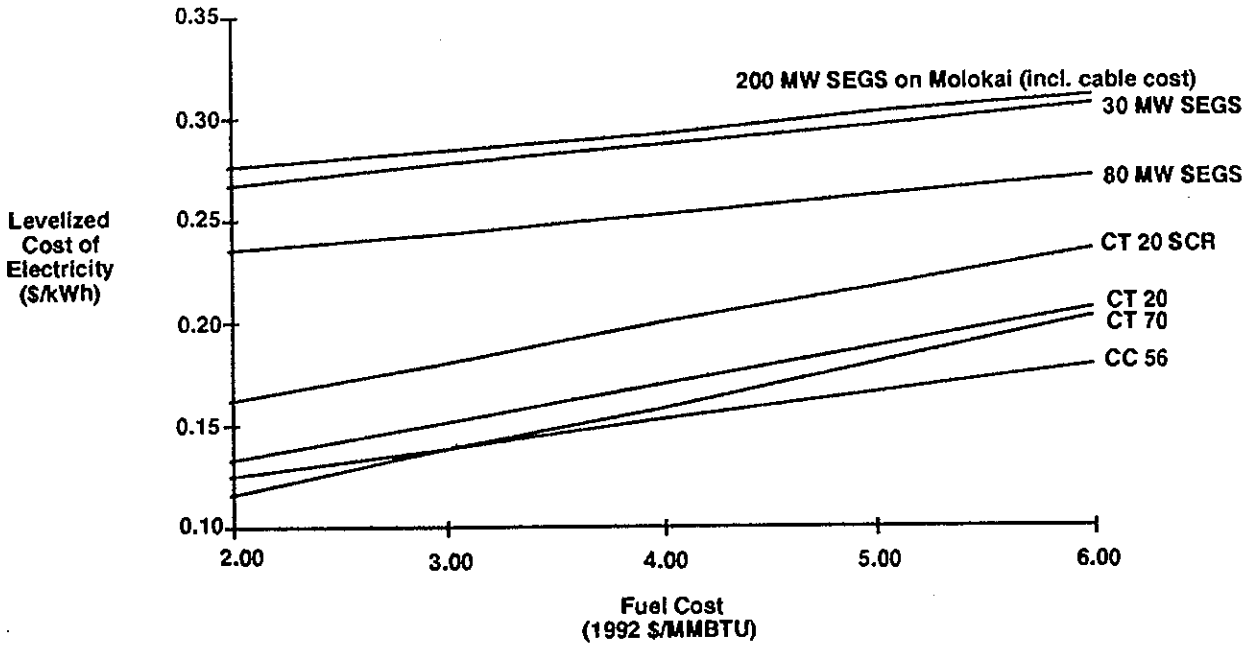

Figure V-1. Levelized Cost of Electricity vs. Fuel Cost

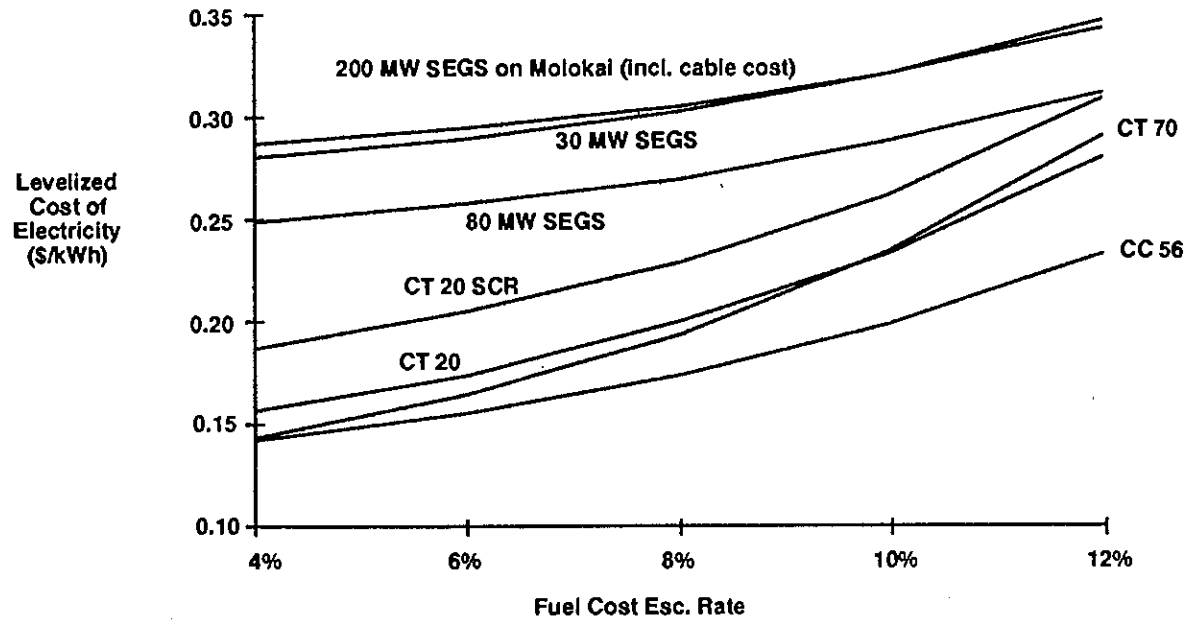

Figure V-2. Levelized Cost of Electricity vs. Fuel Cost Escalation Rate

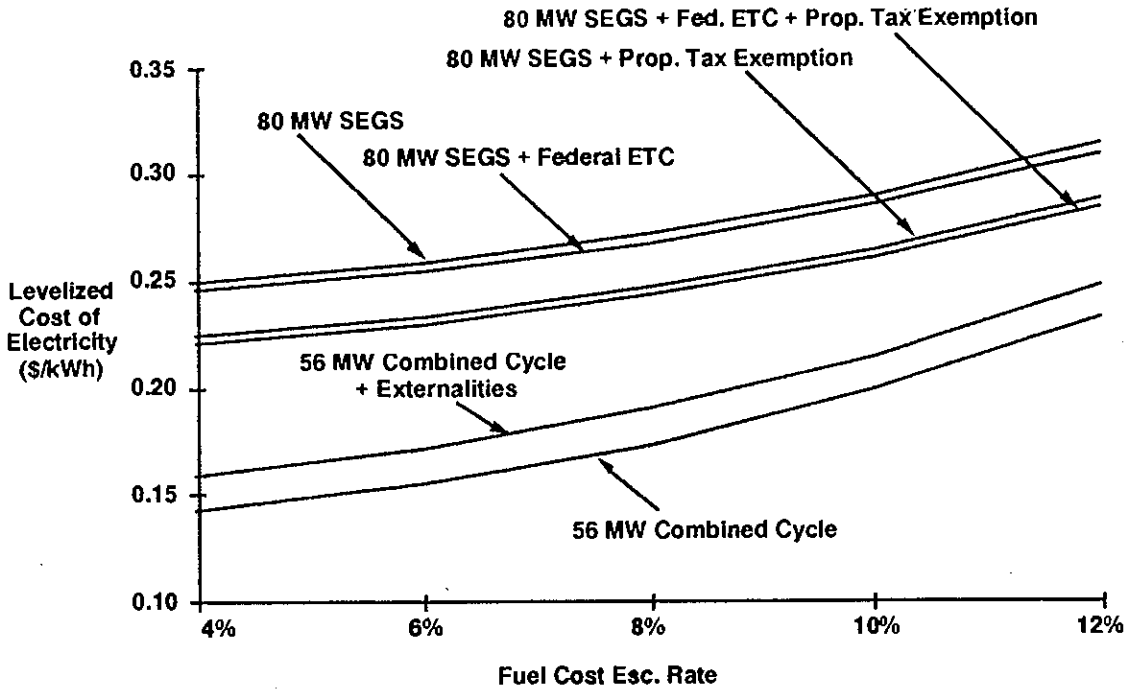

Figure V-3. Impact of Incentives for Oahu Scale Systems

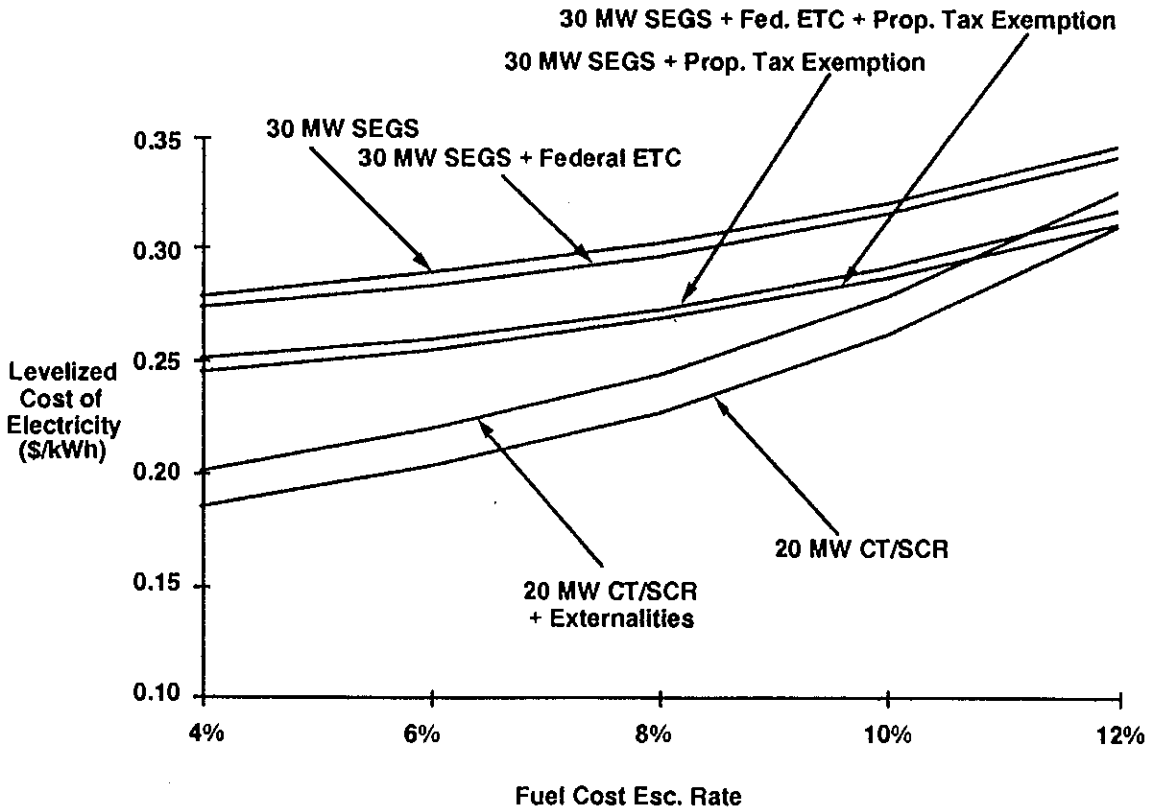

Figure V-4. Impact of Incentives for Neighboring Island Scale Systems

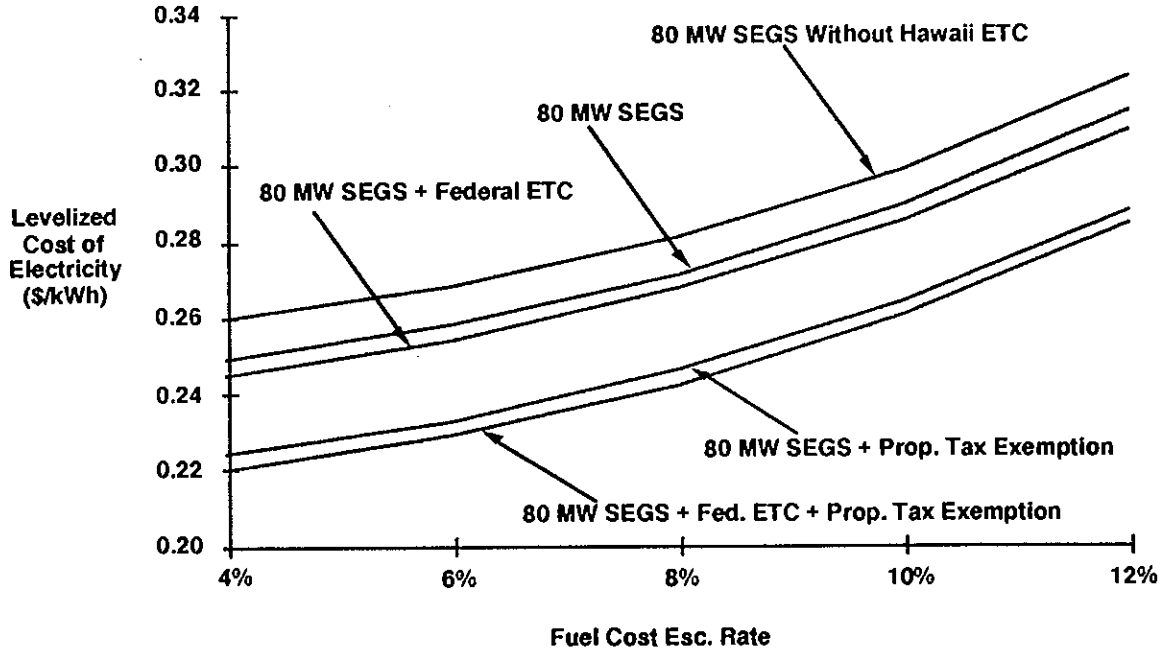

Figure V-5. Cost of SEGS Electricity for Various Incentives

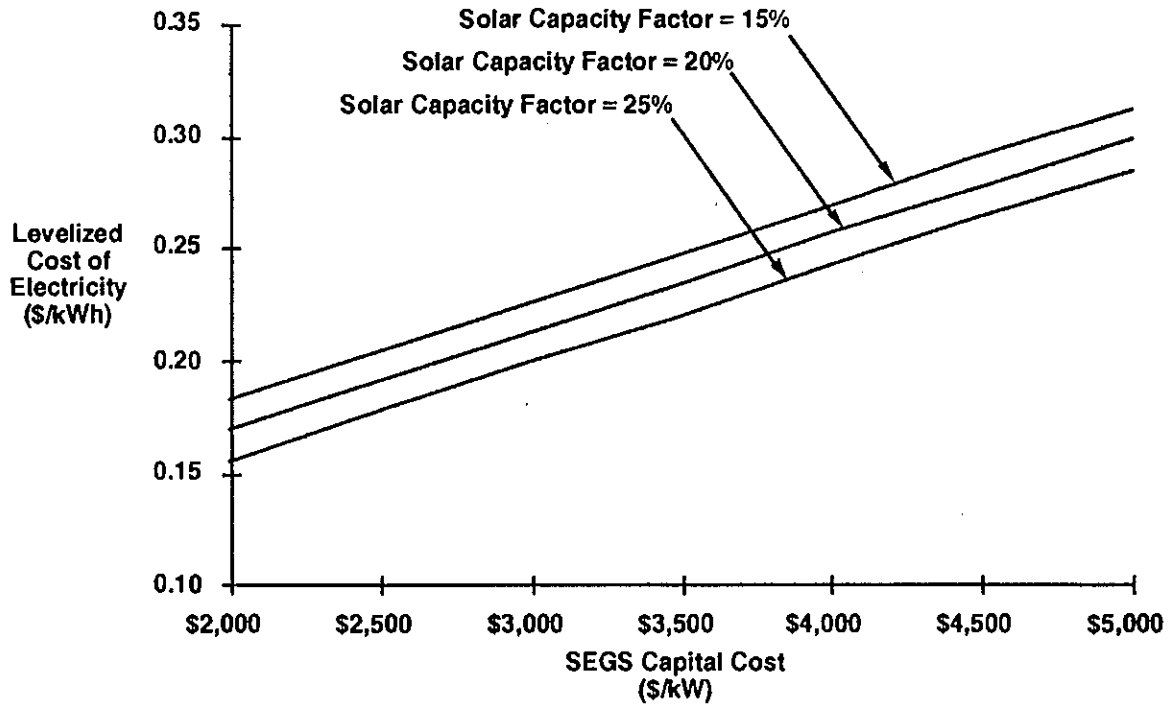

Figure V-6. Impact of SEGS Capital Cost and Solar Capacity Factor on Electricity Cost

CONCLUSIONS

Based on all aspects of this assessment, the following conclnsions can be drawn regarding the viability of SEGS plants in the State of Hawaii:

- Suitable sites exist on the leeward sides of the major islands,
- Electric utility resource plans point to SEGS capacities of 30 MWe or smaller (except on Oahu for which an 80 MWe plant is suitable). Capital costs are significantly increased relative to the latest California SEGS plants due to physical siting characteristics, shipping, taxes and labor adjustment factors,
- The solar resource applicable to SEGS plants in Hawaii is about 25-30% lower than the Mojave Desert on an annual basis, leading to solar performance reductions possibly as high as 40-50%,
- The base case economic analysis finds that SEGS plants do not currently appear to be a cost-effective solar applications for the State of Hawaii,
- Inclusion of commonly discussed incentives for renewable energy technologies such as tax credits, property tax exemptions and incorporation of environmental externalities into generation planning improve the economics for SEGS but do not change this conclusion,
- The principal reasons for the unfavorable economic results are the higher capital costs and lower system performance projected for SEGS plants in Hawaii, even those located in the preferred sites. Significant capital cost reductions compared to current projections appear necessary to alter this finding.

lt is important to bear in mind that these conclusions are drawn *for SEGS plants only,* and do not purport to reflect on the viability of other solar systems (such as photovoltaics) or even other solar thermal systems (such as parabolic dish Sterling concepts or industrial process heat applications), which have different cost and performance characteristics.

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APPENDICES

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APPENDIX A. ACKNOWLEDGEMENTS

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Citizens Utilities; Kauai Electric Division

Kelvin Kai
Gilbert Mackey
Dan McCarty
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Thomas H. Daniel
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The University of Hawaii at Manoa

Arnold Hori
Tom Schroeder

OTHER

Alpha U.S.A., Inc.

Henry Keawe Ayau, Jr.

AMFAC/JMB

Brian Nishimoto

AMFAC; Pioneer Mill Company, LTD.

George "Keoki" Freeland
David Morrell

Energy Resource Systems

John J. Crouch

The Estate of James Campbell

Russell Alger

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Mike Boughton

Molokai Ranch

Pearl Hodgins

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APPENDIX B. HAWAII SOLAR RADIATION INFORMATION

OVERVIEW

This appendix is a compilation of various materials of relevance to the solar radiation resources of Hawaii. It consists of information from various local and national sources. The spectacular variability in climate in Hawaii creates striking differences in insolation availability over very short distances. Development of a clear understanding of the solar radiation environment is prerequisite to large-scale development of solar power technology in any region. Due to the extreme indigenous microclimates, this is likely a more formidable task in Hawaii than in any other state in America.

Because of the correlation between sunshine and sugar cane yields, Hawaiian sugar planters have been monitoring sunshine patterns in Hawaii since 1932. These long-term data collection activities embody some of the longest periods of record for solar radiation data in the United States. The wide distribution of sugar cultivation throughout the state results in a spatial distribution for total radiation information which is reasonably good. The sugar planters' data, augmented by the solar monitoring efforts of the University of Hawaii, HECO, NOAA, and others, provides a wealth of raw information on total solar radiation applicable to the developed areas of the state.

In contrast to the impressive scope and duration of resource assessment activity for total radiation, there have been but a few isolated monitoring efforts concerned with direct insolation. Direct (Beam) radiation is the component of sunlight which can be optically focused with mirrors, reflectors, fresnel lenses or other imaging optics to achieve high radiation fluxes and thereby high temperatures. Direct insolation is the only relevant component of sunshine for applications which require temperatures greater than about 200°F. These applications include SEGS, central receivers, solar thermal dishes, concentrating photovoltaics, solar detoxification and other photochemistry.

This appendix is envisioned as a mechanism for sharing pertinent information on Hawaii's insolation environment which has been acquired through the course of this SEGS feasibility study. Paul Ekern provided the bulk of the material and recommendations presented herein. While DBEDT's global horizontal maps are useful products, there is nonetheless a lack of assimilation and organization of both direct and global insolation data for Hawaii.

The last page of this appendix provides contact information for sources who may prove knowledgeable on Hawaiian insolation patterns and data bases; also included are some potentially useful observations by Mike Sloan which pertain to various insolation resources for Hawaii.

MECHANISMS AFFECTING TERRESTRIAL SOLAR RADIATION

This sub-section briefly reviews the physical processes which influence terrestrial solar radiation. Much of this discussion is taken from *Solar Radiation Resource Assessment of Texas*, by Sloan Solar Engineering (1992). Consideration of these factors should provide some insight into the spatial and temporal variability of the solar radiation environment across Hawaii. For the purposes of this appendix, the major factors influencing terrestrial solar availability will be classified as extraterrestrial solar radiation, atmospheric transmittance, site-specific location parameters, and cloud cover.

Extraterrestrial Solar Radiation

The available radiation at the edge of the earth's atmosphere is a function of the earth's position relative to the sun as well as the radiative intensity of the sun. The sun's surface radiative intensity is

nearly constant, although it does vary extremely slowly with time and noticeably, by as much as 0.5%, during periods of abnormal surface activity (sunspots, solar prominences, solar flares). In spite of these minor variations, the mean annual solar flux reaching the earth's atmosphere is termed the *solar constant*. The currently accepted value for this parameter, integrated over the entire solar spectrum, is 1367 W/m^2 (World Radiation Center, Davos-Dorf, Switzerland, July 1985). Due to the elliptical orbit of earth about the sun, earth's distance to the sun varies throughout the course of the year by +/- 1.7% Solar radiation attenuates from its source, the sun, according to the inverse-square law resulting in a range for extraterrestrial solar flux adjacent to the earth's atmosphere of approximately 1414 W/m^2 at perihelion (on or about January 3) and approximately 1320 W/m^2 at aphelion (on or about July 6).

Atmospheric Transmittance

The earth's atmosphere is comprised of various gases and particulate matter which collectively absorb and scatter various portions of the incident solar spectrum. The gases principally responsible for atmospheric absorption are water vapor (H_2O), carbon dioxide (CO_2), ozone (O_3), and oxygen (O_2). Airborne particles which scatter incoming radiation include air molecules, water droplets, aerosols (suspended colloidal particulates), and other airborne solid and liquid matter. The specific mechanism for scattering is a function of particle size. Very small and molecular particles (<<0.1mm) are governed by Rayleigh scattering which is reasonably isotropic. Large aerosol particles responsible for turbidity exhibit strong forward scattering which accounts for increased sky brightness around the disk of the sun.

The absolute moisture content of air can vary significantly with time as well as over short distances. High absolute humidity results in enhanced atmospheric absorption by water vapor and relatively more scattering by hygroscopic aerosols, which become larger with increasing moisture. Since hot air has a much higher capacity to retain moisture than does cold air, cold, clear conditions generally result in higher direct normal availability than hot, clear conditions.

The solar environments around urban/industrialized areas often show perceptible localized effects. These areas exhibit reduced direct solar availability due to scattering by pollution particles as well as enhanced absorption caused by CO_2 produced from combustion processes. In contrast to the spatially variable nature of humidity and pollution, the effects of volcanic activity are global in extent. Violent volcanic eruptions are capable of ejecting particulates into the highly rarefied stratosphere (6-15 miles above the earth's surface). The high altitude debris from some eruptions eventually form miniature sulfuric acid droplets which disperse globally and persist for years.

Remotely located near the summit of the world's most massive mountain — Hawaii's Mauna Loa — the U.S. National Oceanic and Atmospheric Administration's (NOAA) Mauna Loa Observatory (MLO) performs fundamental research in one of the atmospherically clearest environments in the world. The average monthly clear day atmospheric transmittance as observed from the Mauna Loa Observatory (elevation 11,145 feet) is shown in Figure B-1. This figure depicts the long-term variability of the transmittance of the earth's upper atmosphere.

The influence of volcanic activity on atmospheric transmittance is clearly evident in Figure B-1 from the spiked reductions and exponential recovery which correlate with major volcanic eruptions. The greatest reduction in transmittance evident in B-1 was caused by the March 1982 eruption of El Chichon in southern Mexico. El Chichon's debris trail passed directly over Hawaii magnifying the impact of this eruption. However, even after a few years of dispersion, the effects of the eruption were noticeably apparent. The more modest decrease in transmittance during the mid-1960's followed an eruption of the Balinese volcano Agung in 1963. It is noted that the 1980 Mt. St. Helens eruption, while severe from a vulcanism standpoint by virtue of the massive quantity of material ejected, erupted predominantly from its side. Therefore, the debris trail did not attain a sufficient altitude to significantly impact long-term atmospheric conditions.

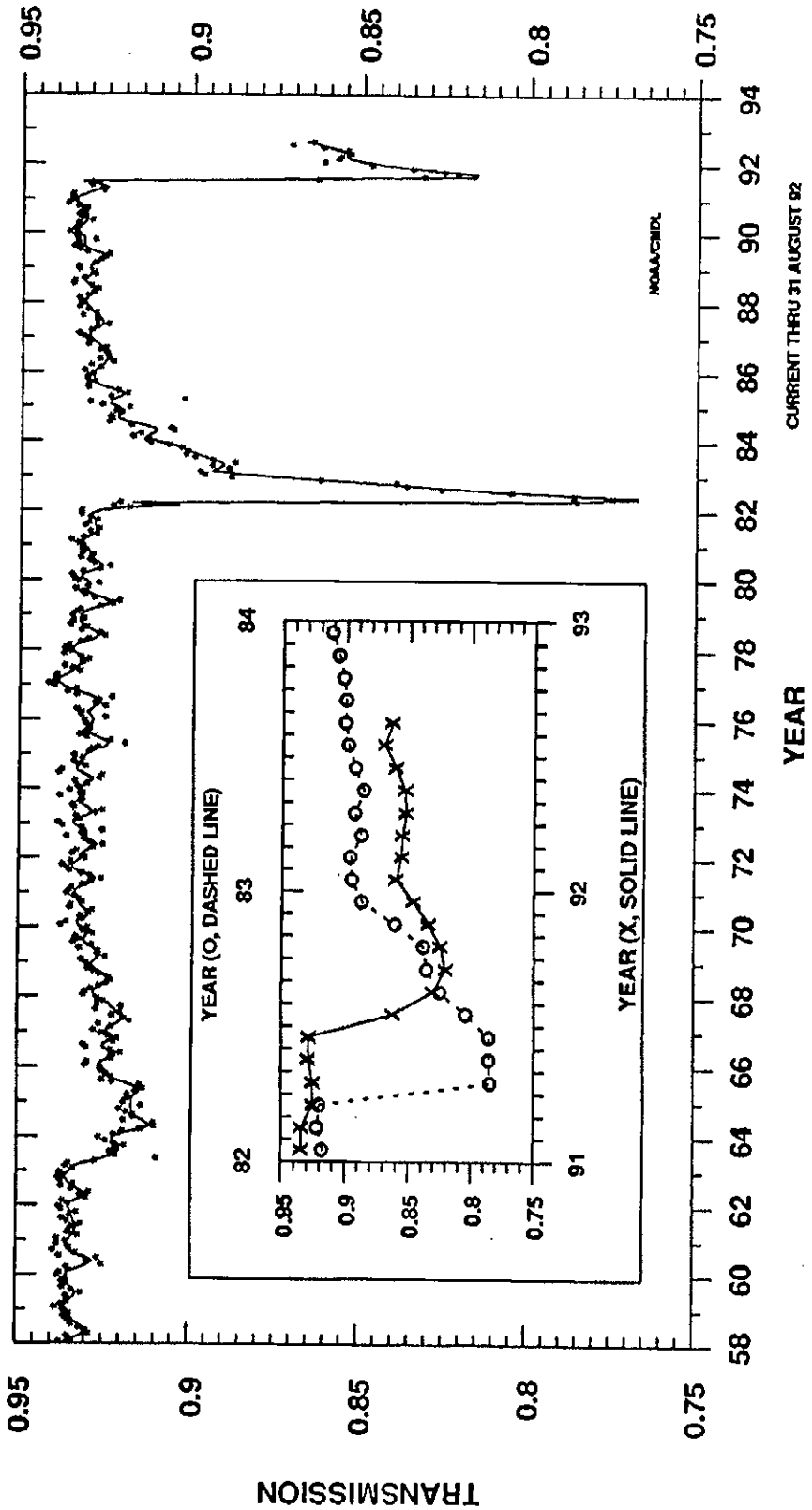


Figure B-1: Clear Sky Atmospheric Transmittance at the NOAA Mauna Loa Observatory, Hawaii

The impact of the 1991 eruption of Mt. Pinatubo in the Philippines is also clearly evident in the MLO data. Pinatubo, which is considered the most significant eruption of the past century from an atmospheric standpoint, ejected about 3 times as much material into the stratosphere as did El Chichon. The relative impact of these two eruptions are compared in the inset of Figure B-1. While the onset of Pinatubo was not as dramatic as El Chichon, the slower recovery rate seemingly confirms the suspicion that Pinatubo will have a greater global impact than El Chichon. Due to Pinatubo's lingering effects, direct normal insolation during clear sky conditions should remain reduced throughout Hawaii and the rest of the world for a few more years.

Site-Specific Location Parameters (Latitude, Longitude, and Elevation)

Solar sites located at higher latitude embody greater seasonal variability in length of daylight than do those nearer the equator. Relative to lower latitudes, days during summer are longer, while days during winter are shorter. These phenomena strongly influence the seasonal output potential of solar energy devices.

One measure of the sun's position is the solar zenith angle—the angular measure to the sun as referenced from the direction directly overhead. The minimum solar zenith angle (when the sun is highest in the sky; maximum solar altitude) generally occurs at solar noon when the sun's azimuth position is due south. Since Hawaii is within the Torrid Zone (equatorial), the sun passes directly overhead (minimum zenith = 0°) during two days near the summer solstice (once in May and once in July). Outside of this summer solstice interval, the minimum solar zenith angle is merely the site's latitude minus the solar declination. Day length and minimum zenith angle are summarized for Honolulu below. Latitudes throughout the inhabited islands of Hawaii range from 18.9° to 22.2° N. Hence, the values quoted for Honolulu are representative for the entire state. It is noted that observed apparent day length will deviate somewhat from the values listed below due to atmospheric diffraction, curvature of the earth, and landscape features such as mountain ranges.

		Summer Solstice		Equinox		Winter Solstice	
LOCATION	LATITUDE (°N)	DAY LENGTH (hr:min)	MINIMUM ZENITH (degrees)	DAY LENGTH (hr:min)	MINIMUM ZENITH (degrees)	DAY LENGTH (hr:min)	MINIMUM ZENITH (degrees)
Honolulu	21.3	13:18	2.2	12:00	21.3	10:42	46.8

Most solar systems perform well during summer when the sun is high in the sky. During winter, horizontal (single) axis tracking concentrating systems, such as the SEGS design, will be much more sensitive to the relative zenith angle differences imposed by latitude. On the other hand, two-axis tracking systems will be affected in winter only slightly: to the extent that increased atmospheric path length reduces available insolation.

For a given latitude, the length of daylight will be the same irrespective of longitude. A site's longitude, however, can provide a useful shift which helps the solar availability better match daily electric demand (With Hawaii's fragmented electric grid, however, this may be of very limited value). The sun moves 15° of longitude per hour (360°/24 hours). At Hawaii's latitude (about 21°N), the sun moves toward the west at a rate of about 16 statute miles per minute. Representative shifts in solar time are given in the table below and are calculated by: D(longitude) x 4 minutes/degree.

LOCATION	LONGITUDE	MEAN SOLAR NOON	SHIFT RELATIVE TO HONOLULU
	(°W)	(Hawaii Std Time)	(Minutes)
Hilo	155.1	11:50 a.m.	-12
Kahului	156.4	11:56 a.m.	-6
Honolulu	157.9	12:02 p.m.	--
Lihue	159.4	12:07 p.m.	+5

The atmosphere is a blanket of gases and other matter which is held to earth by gravitational forces. Air is thinner at higher elevation since part of the atmospheric blanket lies below. Roughly half of the atmosphere's gaseous mass and most of the heavy aerosols responsible for turbidity scattering exist below an altitude of 18,000 feet above sea level. Another consequence of higher elevation is cooler temperature (about -3°F per 1,000 feet of elevation rise). Companion to cooler temperature is lower absolute humidity. Consequently, there are less opportunities for atmospheric absorption and scattering at higher elevations. The net effect of these conditions is that clear sky direct normal insolation increases with increasing elevation.

Cloud Cover

Clouds are typically formed when rising air expands and cools sufficiently to condense water vapor into visible particles. These water particles will remain aloft or evaporate unless they achieve sufficient mass to overcome the buoyant forces acting upon them and return to the earth's surface as precipitation. There are numerous types and sub-classifications of clouds which impact terrestrial solar availability. Some types are effectively opaque; others are almost transparent. Often multiple strata of cloud are present at the same time. The net impact on solar availability will depend on the type, extent, and movement of the constituent cloud formations.

Definitions of Diffuse, Direct, and Global Insolation

Measurements of solar radiation are generally expressed as *insolation* (incoming solar radiation) in units of energy per unit area (kWh/m^2, cal/cm^2, etc.). Instantaneous measurements of radiative flux are expressed in units of power per unit area (W/m^2, etc.). Incident beam radiation which is not scattered by earth's atmosphere is termed *direct normal insolation*, while the scattered portion which emanates from all portions of the sky is termed *diffuse insolation*. The combined contributions of direct and diffuse result in the total *global insolation*. In practice, diffuse and global insolation are measured with horizontal devices (instruments placed on a level surface and not tilted) which integrate the available insolation over the entire sky dome. Insolation measurements conducted in this manner quantify *diffuse horizontal insolation* and *global horizontal insolation*.

Insolation Conversion Factors

1 cal/cm^2 = 1 Langley; 86.04 cal/cm^2 = 1 kWh/m^2; 3.6 MJ/m^2 = 1 kWh/m^2; 17.2 BTU/ft^2 = 1 kWh/m^2

CLOUD PATTERNS IN HAWAII

Hawaii's highly variable microclimates stem from the interaction between the region's normal air flow patterns and the state's rugged topography. The Hawaiian Islands lie in the North East Trade Wind zone of the mid Pacific Ocean. In summer, this flow dominates local weather patterns, with occasional disruptions induced by tropical storms which pass south of the island chain. Characteristic trade wind conditions embody a moist marine air layer averaging 6,500 feet thick, capped by a stabilizing temperature inversion, above which the air is very dry. When the layer of moist air is forced to pass over island terrain beneath the stable inversion, clouds and rainfall develop. On windward slopes, cloud and rainfall typically scale with elevation. On leeward slopes, descending air warms and saturation values increase. Accordingly, leeward sides of Hawaii's mountainous islands are warmer, dryer, and less cloudy.

The distortion of the trade winds by island topography produce extreme variations in annual rainfall. Approximately 30 inches of precipitation falls over the open ocean in the vicinity of Hawaii. Rainfall for leeward sites is generally less than 20 inches to as low as 6 inches per year (Kawaihae, Hawaii) . Orographic (mountain caused) rainfall is most exceptional on Kauai and West Maui — about 450 inches per year — over mountains which slightly exceed 5,000 feet in elevation. The largest volcanoes of Hawaii, which approach 14,000 feet MSL, project through the inversion and remain

relatively sunny and dry (annual precipitation of about 15 inches) since the moist air streams below the inversion flow around, rather than over, these peaks.

In winter, polar frontal systems in the westerly flow zone to the north reach the islands and disrupt the trade wind stream so often that trades are no longer dominant. Rainfall and cloud patterns are much more complex in the highly variable moisture and wind regimes which result. Winter storm systems impact the western islands of the Hawaiian chain with more frequency than the islands to the east. Hence, winter cloudiness associated with storms is expected to have a progressively reduced impact going from Kauai toward Hawaii.

When the trade flow is absent or weak, heating and cooling of the mountain slopes coupled with the proximity of the ocean cause day to night reversal of land-sea and mountain-valley breeze forms. These local wind conditions dominate the weather patterns on the lee slopes of Hawaii's large mountains. Year-to-year changes in trade wind strength and predominance accompany the worldwide changes in tropical weather stemming from the El Niño-Southern Oscillation. The variability is more evident during winter months than during summer.

INSOLATION IN HAWAII

Cloud cover is the dominating factor for solar radiation availability. The highest annual insolation in the State occur on the leeward uplands and tops of Mauna Kea and Mauna Loa. These areas combine low atmospheric scattering and absorption with relatively low cloud cover. For the purposes of SEGS siting, however, these areas are inaccessible and steeply sloped and are not considered as suitable sites. The remainder of this appendix concentrates on discriminating between the relative insolation availability of low-altitude sites.

Consistent with prevailing cloud patterns, the sunniest low elevation areas in Hawaii are on the leeward sides of islands, in the rain shadow of large volcanoes. Also, winter insolation is expected to improve going from west (Kauai) toward the east (Hawaii). Aside from these two generalizations, analysis of the insolation environment in Hawaii will depend on evaluation of measured data sources.

SOLAR DATA BASES RELEVANT TO HAWAII

The following solar data bases are briefly discussed:

1) SOLMET/ERSATZ
2) TMY
3) NSRDB
4) University of Hawaii.
5) Other (NOAA Honolulu & Mauna Loa Observatory, HECO, PVUSA, Ascension Technologies, etc.)

The three national solar data bases (SOLMET/ERSATZ, TMY, NSRDB) are described in some detail since many users are unfamiliar with the origins and methodology defining these commonly used data sets. The SOLMET and TMY products for Hawaiian stations are not highly regarded; however, as was discovered during the course of this SEGS assessment, local measured data sets of hourly data (UH-Manoa, etc.) are not readily available. Since the national data sets are readily available, they may be utilized more often than the numerous local measured data bases. The recently revised national data base (NSRDB), which utilizes a few years of measured insolation data from the NOAA monitoring station at the Honolulu Airport, should prove more reasonable for Hawaiian stations than its predecessors. The NSRDB became available in November, 1992.

SOLMET/ERSATZ

Prior to the NSRDB, the SOLMET/ERSATZ was the only long-term national solar radiation data base available in the United States. The intent of this network was to provide long term SOLar and METeorological parameters for a vast number of sites throughout the country. Global horizontal insolation measurements taken at 26 sites representatively distributed about the country provide the foundation for this data base. The period of record for nearly all stations spans the period 1952-1975. There are no measured SOLMET stations in Hawaii.

The 26 SOLMET sites which had measured long-term solar records are referred to as SOLMET control data stations (or just SOLMET). Statistical modeling procedures were developed to rehabilitate all missing data and incongruencies introduced by the historical use of different types of solar instrumentation. These rehabilitated data served as the primary basis to estimate global horizontal insolation for an additional 222 derived SOLMET sites (also known as ERSATZ sites). Rather than interpolating among several stations, ERSATZ data were derived from the individual control data station which was most similar (usually geographically nearest) to the derived data site. Due to the lack of a local control station, all four (4) derived ERSATZ stations in Hawaii were based on Miami, Florida. The estimation procedure involved the comparison of several meteorological parameters such as cloud cover and visibility. For example, if these meteorological parameters were identical for both Miami and Honolulu for a given hour, the Miami global horizontal datum was substituted directly. In other cases, a regression formula modulated the substitution. This procedure yielded hourly global horizontal data for all 248 SOLMET/ERSATZ sites. The summarized long-term annual average and monthly average global horizontal insolation for each SOLMET station are provided in *Input Data for Solar Systems* and the *Insolation Data Manual.*

TMY

The Typical Meteorological Year (TMY) data sets were developed during the late 1970's to provide a single year data base representative of long-term average conditions for the 248 SOLMET/ERSATZ stations. These single design years were reduced from the 20+ years of data contained for each site in the full SOLMET data base. Procedurally, complete individual months — Typical Meteorological Months (TMM) — were selected from the long-term SOLMET data set as being most typical of the long-term conditions demonstrated at each site. For instance, the July which was most representative of the long-term conditions for Fort Worth, Texas over the period of 1953-1973, was July 1965. The individual TMM months were concatenated into the Typical Meteorological Year (TMY). Discontinuous weather records from days at the beginning and end of months from different years were smoothed numerically. Direct normal insolation values were generated for each hour of the TMY from the corresponding TMY global horizontal hourly values using the Aerospace Corporation model developed by Randall and Whitson. Several meteorological parameters were also added to complete the TMY data base.

NSRDB

During the fall of 1992, a revised SOLMET data base developed by NREL and the NCDC became available. This new product, the National Solar Radiation Data Base (NSRDB), essentially replaces the old SOLMET/ERSATZ and related TMY data bases. The NSRDB is a 30 year data base (1961-1990) consisting of 56 Primary stations (some measured solar data) and 183 Secondary stations (solar data are *entirely* modeled). The NSRDB incorporates far more measured solar data than the earlier SOLMET (1952-1975) and uses much improved quality control procedures and direct normal modeling techniques.

The NSRDB is currently available on magnetic tape from the National Climatic Data Center in Ashville, NC. The data base is expected to be available on CD-ROM during the spring of 1993 at a cost of about $50 per CD. The entire 6 CD data base will cost about $300. Contact Tom Ross at NCDC for ordering information (704/259-0994). Future products should include preliminary

national insolation maps (Spring '93), an updated Solar Atlas (Late '93), and improved TMY ('94). Contact Gene Maxwell at NREL for more information (303/231-7088).

The NSRDB shows some interesting changes relative to the previous SOLMET effort. Now the sunniest (highest direct normal) region of the country is the Mojave Desert/Death Valley area (where the current SEGS projects are located). The differences stem from two principal sources: 1) rehabilitation of historical measured data; and 2) improvements in direct normal modeling. The new direct normal model used by NREL tended to reduce insolation estimates for clear climates but increase direct estimates somewhat in relatively cloudy climates.

Figure B-2 provides a summary of NSRDB global and direct data for each Hawaiian station. The annual averages are compared with previous SOLMET averages. The NSRDB appears to be more consistent with local measured data (UH-Manoa averages are also included in B-2) and should prove a significant improvement over the SOLMET/ERSATZ data for Hawaiian stations.

University of Hawaii at Manoa (Holmes Hall)

The university of Hawaii at Manoa maintained a solar/weather monitoring station on the roof of Holmes Hall for over 10 years. These measurements are the most extensive of any low elevation site in Hawaii. In spite of plentiful information for this site, determination of "typical" solar conditions for design purposes is problematic. Among the circumstances which must be evaluated are:

1) Apparent systematic drift in long-term global insolation
2) Periodic influence of volcanic activity
3) Weather variability, particularly in winter (periodic El Nino-Southern Oscillation events)
4) Spatial variability - sensitivity to locality.

The 50+ year measured global horizontal record for the Honolulu area provides a rare opportunity to analyze truly long-term trends in insolation. Figure B-3 presents the global horizontal record for the University of Hawaii-Manoa area. The period from 1932 through about 1976 was recorded by the HSPA Makiki station near the University; after 1976, measurements were made with high quality equipment at Holmes Hall. Figure B-3 shows an apparent systematic drift in long-term global insolation. The average daily global horizontal for 1955-1964 is about 525 cal/cm^2-day while the average for 1977-1986 (from Holmes Hall) is 463 cal/cm^2-day. This represents a surprising 13% change in 10 year averages. While volcanic activity is a likely contributor, there appear to be other factors which are responsible.

Given the high level of uncertainty associated with solar radiation measurements, particularly the relatively primitive wig-wag equipment used by the HSPA, it was speculated that the large changes could stem from calibration errors. Figure B-4 compares measured global horizontal for Holmes-Makiki and the NOAA Mauna Loa Observatory from 1958 through 1983. The MLO measurements, taken with the highest quality equipment available, also indicates a significant drop in insolation since the mid-50's. With the reasonableness of Figure B-3 established, obvious questions come to mind. What are the climatic mechanisms bringing about these trends? If this is a long-term climatic cycle, what is the period? Stated another way, how long will annual insolation in Hawaii continue to drop?

The average recorded global horizontal and average direct normal insolation for Holmes Hall are presented in Figure B-5. The data are averaged and compared to the longer-term global horizontal record for Makiki. No such comparison was performed for direct normal insolation since there are no long-term direct normal averages available. It is noted that clouds impact direct insolation more strongly than global insolation, since some portion of the incoming direct radiation which is scattered will be included in the diffuse contribution to total global insolation. A general observation based on numerous insolation data for mainland sites is that fluctuation from a reference level for direct

Figure B-2. National Solar Radiation Data Base (NSRDB: 1961-1990) - Hawaii Stations

Daily Averages of Global Horizontal and Direct Normal Insolation

AVERAGE DAILY GLOBAL HORIZONTAL INSOLATION (kWh/m2-day)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NSRDB	ERSATZ	%Change
Hilo	3.8	4.3	4.6	4.8	5.2	5.4	5.2	5.3	5.0	4.3	3.7	3.5	**4.58**	**4.37**	**5**
## Honolulu	3.9	4.7	5.4	5.9	6.4	6.5	6.6	6.4	5.9	5.0	4.1	3.7	**5.39**	**5.17**	**4**
Kahului	4.0	4.7	5.4	5.9	6.4	6.7	6.7	6.5	6.1	5.1	4.3	3.9	**5.48**		
Lihue	3.7	4.3	4.9	5.3	5.9	6.0	6.0	5.9	5.6	4.7	3.7	3.5	**4.96**	**4.81**	**3**
Barbers Pt.														**5.24**	
$$ Manoa (Holmes)	4.0	4.7	5.4	5.9	6.2	6.4	6.4	6.4	6.1	5.1	4.3	3.6	**5.37**		

AVERAGE DAILY DIRECT NORMAL (BEAM) INSOLATION (kWh/m2-day)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NSRDB	ERSATZ	%Change
Hilo	3.9	3.9	3.4	3.1	3.5	3.8	3.6	4.0	4.0	3.6	3.2	3.5	**3.62**	**3.10**	**17**
## Honolulu	4.3	4.9	5.0	4.9	5.6	5.8	6.0	6.0	5.7	5.0	4.4	4.3	**5.16**	**4.44**	**16**
Kahului	5.0	5.4	5.5	5.5	6.3	6.8	6.8	6.8	6.5	5.7	5.1	5.0	**5.82**		
Lihue	4.0	4.4	4.1	4.1	4.8	5.0	4.9	5.1	5.3	4.5	3.7	3.9	**4.48**	**3.82**	**17**
Barbers Pt.														**4.57**	
$ Manoa (Holmes)	4.2	4.5	4.6	4.4	4.8	5.1	5.2	5.5	5.4	4.9	4.3	4.1	**4.74**		

Notes:

- Primary NSRDB station for Honolulu @ Honolulu International Airport (Latitude = 21-19' N; Longitude = 157-55' W; Elevation = 5 meters)
Measured interval for Direct Normal: July 31, 1979 to May 31, 1980 (10 months)
Measured interval for Global Horizontal: July 1, 1978 to December 31, 1980 (30 months)

$ - University of Hawaii at Manoa (Holmes Hall) DOE/SEMRTS program (Latitude = 21-18' N; Longitude = 157-49' W, Elevation = 23 meters)
Measured interval for Direct Normal: May 1978 to September 1987 (111 months)
Measured interval for Global Horizontal including HSPA data: 1932-1987(& beyond?) (55+ years)

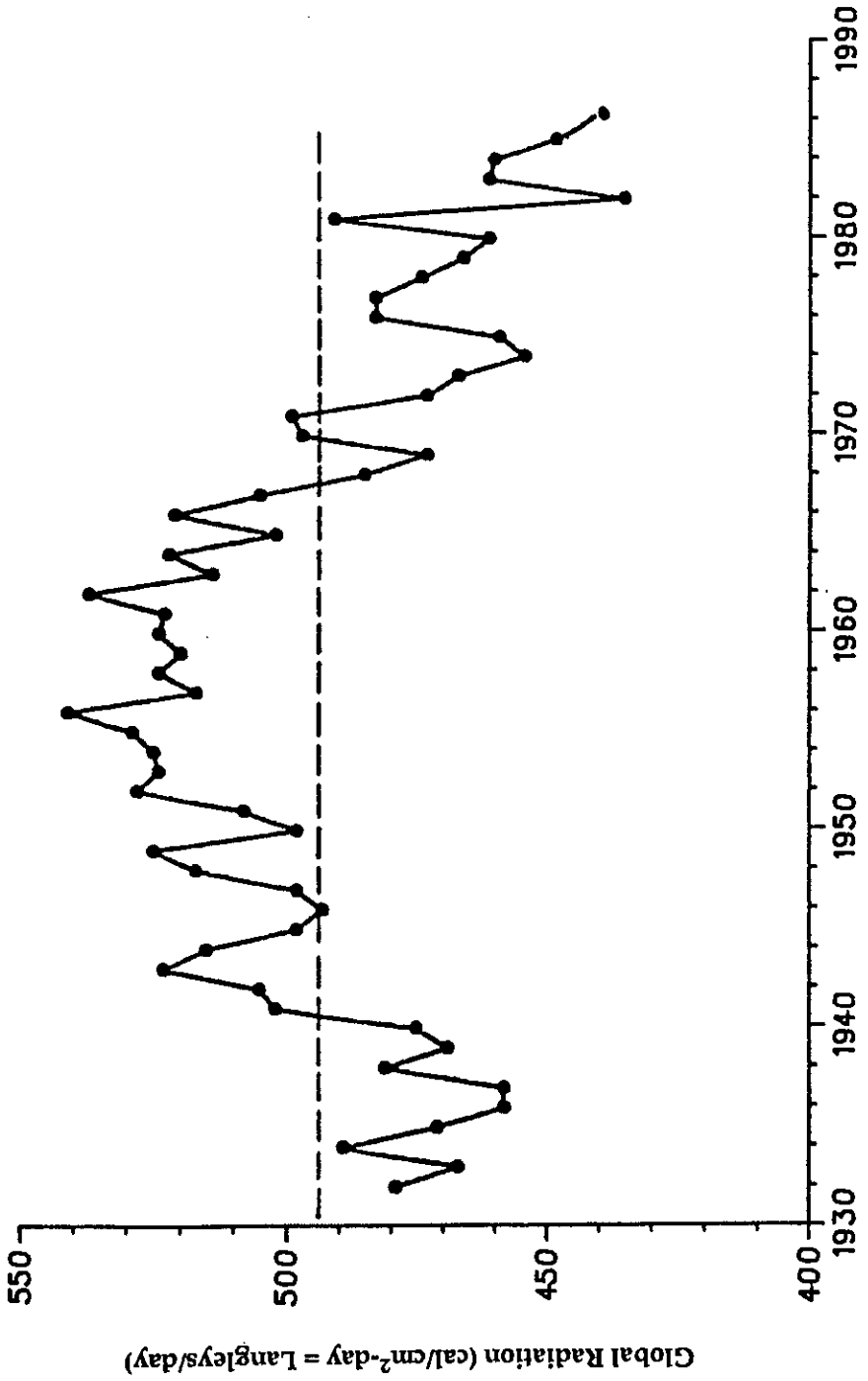


Figure B-3: Global Horizontal Insolation for Honolulu (Holmes Hall-Makiki HSPA), 1932-1986

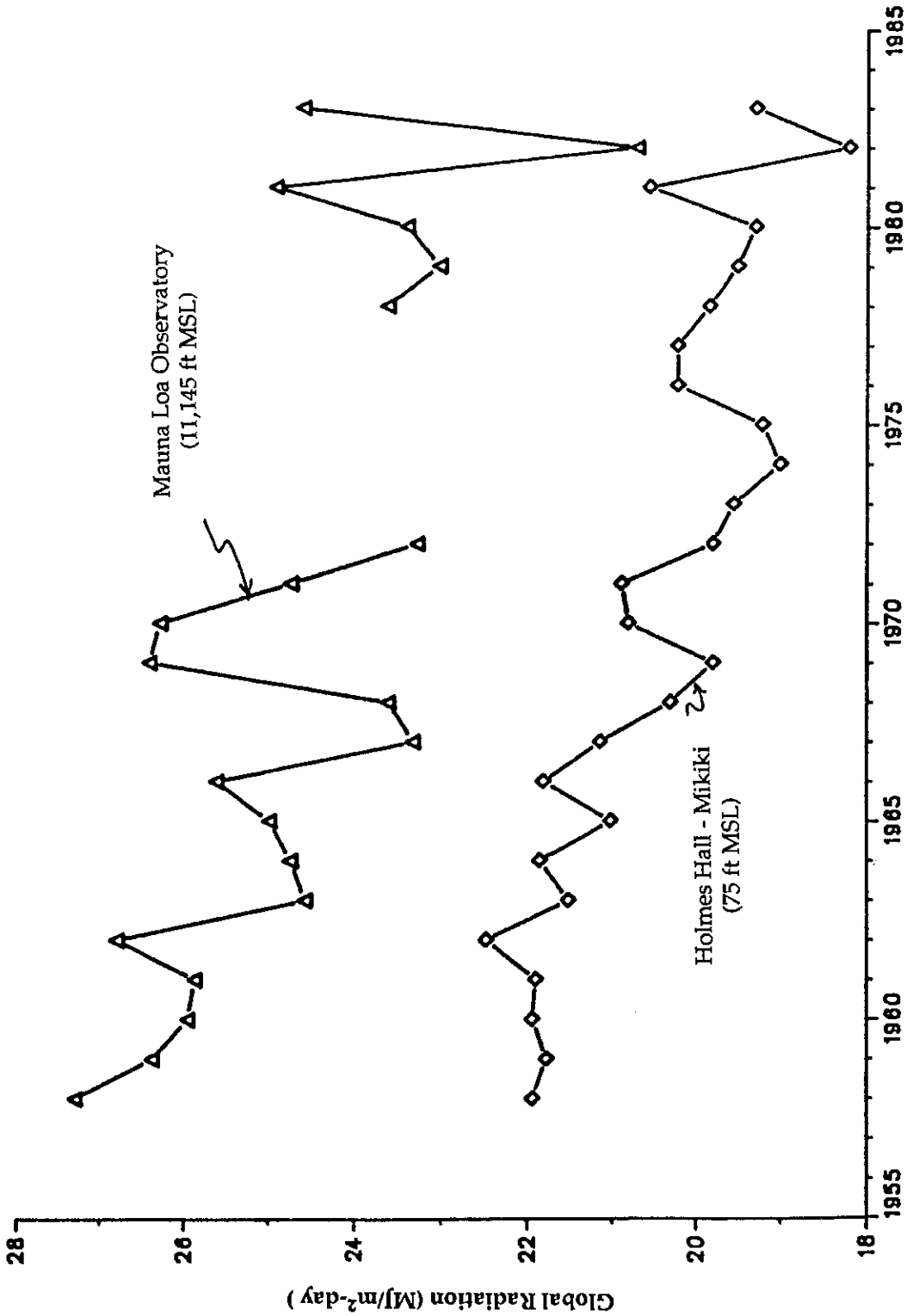


Figure B-4: Global Horizontal Insolation for Holmes Hall-Makiki and Mauna Loa Observatory, 1958-1983

Figure B-5: Measured Solar Radiation Data from Holmes Hall, The University of Hawaii at Manoa

(cal/cm^2-day = Langleys/day; unless otherwise noted)

AVERAGE DAILY GLOBAL HORIZONTAL INSOLATION BY MONTH

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	(kWh/m2-day)
1977	382	457	490	546	552	527	577	550	533	454	391	335	463	5.61
1978	367	433	497	507	529	569	545	546	633	425	413	320	482	5.60
1979	318	325	484	546	550	549	558	566	525	426	372	334	463	5.38
1980	318	367	469	503	517	557	536	587	543	481	392	322	466	5.42
1981	380	422	521	542	560	595	588	559	545	449	391	310	489	5.68
1982	315	384	363	476	549	534	550	512	519	442	316	257	435	5.05
1983	336	411	462	474	529	574	567	542	525	425	362	306	459	5.34
1984	341	434	476	515	555	550	559	568	524	417	347	307	466	5.42
1985	319	386	447	530	507	562	565	537	482	421	328	322	451	5.24
1986	367	408	471	491	489	520	442	514	443	421	358	318	437	5.08
1987	311	392	449	478	507	552	557	543	493				476	5.53

Average	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	
'77-'87	341	402	466	510	531	554	549	548	524	436	367	313	462	5.37
'32-'76	372	434	492	545	585	601	602	594	554	475	394	356	500	5.81
'32-'87	366	427	487	538	574	592	591	585	548	468	389	348	493	5.73
Average (kWh/m2-day)														
'77-'87	3.97	4.67	5.42	5.93	6.17	6.43	6.39	6.36	6.09	5.07	4.27	3.64	5.37	
'32-'76	4.32	5.04	5.72	6.34	6.80	6.98	6.99	6.90	6.44	5.52	4.58	4.14	5.81	
'32-'87	4.25	4.97	5.66	6.26	6.68	6.87	6.87	6.79	6.37	5.43	4.52	4.04	5.73	

Percentage by which older averages ('32-'76) are higher than Holmes decade averages ('77-'87):

8.9%	7.9%	5.5%	7.0%	10.1%	8.5%	9.5%	8.4%	5.7%	9.0%	7.5%	13.7%	8.3%	

AVERAGE DAILY DIRECT NORMAL (BEAM) INSOLATION BY MONTH

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	(kWh/m2-day)
1978					408	457	455	484	485	493		290	439	5.10
1979	310	239	432	476	462	405	505	546	558	438	370	415	430	5.00
1980	339	358	362	335	371	454	387	506	432	492	449	383	406	4.72
1981	464	400	490	473	468	471	561	527	523	438	417	326	463	5.39
1982	307	329	231	225	365	329	304	302	366	318	228	208	293	3.40
1983	319	386	393	332	401	425	389	430	473	359	375	315	383	4.45
1984	341	455	435	378	442	348	473	523	529	418	375	374	424	4.93
1985	359	354	312	495	383	525	529	481	462	378	368	458	425	4.95
1986	488	480	432	349	408	454	426	434	379	473	361	389	423	4.92
1987	318	448	441	363	443	522	455		432				428	4.97

Average	361	383	392	381	415	439	448	470	464	423	368	351	408	4.74
(kWh/m2-day	4.19	4.46	4.56	4.43	4.83	5.11	5.21	5.47	5.39	4.92	4.28	4.08		4.74

insolation is typically about twice as much as the observed fluctuations for global insolation. From Figure B-5, the older (1932-1976) Makiki global horizontal data is 8% higher than the more recent (1977-1987) Holmes Hall data. Based on the generalization described above, a comparison of direct normal over the same period would likely show the 1932-1976 average to be about 15% higher than the (1977-1987) Holmes Hall direct normal average.

In order to generate a representative data base for solar system design in Hawaii, the long-term insolation trends must be considered. Assuming the solar equipment will have a 30 year useful lifetime, some projection must be made for the insolation trend in those years. Will the insolation continue to drop over the entire interval, or is the period of this apparent climatic cycle over and insolation will steadily increase over the interval? Should the solar design year be the measured Holmes Hall average, should it be modulated to a level consistent with average conditions for the Holmes-Makiki global horizontal record, or should it be some other methodology?

Since the impact of El Chichon is a known factor contributing to the lower level of insolation recorded at Holmes Hall, a method was devised by Paul Ekern to strip away this influence from the measured data. This method involving computing direct insolation as a fraction of clear conditions. The long-term average direct fractions can then be multiplied times the maximum clear sky insolation to reasonably eliminate the influence of reduced atmospheric transmittance caused by volcanic activity. This method is presented in Figures B-6 and B-7. It is noted that for this SEGS assessment, measured direct insolation data for 1979 was utilized.

Figure B-8 provides estimates of direct insolation relative to Holmes Hall for other sites throughout Hawaii (candidate SEGS sites). These estimates are based largely on input from Paul Ekern.

Figure B-9 (3 pages) provides station notes for the University of Hawaii network as it existed in 1980. Data for these stations are available from Arnold Hori at the University of Hawaii. The data, as available during the summer of 1992, are in need of rehabilitation through some quality control measures.

RECOMMENDATIONS

There is currently a lack of organization and assimilation of measured insolation data for Hawaii. DBEDT's sunshine maps are excellent products; however, they are inadequate for the design of many solar systems. An additional useful product would be a high quality solar design year comprised of local measured solar and meteorological parameters. Given the apparent long-term trends in global insolation and periodic influence of volcanic activity, developing this "TMY" year is not a straightforward task. Due to the prevalence of intermittent clouds, high resolution data integrated over short time intervals, perhaps 5 or 10 minutes, are required to accurately model the performance of thermal systems like SEGS. Performance results from the hour-averaged data used in this study had to be adjusted -- based on judgment -- to account for the impact of intermittent clouds. It is noted that one product of the University of Hawaii SEMRTS program was to be a high quality data year integrated over one minute time intervals. Selected hard-copy printouts of these data were provided by Dr. Paul Ekern but, unfortunately, a computer file of these data could not be located.

Due to Hawaii's compressed microclimates and non-precipitating cloud formations, standard interpretation techniques used to estimate insolation between measured sites are generally not reasonable for Hawaii. The mesoscale variability in Hawaiian insolation could be determined through consideration of satellite imagery. Satellite techniques should be well suited to Hawaii since determination of baseline reflectance should be straightforward (very little snow, generally small urban and desert areas, good background contrast) and the weather patterns are consistent, thereby allowing meaningful observations from consideration of relatively few images. A good example of this type of study is the climate mapping project performed by Steven Pease for the California Energy Commission in 1981, entitled *Satellite Mapping of California Solar Radiation Distribution.*

Creation of a suitable typical meteorological year and thorough satellite study would have been very useful for estimating SEGS performance for this project. These products, if available, would likely prove beneficial in assessments of feasibility of other solar technologies such as photovoltaics or dish-Stirling engine systems. Perhaps the most useful project, however, would be resolution of the long-term insolation trends in Hawaii. If the startling trend of the last 30 years depicted in Figure B-3 were projected into the future (-3 cal/cm-day/year), the sun will apparently cease to shine in Hawaii in another 150 years! Future monitoring efforts and the reevaluation of historical materials are both needed to understand the significance of the current information.

POTENTIALLY USEFUL CONTACTS ON HAWAIIAN INSOLATION

Name	Position Affiliation	Phone	Fax
Paul Ekern	Retired Professor, UH-Manoa	(808) 988-2530	none
Tom Schroeder	Professor, UH-Manoa, Meteorology	(808) 956-7476	
Art Seki	HECO	(808) 543-7987	(808) 543-7519
Arnold Hori	Computer Specialist, UH-Manoa., Meteorology	(808) 956-7944	(808) 956-2877
Tom Daniel	Technical Director, NH (Kailua-Kona)	(808) 329-7341	(808) 326-3262
Richard Rocheleau	Research Engineer, HNEI	(808) 956-2337	(808) 956-2336
Dave Rezachek	Program Manager, DBEDT	(808) 548-4195	(808) 531-5243
Hawaii Sugar Planters Assn (HSPA)		(808) 487-5561	
Mike Sloan	Solar Consultant (Austin, TX)	(512) 452-9899	(512) 452-9896
Tom Ross	NCDC (Ashville, NC)	(704) 259-0994	(704) 259-0876
Gene Maxwell	NREL (Golden, CO)	(303) 231-7088	(303) 231-7811

Miscellaneous Comments

Paul Ekern is a tremendous resource who was intimately involved with the University of Hawaii's solar monitoring activities. He has impressive recall about what was done and has hardcopy of all Holmes Hall data at his residence. The University of Hawaii has recently uncovered magnetic tape reel(s) that contain practically all of the solar data recorded by the UH program. Contact Arnold Hori. Mike Sloan (Austin, Texas) also has copies of these data on DOS-compatible diskettes. A sampling of these data files showed minor problems (such as out-of-bound voltage readings and insufficient calibration notes). Some effort will be required to rehabilitate these data.

The UH monitoring program's original data, previously in the possession of Dick Neill, were traced to Peter Shackelford on Hawaii, (808) 882-4069. A sampling of the original diskettes showed that they were no longer readable. The Keahole Point data from Tom Daniel were useful but should be used with caution. Quality monitoring programs require annual re-calibration of instrumentation. My recollection is that these instruments were not calibrated for numerous years. Systematic drift in calibration could easily have resulted in significant errors (5-10%) if they have not been calibrated in over 5 years.

Art Seki's 1987 HNEI report, *Site Selection for Concentrated Solar Thermal Systems in Hawaii,* summarizes the data collected by the UH solar program. It is noted that the tabulated direct data are the direct horizontal component. One exception is the total presented for Kahe, which is suspected of being direct normal.

The extensive measured data record for Holmes Hall could be rehabilitated and used to develop a high quality TMY data year. (Our SEGS performance runs were based on a built-up TMY-type input file). A Hawaii TMY data set based on local measured data is expected to be much superior to current TMY data from NCDC and future TMY products based on modeled data.

Based on initial contact, the University of Hawaii SEMRTS data are not readily available from NREL. Call Gene Maxwell for information.

Figure B-6: Holmes Hall Direct Normal Insolation, Average/Maximum Clear Day Fractions (Ekern Technique)

AVERAGE DAILY DIRECT NORMAL BY MONTH (cal/cm2 unless otherwise noted)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	(kWh/m2-day)
1978					408	457	455	484	485	493		290	439	5.10
1979	310	239	432	476	462	405	505	546	558	438	370	415	430	5.00
1980	339	358	362	335	371	454	387	506	432	492	449	383	406	4.72
1981	464	400	490	473	468	471	561	527	523	438	417	326	463	5.39
1982	307	329	231	225	365	329	304	302	366	318	228	208	293	3.40
1983	319	386	393	332	401	425	389	430	473	359	375	315	383	4.45
1984	341	455	435	378	442	348	473	523	529	418	375	374	424	4.93
1985	359	354	312	495	383	525	529	481	462	378	368	458	425	4.95
1986	488	480	432	349	408	454	426	434	379	473	361	389	423	4.92
1987	318	448	441	363	443	522	455		432				428	4.97
Average	361	383	392	381	415	439	448	470	464	423	368	351	408	
(kWh/m2-day)	4.19	4.46	4.56	4.43	4.83	5.11	5.21	5.47	5.39	4.92	4.28	4.08	4.74	

AVERAGE DIRECT/MAXIMUM CLEAR DAY DNI FRACTIONS BY MONTH

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1978					0.495	0.557	0.574	0.592	0.604	0.649		0.418	0.556
1979	0.436	0.322	0.565	0.593	0.560	0.505	0.575	0.634	0.656	0.542	0.510	0.571	0.539
1980	0.445	0.487	0.457	0.435	0.455	0.553	0.480	0.624	0.565	0.673	0.631	0.518	0.527
1981	0.636	0.532	0.612	0.563	0.559	0.557	0.650	0.635	0.655	0.587	0.583	0.458	0.586
1982	0.432	0.449	0.301	0.380	0.539	0.528	0.506	0.502	0.617	0.538	0.429	0.359	0.465
1983	0.520	0.581	0.556	0.460	0.536	0.610	0.575	0.610	0.694	0.575	0.619	0.513	0.571
1984	0.545	0.642	0.651	0.535	0.592	0.486	0.616	0.712	0.661	0.565	0.573	0.564	0.594
1985	0.496	0.478	0.445	0.610	0.491	0.624	0.653	0.577	0.618	0.514	0.534	0.636	0.556
1986	0.659	0.668	0.551	0.456	0.521	0.545	0.527	0.534	0.486	0.629	0.541	0.561	0.557
1987	0.454	0.616	0.576	0.496	0.526	0.643	0.568		0.551				0.554
Average	0.514	0.529	0.523	0.508	0.527	0.560	0.575	0.604	0.610	0.587	0.555	0.514	0.551

MAXIMUM COMPOSITE CLEAR DAY DIRECT INSOLATION BY MONTH (cal/cm2)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	(kWh/m2-day)
1978					824	821	793	818	803	760		693	787	9.15
1979	712	743	765	803	825	801	878	861	851	808	724	727	792	9.20
1980	762	736	791	770	815	820	806	810	765	731	711	743	772	8.97
1981	730	752	801	840	837	846	863	829	799	746	716	711	789	9.18
1982	712	733	767	592	678	624	601	601	594	591	530	581	634	7.37
1983	614	664	706	722	748	697	676	705	682	624	605	615	672	7.81
1984	626	709	668	706	748	745	768	734	799	739	655	664	713	8.30
1985	724	740	702	812	779	842	811	834	747	736	689	720	761	8.85
1986	742	719	783	765	783	834	809	813	780	752	667	693	762	8.86
1987	701	728	766	732	843	812	800		783				771	8.96
Average	702	725	750	749	788	784	780	778	760	721	662	683	740	
(kWh/m2-day)	8.17	8.43	8.72	8.71	9.16	9.12	9.08	9.05	8.84	8.38	7.70	7.94	8.61	
Max Day	8.86	8.75	9.31	9.77	9.80	9.83	10.21	10.01	9.89	9.40	8.42	8.64	9.41	

Figure B-7: Holmes Hall Direct Normal Insolation by Various Techniques

Maximum Observed Clear Day Direct Normal Insolation for Holmes Hall, 1978-1987 (W/m2)

(hour ending)	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	Daily Total (kWh/m2/day)
January	1	353	766	878	909	928	945	938	938	891	791	552	60	8.95
February	0	369	702	830	893	936	942	951	928	900	800	617	107	8.98
March	113	644	793	879	922	947	953	950	928	881	809	623	156	9.60
April	256	694	815	857	900	919	936	936	928	886	801	679	191	9.80
May	341	714	821	877	877	908	916	919	899	865	787	693	333	9.95
June	305	686	843	857	887	913	910	922	900	878	836	729	481	10.15
July	284	695	829	869	906	912	916	916	920	890	849	767	517	10.27
August	160	703	831	878	912	934	943	938	921	888	836	745	490	10.16
September	163	673	824	897	917	953	945	956	936	908	871	638	205	9.89
October	140	656	842	900	970	976	981	984	959	888	753	420	30	9.50
November	22	538	763	843	890	930	934	928	907	864	787	545	64	9.02
December	23	481	762	867	927	944	950	942	907	856	723	355	71	8.81
Average														9.59

Average Daily Direct Normal Insolation (DNI) for Holmes Hall, 1978-1987 (kWh/m2-day)

	Average DNI/ Clear Day DNI Fractions* (1)	Average Clear Day DNI (2)	Actual Average DNI (1 x 2)	Maximum Clear Day DNI (3)	Adjusted Average DNI** (1 x 3)	1981 DNI***
January	0.514	8.17	4.20	8.95	4.60	5.39
February	0.529	8.43	4.46	8.98	4.75	4.65
March	0.523	8.72	4.56	9.60	5.02	5.70
April	0.508	8.71	4.42	9.80	4.98	5.50
May	0.527	9.16	4.83	9.95	5.24	5.44
June	0.560	9.12	5.11	10.15	5.68	5.48
July	0.575	9.08	5.22	10.27	5.91	6.52
August	0.604	9.05	5.47	10.16	6.15	6.13
September	0.610	8.84	5.39	9.89	6.03	6.08
October	0.587	8.38	4.92	9.50	5.58	5.09
November	0.555	7.70	4.27	9.02	5.00	4.85
December	0.514	7.94	4.08	8.81	4.53	3.79
Annual	0.551	8.61	4.75	9.59	5.29	5.39

Notes:

* The average/clear day fractions are an indicator of the relative cloudiness by month: September - clearest, April - least clear.

** The Adjusted Average DNI is an attempt to strip away the impact of El Chicon and other abnormal atmospheric conditions. The Adjusted Average DNI is an estimate of what DNI would have been with actual cloud conditions, but a clearer atmosphere.

*** The global horizontal for 1981 is close to the 1932-1987 long-term mean; 1981 DNI may be representative of long-term conditions.

Figure B-8: Estimates of Direct Normal Insolation Relative to Holmes Hall

ISLAND	SITES	Summer (MJJ)	Annual	Winter (NDJ)	Annual Rainfall
OAHU	Holmes Hall	1.00	1.00	1.00	(40")
	Pearl HBZ	1.08	1.05	1.02	(20")
	N. Ewa Plain		0.97		(30-40")
	Ewa Plain	1.08	1.05	1.02	(20-25")
	Lualualei		1.00		(20-25")
	Waialua		0.90		(25-40")
	Kahuku Pt.		0.85		(40-50")
HAWAII	Waikoloa		1.10		(8-20")
	N. Kohala		1.20		(6-12")
	Keahole Pt.		1.13		(10-20")
	South Pt.		0.90		(20-40")
	Kau Desert		1.10		(20-40")
	Saddle Rd.		0.95		(15")
KAUAI	Mana Plain	1.05	1.00	0.95	(20")
	Poipu		0.90		(40-75")
MAUI	Old Airport		1.00		(12")
	Kihei	1.00	1.03	1.07	(10")
	Lihaina	1.00	1.03	1.06	(15")
	Kahului		0.97		(20")
MOLOKAI	Palaau Flat		1.00		(10-12")
	SW/W		0.97		(14-24")

Figure B-9 (1 of 3): Sample Station Notes for the University of Hawaii SEMRTS Solar Program, circa 1980

PART II: NETWORK/STATION DESCRIPTION

Network Name: HAWAII — N/A ___ — Recording Interval(s)**(codes): 1,2,5,6,9 — Name of Person Completing This Form: ___

Geographic Coverage (country, region, etc.): HAWAII — Are These Common to All Stations? YES ___ NO ___ N/A ___ — Organization: ___

Total Number of Stations For Which Data Is Available: 52 179 — Status: IPS 1956 ___ APS ✓ 1975 — Department: ___

Period of Record***: 38-80 — Data Archiving Media† (codes): A,E,H

Station(s) Still Operating? YES ✓ NO ___ — Date of Latest Collection: ___

PART III: DATA DESCRIPTION BY STATION

STATION NAME	Location: Latitude (° ')	Location: Longitude (° ')	Location: Elevation (meters)	Global - (Joules/cm²): Instrument*	Global - (Joules/cm²): Sensor*	Global - (Joules/cm²): Period*** From	Global - (Joules/cm²): Period*** To	Global - (Gm-cal/cm²): Instrument*	Global - (Gm-cal/cm²): Sensor*	Global - (Gm-cal/cm²): Period*** From	Global - (Gm-cal/cm²): Period*** To	Short Wave: Instrument*	Short Wave: Sensor*	Short Wave: Period*** From	Short Wave: Period*** To	Insolation Data: Diffuse Sky: Instrument*	Insolation Data: Diffuse Sky: Sensor*	Insolation Data: Diffuse Sky: Period*** From	Insolation Data: Diffuse Sky: Period*** To	Insolation Data: 5 Sunshine: Instrument*	Insolation Data: 5 Sunshine: Sensor*	Insolation Data: 5 Sunshine: Period*** From	Insolation Data: 5 Sunshine: Period*** To	Spectral (Codes)	Meteorological Data****: Cloud Cover	Meteorological Data****: Temperature	Meteorological Data****: Rel. Humidity	Meteorological Data****: Wind
HOLMES	21° 18'	157° 49'	23	02	5	76	99					02	05	78	99	19	05	77	99					1	✓			
LYON	21° 20'	157° 48'	152	03	5	76	99																					
MAUNAWILI	21° 21'	157° 46'	125	03	5	76	99									03	5	78	99									
KAENA POINT	21° 36'	158° 15'	378	03	2	76	78																					
KAHUKU	21° 40'	157° 58'	148	03	2	76	78																					
MILILANI	21° 26'	158° 02'	131	03	5	76	99	Ordered	'81																			
WAIKIKI	21° 17'	157° 50'	3	03	5	76	99																					
WAIMANO	21° 26'	157° 56'	320	03	5	76	78																					

*Instruments

00 - Derived, modeled
01 - Pyranometer, thermo-electric
02 - Pyranometer, Eppley PSP
03 - Pyranometer, Eppley Black & White
04 - Pyranometer, solar cell (photovoltaic)
05 - Pyranometer, star
06 - Pyranometer, Yellodin
07 - Pyranometer, F 3X3
08 - Pyranometer, bimetallic
09 - Actinograph, bimetallic, Robitzsch
10 - Pyranometer, distillation, Belland (with hemisphered surface)
11 - Pyranometer, distillation, Belland (with spherical surface)
12 - The pyranometer constructed in the Physical and Meteorological Observatory in Davos
13 - UV Pyranometer, Eppley
14 - UV Pyranometer, other
15 - Pyranometer Spec SR-75
16 - Pyranometer, other
17 - Solarimeter, Moll-Gorczynski
18 - Pyrheliometer, 1SP, Eppley
19 - Pyrheliometer, Eppley NIP
20 - Pyrheliometer, other
21 - Robert-water
22 - Heliograph, Campbell-Stokes
23 - Heliograph, Jordan
24 - Heliograph, Marvin
25 - Photo-electric cell switch
26 - Heliograph, Foster
27 - Heliograph, Lambrecht
28 - Normal Sunshine Switch-110
29 - ___
30 - ___
31 - ___

†Data Archiving Media

A – Tape
B – Disc
C – Cassette
D – Strip Chart
E – Cards
F – Tabular
G – Microfiche
H – Report/Publication
I – Graphics
J – Other (specify) ___

**Recording Interval

1 – Minute
2 – Between 1 and 15 minutes
3 – 15 Minutes
4 – 30 Minutes
5 – Hourly
6 – Daily
9 – Other (specify) Weekly

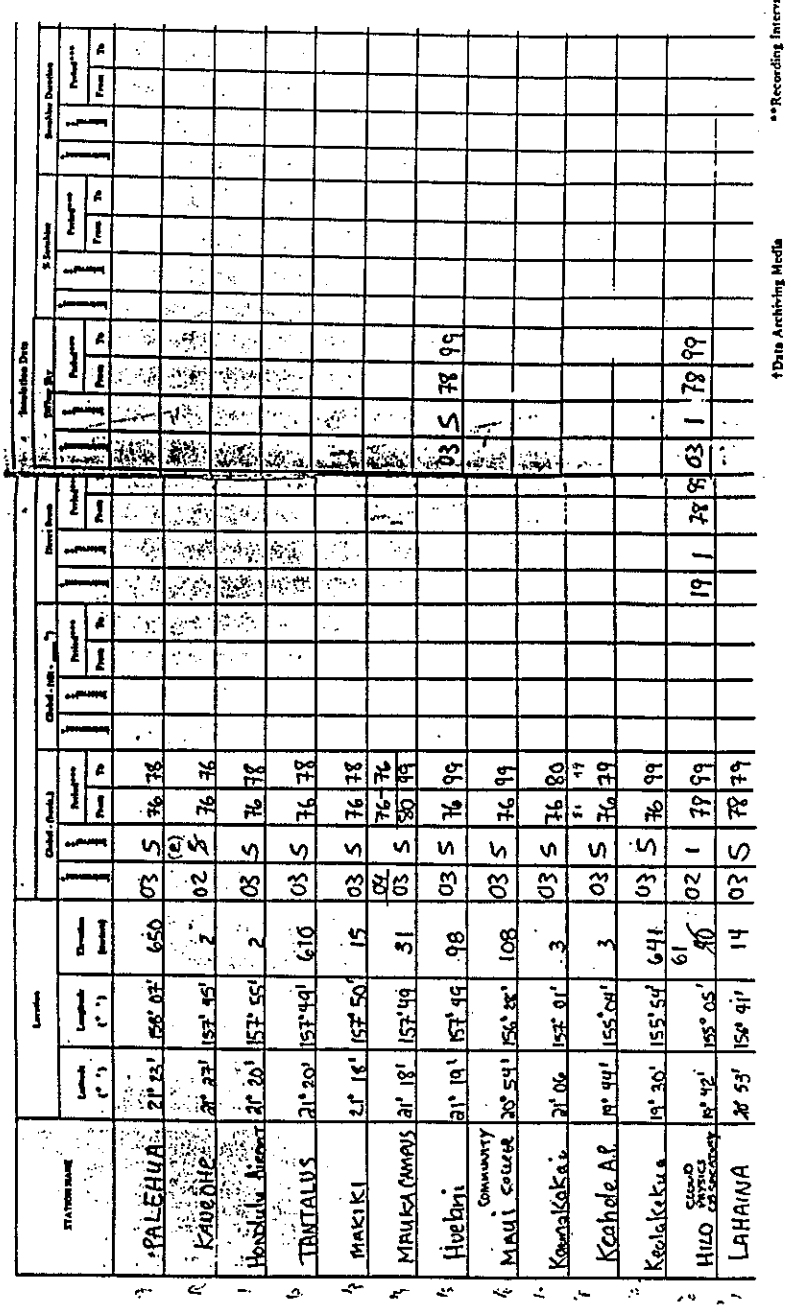
Spectral Data

1 – Ultraviolet (UV)
2 – Infrared (IR)
3 – Visible

***For "Period", enter the last two digits of the start year (From) and end year (To). A "99" in the latter column indicates ONGOING DATA COLLECTION.

****For METEOROLOGICAL DATA, enter a check (✓) to indicate data is available. Otherwise leave blank.

Figure B-9 (2 of 3): Sample Station Notes for the University of Hawaii SEMRTS Solar Program, circa 1980



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APPENDIX C. RESOURCES

Below is a listing of various data, reports, maps, and other significant sources which aided in the development of this SEGS site assessment report.

INSOLATION

- UH MET Solar Radiation data, ASCII files for all stations, Arnold Hori, 1992.
- UH MET Solar Radiation Data: selected hardcopy and extensive analysis, Paul Ekern, 1990-1992.
- "Site Selection for Concentrated Solar Thermal Systems in Hawaii", HNEI (Art Seki), 1987.
- "A Comparison of Data from SOLMET/ERSATZ and the NSRDB", NREL (W. Marion and D. Dyers), 1992.
- "National Solar Radiation Data Base User's Manual (1961-1990) - Volume I", NREL, 1992
- "Interim Solar Radiation Data Manual: 30 year statistics from the NSRDB", NREL, 1992
- 'Shining On: A Primer on Solar Radiation Data", NREL, 1992.
- "Solar Radiation Resource Assessment of Texas", Sloan Solar Engineering, 1992.
- "Comprehensive Review and Evaluation of Hawaii's Renewable Energy Resource Assessments", R. Lynette & Associates, 1992.
- "Project Ahupua'a--Solar Meteorological Field Measurements on the Island of Hawaii, Summer 1978. 1. Narrative." University of Hawaii and U.S. Department of Energy. February 1979.
- "Project Ahupua'a--Solar Meteorological Field Measurements on the Island of Hawaii, Summer 1978. 2. Eastern Flank of Mauna Loa." University of Hawaii and U.S. Department of Energy. August 1979.
- "Project Ahupua'a--Solar Meteorological Field Measurements on the Island of Hawaii, Summer 1978. 3. Trade Wind Interactions with the Local Winds in South Kohala." University of Hawaii and U.S. Department of Energy. February 1980.
- "Project Ahupua'a--Solar Meteorological Field Measurements on the Island of Hawaii, Summer 1978. 4. Wind Power Assessment for the Waimea Saddle." University of Hawaii and U.S. Department of Energy. September 1980.
- "Project Ahupua'a--Solar Meteorological Field Measurements on the Island of Hawaii, Summer 1978. 5. Southern Flank of Mauna Loa." University of Hawaii and U.S. Department of Energy. October 1982.
- "Final Report: Hawaiian Photovoltaic Residential Systems and Evaluation." Hawaii Natural Energy Institute, University of Hawaii at Manoa. April 1984.
- "Hawaii: Solar and Weather Information." Western SUN. September 1980.
- Summary insolation and weather plots from the Natural Energy Laboratory of Hawaii, Keahole Pt.,1990.
- Summary insolation and weather data for Kihei, Maui; PVUSA, 1990.
- Cloud cover maps for the island of Hawaii; Tom Schroeder, 1990.
- "A Home Owner's Guide to Solar Water Heating on Oahu with Oahu Sunshine Map." Department of Planning and Economic Development.
- "Hawaii Sunshine Map." Department of Business and Economic Development.
- "Kauai Sunshine Map." Department of Business and Economic Development.
- "Molokai Sunshine Map." Department of Business and Economic Development.
- "Maui Sunshine Map." Department of Business and Economic Development.

GENERAL SITING

- *Atlas of Hawai*, Second Edition. University of Hawaii Press. 1983.
- "HECO Generating Facility Siting Study: Initial Candidate Sites Report", Black & Veatch/ engineers-architects, 1991.
- "HECO Generating Facility Siting Study: Candidate Sites Report", Black & Veatch/ engineers-architects, 1992.
- "HECO Generating Facility Siting Study: Preferred and Alternate Site/Technology Report", Black & Veatch/ engineers-architects, 1992.
- "Lahaina Community Plan", December 1983. County of Maui.

- "Molokai Community Plan", January, 1984. County of Maui.
- "Kapolei Area Long Range Master Plan". The Estate of James Campbell; April 1990.
- "Kahuku Land Use Plan". The Estate of James Campbell; November, 1988.
- "Selection of a Location for a Space Launch Facility in Hawaii: Executive Summary." Arthur D. Little, Final Report to Department of Business and Economic Development, State of Hawaii. April 1988.
- "County of Hawaii: Land Use Pattern Allocation Guide Map." County of Hawaii.
- "West Hawaii Regional Plan," Office of Governor, Office of State Planning, November 1989.
- "Volcanic and Seismic Hazards on the Island of Hawaii," U.S. Department of Interior, Geological Survey, 1990.
- "Soil Survey of the Island of Hawaii, State of Hawaii", U.S. Department of Agriculture, Soil Conservation Service, 1973.
- Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. U.S. Dept. of Agriculture, Soil Conservation Service. August 1972.
- "Underground Injection Control, Application for Permit". State of Hawaii, Department of Health; July, 1984.
- "Title 11, Department of Health, Chapter 23, Underground Injection Control". State of Hawaii, Department of Health; June, 1989.
- Table on Environmental Data for 1990, Maui PVUSA Site. Provided by Maui Electric Company, LTD.
- USGS topographic maps (various)
- Local Climatological Data, summary for Honolulu, Hawaii, NOAA, 1990.
- Electric transmission maps (all islands)
- DLNR precipitation maps (all islands)

UNDERSEA ELECTRIC CABLE

- Hawaii Deep Water Cable Program, PHASE II-C, Task 5 - Bibliography. Prepared by G. Krasnick and J. Mansur of Parsons Hawaii for HECO and the State of Hawaii DBED; August 1988.
- Executive Summary, Tri-Island Study. Prepared by Bechtel Group, Inc. for Maui Electric Company, Inc.; August, 1985.
- Undersea Cable to Transmit Geothermal-Generated Electrical Energy from the Island of Hawaii to Oahu: Economic Feasibility. Prepared by Decision Analysts Hawaii, Inc. for State of Hawaii DBED; February 1988.
- Hawaii Deep Water Cable Program, PHASE II-C, Task 5 - Submarine vs. Overhead Routing: a Cost Comparison for Molokai. Prepared by G. Krasnick and J. Mansur of Parsons Hawaii for HECO and the State of Hawaii DBED; July 1987.
- Preliminary Overview of the Power Supply Alternatives for Molokai. Prepared by CH2M HILL for the State of Hawaii, Department of Planning and Economic Development; February 1983.

PERMITTING

- *Regulatory and Institutional Issues Affecting the Commercialization of Photovoltaics in the State of Hawaii,* Department of Business and Economic Development, June 1989.
- *Hawaii Geothermal/Transmission Master Plan,* ERC Environmental and Energy Services Company, Inc., Draft version: December 1990 (not yet accepted by DBED).
- *Rules, Regulations, Permits and Policies Affecting the Development of Alternate Energy Sources in Hawaii,* Department of Planning and Economic Development, 1980.
- *A Guidebook for the Hawaii State Environmental Impact Review Process,* Office of Environmental Quality Control, January 1990.
- Hawaii Administrative Rules, Title 11, Department of Health, Chapter 23, Underground Injection Control Regulations.
- Hawaii Administrative Rules, Title 11, Department of Health, Chapter 54, Water Quality Standards Regulations.
- Hawaii Administrative Rules, Title 11, Department of Health, Chapter 60, Air Pollution Control Regulations.

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PUC Regulations:
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DESIGN, STORAGE AND BACK-UP SYSTEMS

- HECO Generating Facility Siting Study: Preferred and Alternate Site Technology Report, Hawaiian Electric Company, Inc., Black & Veatch, August 1992.
- M. A. Geyer, "Thermal Storage for Solar Power Plants", Ch. 6 of C.-J. Winter, R.L. Sizmann, L.L. Vant- Hull (Eds.), Solar Power Plants, Springer-Verlag, New York, 1991.
- F. Dinter, M. Geyer and R. Tammer (Eds.), Thermal Energy Storage for Commercial Applications, Springer-Verlag, New York, 1990.
- Phase-Change Thermal Energy Storage, SERI/STR-250-3516, Solar Energy Research Institute, November 1989.
- R. Brown and J. A. Russel, A Review of Storage Battery System Cost Estimates, Report PNL-5741 (Batelle Pacific Northwest Laboratory), Richland, WA, 1986.
- R. Brown, et al., Chemical Energy Storage System for SEGS Solar Thermal Power Plant, Report PNL-7799 (Batelle Pacific Northwest Laboratory), Richland, WA, 1991.
- C. M. Kinoshita, "Cogeneration in the Hawaii Sugar Industry", Bioresource Technology, Vol.35, pp 231-237, 1991.
- Personal communication with C. M. Kinoshita, Hawaii Natural Energy Institute, Honolulu, Hawaii.
- Electricity from Biomass, Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, U.S. Dept. of Energy, DOE/CH10093-152, 1992.

APPENDIX D. SAMPLE OUTPUT OF THE ECONOMIC MODEL

Levelized Bus Bar Electricity Cost Model

Hawaii Levelized Bus Bar Cost Calculation
HlBusBarCost-HE 24-Dec-92

200MW SEGS (with Oahu-Molokai Cable)	Fossil	SEGS
Unit Size (kW)	56,000	80,000
Capital Cost (1992 $/kW)	1377	3845
Annual Capacity Factor	35%	35%
Fixed O&M Costs ($/kW-yr)	32.59	81.13
Variable O&M Costs (mills/kWh)	3.04	0
Fuel Cost (1992 value, $/MMBTU)	4.99	4.99
Fuel Cost Escalation Rate	5.50%	5.50%
Full Load Heat Rate	8067	11500
Fixed Charge Rate (before tax)	10.48%	10.48%
Disc Rate	10.48%	10.48%
Prop Tax + Ins Rate	3.00%	3.00%
State Energy Tax Credit Rate	0.00%	35.00%
Utility's Federal Tax Bracket	34.00%	34.00%
Solar Capacity Factor		17.50%
Needed Fuel Capacity Factor to Reach Target		17.50%
Federal Energy Tax Credit		0.00%
Levelized Bus Bar Electricity Cost	$0.15	$0.26

Fossil LEC	0.151
NPV of Sum	1.372
NPV of Sum L	1.369
SEGS LEC	0.255
NPV of Sum	2.317
NPV of Sum L	2.311

Levelized Bus Bar Electricity Cost Model

SEGS	Year	Capital Chg	Depreciation	O&M	Fuel	Prop Tax+Ins	Amortized ETC	Total	Depr Cst (EOY)	Bus Bar C	Levl Cost
	1	32,227,252	10,253,333	6,490,400	7,037,696	9,228,000	-2,368,520	62,868,162	297,346,667	$0.26	0.255
	2	31,153,010	10,253,333	6,814,920	7,424,770	9,228,000	-2,368,520	62,505,513	287,093,333	$0.25	0.255
	3	30,078,769	10,253,333	7,155,666	7,833,132	9,228,000	-2,368,520	62,180,380	276,840,000	$0.25	0.255
	4	29,004,527	10,253,333	7,513,449	8,263,954	9,228,000	-2,368,520	61,894,744	266,586,667	$0.25	0.255
	5	27,930,285	10,253,333	7,889,122	8,718,472	9,228,000	-2,368,520	61,650,692	256,333,333	$0.25	0.255
	6	26,856,043	10,253,333	8,283,578	9,197,988	9,228,000	-2,368,520	61,450,422	246,080,000	$0.25	0.255
	7	25,781,802	10,253,333	8,697,757	9,703,877	9,228,000	-2,368,520	61,296,249	235,826,667	$0.25	0.255
	8	24,707,560	10,253,333	9,132,645	10,237,590	9,228,000	-2,368,520	61,190,608	225,573,333	$0.25	0.255
	9	23,633,318	10,253,333	9,589,277	10,800,658	9,228,000	-2,368,520	61,136,066	215,320,000	$0.25	0.255
	10	22,559,076	10,253,333	10,068,741	11,394,694	9,228,000	-2,368,520	61,135,324	205,066,667	$0.25	0.255
	11	21,484,835	10,253,333	10,572,178	12,021,402	9,228,000	-2,368,520	61,191,228	194,813,333	$0.25	0.255
	12	20,410,593	10,253,333	11,100,787	12,682,579	9,228,000	-2,368,520	61,306,772	184,560,000	$0.25	0.255
	13	19,336,351	10,253,333	11,655,826	13,380,121	9,228,000	-2,368,520	61,485,112	174,306,667	$0.25	0.255
	14	18,262,109	10,253,333	12,238,617	14,116,028	9,228,000	-2,368,520	61,729,568	164,053,333	$0.25	0.255
	15	17,187,868	10,253,333	12,850,548	14,892,409	9,228,000	-2,368,520	62,043,638	153,800,000	$0.25	0.255
	16	16,113,626	10,253,333	13,493,075	15,711,492	9,228,000	-2,368,520	62,431,007	143,546,667	$0.25	0.255
	17	15,039,384	10,253,333	14,167,729	16,575,624	9,228,000	-2,368,520	62,895,551	133,293,333	$0.26	0.255
	18	13,965,143	10,253,333	14,876,116	17,487,283	9,228,000	-2,368,520	63,441,355	123,040,000	$0.26	0.255
	19	12,890,901	10,253,333	15,619,921	18,449,084	9,228,000	-2,368,520	64,072,719	112,786,667	$0.26	0.255
	20	11,816,659	10,253,333	16,400,918	19,463,783	9,228,000	-2,368,520	64,794,173	102,533,333	$0.26	0.255
	21	10,742,417	10,253,333	17,220,963	20,534,291	9,228,000	-2,368,520	65,610,485	92,280,000	$0.27	0.255
	22	9,668,176	10,253,333	18,082,012	21,663,677	9,228,000	-2,368,520	66,526,678	82,026,667	$0.27	0.255
	23	8,593,934	10,253,333	18,986,112	22,855,180	9,228,000	-2,368,520	67,548,039	71,773,333	$0.28	0.255
	24	7,519,692	10,253,333	19,935,418	24,112,215	9,228,000	-2,368,520	68,680,138	61,520,000	$0.28	0.255
	25	6,445,450	10,253,333	20,932,189	25,438,386	9,228,000	-2,368,520	69,928,839	51,266,667	$0.29	0.255
	26	5,371,209	10,253,333	21,978,798	26,837,498	9,228,000	-2,368,520	71,300,318	41,013,333	$0.29	0.255
	27	4,296,967	10,253,333	23,077,738	28,313,560	9,228,000	-2,368,520	72,801,078	30,760,000	$0.30	0.255
	28	3,222,725	10,253,333	24,231,625	29,870,806	9,228,000	-2,368,520	74,437,969	20,506,667	$0.30	0.255
	29	2,148,483	10,253,333	25,443,206	31,513,700	9,228,000	-2,368,520	76,218,203	10,253,333	$0.31	0.255
	30	1,074,242	10,253,333	26,715,366	33,246,954	9,228,000	-2,368,520	78,149,375	0	$0.32	0.255
									NPV	2.31749	2.3114

Levelized Bus Bar Electricity Cost Model

Fossil	Year	Capital Chg	Depreciation	O&M	Fuel	Prop Tax+Ins	Amortized ETC	Total	Depr Cst (EOY)	BB Cost	Levl Cost
	1	8,079,024	2,570,400	2,346,996	6,911,507	2,313,360	0	22,221,288	74,541,600	$0.13	0.151
	2	7,809,723	2,570,400	2,464,346	7,291,640	2,313,360	0	22,449,469	71,971,200	$0.13	0.151
	3	7,540,423	2,570,400	2,587,563	7,692,681	2,313,360	0	22,704,426	69,400,800	$0.13	0.151
	4	7,271,122	2,570,400	2,716,941	8,115,778	2,313,360	0	22,987,601	66,830,400	$0.13	0.151
	5	7,001,821	2,570,400	2,852,788	8,562,146	2,313,360	0	23,300,515	64,260,000	$0.14	0.151
	6	6,732,520	2,570,400	2,995,428	9,033,064	2,313,360	0	23,644,772	61,689,600	$0.14	0.151
	7	6,463,219	2,570,400	3,145,199	9,529,882	2,313,360	0	24,022,061	59,119,200	$0.14	0.151
	8	6,193,919	2,570,400	3,302,459	10,054,026	2,313,360	0	24,434,163	56,548,800	$0.14	0.151
	9	5,924,618	2,570,400	3,467,582	10,606,997	2,313,360	0	24,882,957	53,978,400	$0.14	0.151
	10	5,655,317	2,570,400	3,640,961	11,190,382	2,313,360	0	25,370,420	51,408,000	$0.15	0.151
	11	5,386,016	2,570,400	3,823,009	11,805,853	2,313,360	0	25,898,638	48,837,600	$0.15	0.151
	12	5,116,715	2,570,400	4,014,159	12,455,175	2,313,360	0	26,469,810	46,267,200	$0.15	0.151
	13	4,847,415	2,570,400	4,214,867	13,140,210	2,313,360	0	27,086,252	43,696,800	$0.16	0.151
	14	4,578,114	2,570,400	4,425,611	13,862,921	2,313,360	0	27,750,406	41,126,400	$0.16	0.151
	15	4,308,813	2,570,400	4,646,891	14,625,382	2,313,360	0	28,464,846	38,556,000	$0.17	0.151
	16	4,039,512	2,570,400	4,879,236	15,429,778	2,313,360	0	29,232,286	35,985,600	$0.17	0.151
	17	3,770,211	2,570,400	5,123,198	16,278,416	2,313,360	0	30,055,585	33,415,200	$0.18	0.151
	18	3,500,911	2,570,400	5,379,357	17,173,729	2,313,360	0	30,937,757	30,844,800	$0.18	0.151
	19	3,231,610	2,570,400	5,648,325	18,118,284	2,313,360	0	31,881,979	28,274,400	$0.19	0.151
	20	2,962,309	2,570,400	5,930,742	19,114,789	2,313,360	0	32,891,600	25,704,000	$0.19	0.151
	21	2,693,008	2,570,400	6,227,279	20,166,103	2,313,360	0	33,970,149	23,133,600	$0.20	0.151
	22	2,423,707	2,570,400	6,538,643	21,275,238	2,313,360	0	35,121,348	20,563,200	$0.20	0.151
	23	2,154,406	2,570,400	6,865,575	22,445,376	2,313,360	0	36,349,118	17,992,800	$0.21	0.151
	24	1,885,106	2,570,400	7,208,853	23,679,872	2,313,360	0	37,657,591	15,422,400	$0.22	0.151
	25	1,615,805	2,570,400	7,569,296	24,982,265	2,313,360	0	39,051,126	12,852,000	$0.23	0.151
	26	1,346,504	2,570,400	7,947,761	26,356,290	2,313,360	0	40,534,315	10,281,600	$0.24	0.151
	27	1,077,203	2,570,400	8,345,149	27,805,886	2,313,360	0	42,111,998	7,711,200	$0.25	0.151
	28	807,902	2,570,400	8,762,406	29,335,209	2,313,360	0	43,789,278	5,140,800	$0.26	0.151
	29	538,602	2,570,400	9,200,527	30,948,646	2,313,360	0	45,571,534	2,570,400	$0.27	0.151
	30	269,301	2,570,400	9,660,553	32,650,821	2,313,360	0	47,464,435	0	$0.28	0.151
									NPV	1.37245	1.36871

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