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HAWAII DEEP WATER CABLE PROGRAM

PHASE II-C

EXECUTIVE SUMMARY

Department of Business and Economic Development

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for

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and the

State of Hawaii

Department of Business and Economic Development

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INTRODUCTION

The Hawaii Deep Water Cable (HDWC) Program is a multi-year, multi-million dollar study of the feasibility of transmitting electricity via a submarine cable system from the Island of Hawaii (the "Big Island") to Maui and Oahu. The study is being funded by the U.S. Department of Energy (DOE) and the Hawaii Department of Business and Economic Development (DBED), and through cost-sharing by the Program team. This Executive Summary, produced under the State-funded portion of the Program, reviews the accomplishments of the Program through the recently completed State-funded Phase II-C and describes the work remaining to prove system feasibility.

Background

The State of Hawaii depends almost completely on imported petroleum for its energy needs, and consequently is extremely sensitive to fluctuations in oil price and supply. Paradoxically, Hawaii has abundant undeveloped geothermal, direct solar, wind, biomass, and ocean thermal energy resources. Recognizing the potential of these undeveloped resources and the State's vulnerability to disruptions of world oil markets, the State of Hawaii is committed to the full development of its renewable energy resources.

In terms of the potential magnitude of the resource and the maturity of existing technology, the most promising near-term, baseload alternative energy resource in the State is geothermal. The potential for development of this resource is greatest on the Island of Hawaii, but the demand for electricity is greatest on Oahu. It is estimated that the geothermal resource on the Big Island could satisfy at least half of Oahu's present electricity requirements if the energy could be transmitted. It appears that the most feasible method of transporting electrical power produced from the geothermal resource to Oahu is by high-voltage, direct-current (HVDC) submarine cables.

The current state-of-the-art in submarine cable technology is represented by the HVDC cables linking Norway and Denmark (the "Skagerrak" system). These cables traverse a distance of 78 miles at a maximum depth of 1,800 feet. Interconnection of Hawaii and Oahu will require the development of a submarine cable and cable deployment/retrieval systems to operate in water depths to 6,300 feet and over a distance of about 150 miles.

Program Phasing

The HDWC Program consists of two phases: Phase I - Preliminary Program Definition, and Phase II - Final Program Definition and Cable, Cable Vessel and Cable Handling Equipment Design/Verification. Phase I, funded by the State of Hawaii and augmented by additional funds provided by members of the Program team, began in October, 1981 and was completed eight months later. The remainder of the Program is termed Phase II, although the State-funded activities have been divided into Phases II-A through II-D corresponding to successive funding increments.

Participants

The HDWC Program draws from an international resource pool made up of private sector, government agency, public utility and university personnel. For both the State-funded and Federally-funded portions of the HDWC Program, Hawaiian Electric Company, Inc. (HECO) is the prime contractor. The Ralph M. Parsons Company through its Honolulu office (Parsons Hawaii), is the Program Integration Manager with subcontract management and technical support responsibilities throughout the Program. In addition, the DBED has independently funded several studies of the cable system economics and potential financing methods. Figure 1 is an organizational chart showing all of the Program participants, contractual linkages and areas of responsibility.

Program Schedule

Timelines for the State-funded and Federally-funded portions of the HDWC Program and a most optimistic target schedule for commercial development of the system are shown in Figure 2. State-funded efforts are projected to proceed through January, 1988. At-sea testing under the Federal program is scheduled to be completed in 1990.

HDWC PROGRAM

FIGURE 1

PROGRAM ORGANIZATION / FUNCTIONS

(Through Phase II–C)

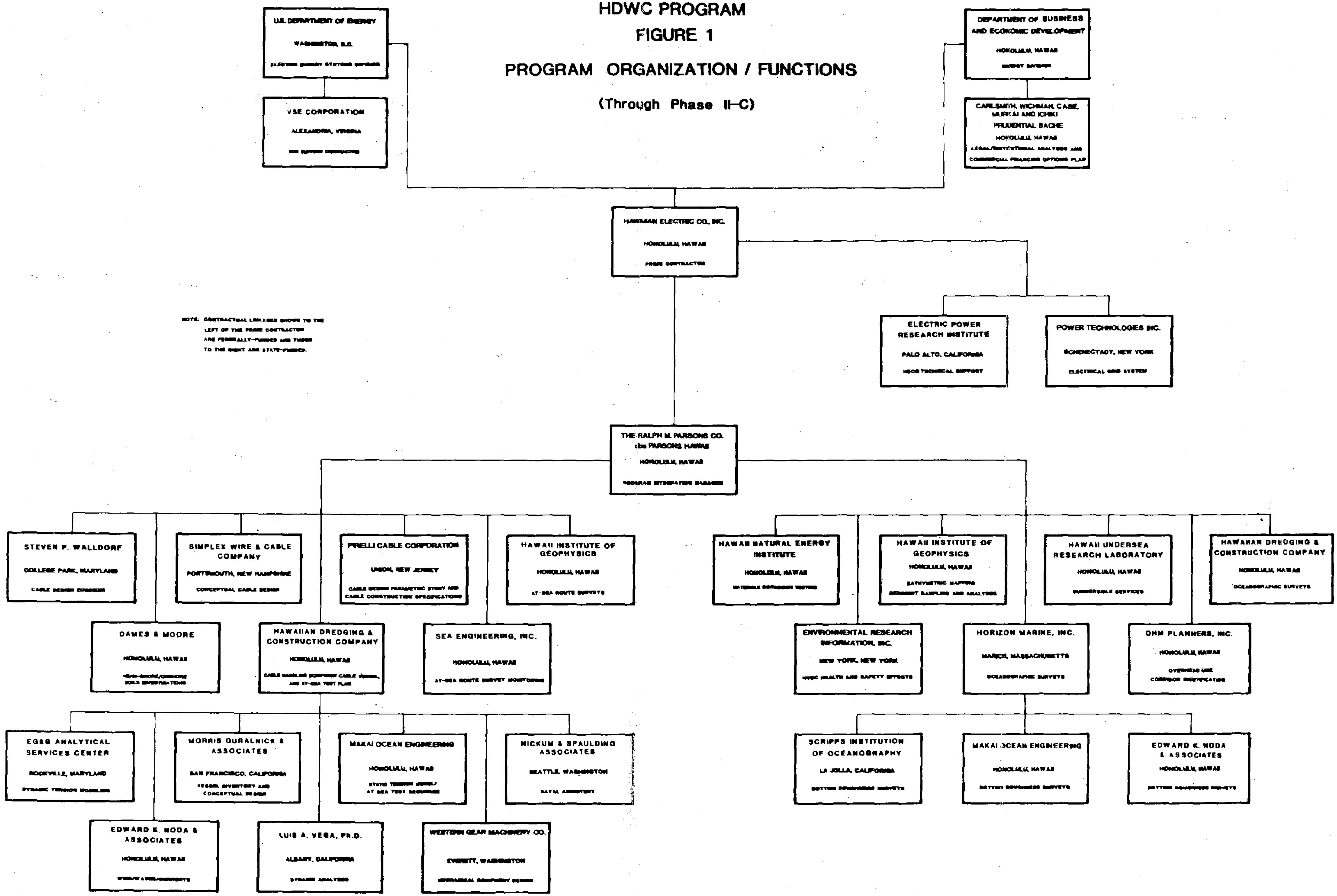
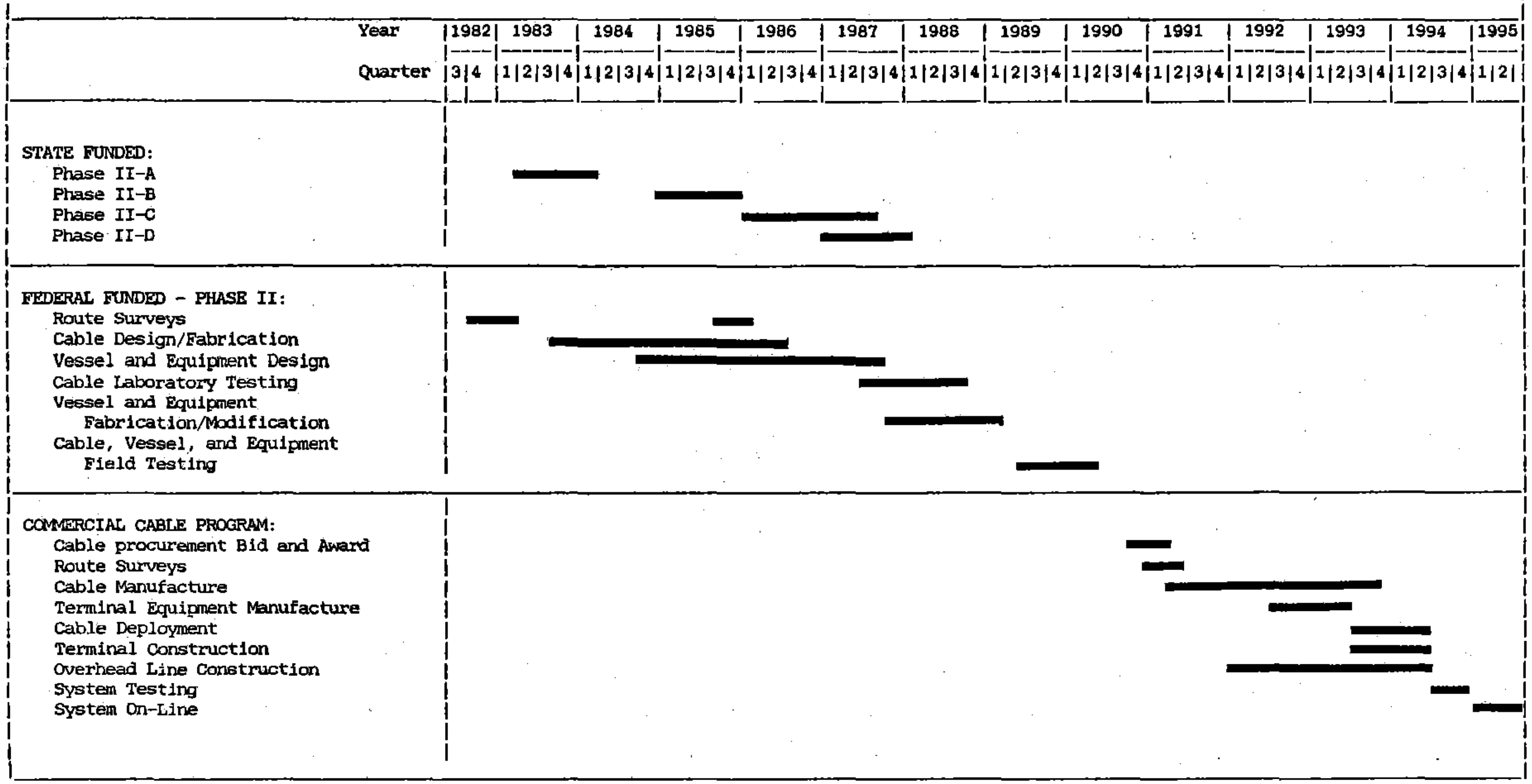


FIGURE 2
HAWAII DEEP WATER CABLE PROGRAM AND
COMMERCIAL CABLE SYSTEM DEVELOPMENT PLANNING SCHEDULE



State and Federal Focal Areas

Although the HDWC Program is being funded cooperatively by the State and Federal governments, each portion has its own focus. Generally, the Federally-funded portion of the Program emphasizes generic aspects of the technologies involved, while the State-funded portion of the Program is considering more site-specific issues. One area of research that is shared by both Federal and State sub-programs involves the study of bottom conditions along the submarine route. These surveys have included bathymetric mapping, bottom photography, sediment sampling, and investigation of near-surface and near-bottom water currents.

ACCOMPLISHMENTS OF THE STATE-FUNDED SUB-PROGRAM

PRELIMINARY PROGRAM DEFINITION

In Phase I, investigations were initiated into each of the major variables which will define the eventual commercial cable system, including cable design, cable laying vessels, cable handling equipment, electrical grid system integration and routing. Elements of the cable design included materials characteristics (type, composition and weight) and dimensions (diameter, area and thickness) of cable conductors, insulations, sheaths and armors. Identified were five basic cable designs that could possibly operate successfully in the deep ocean around Hawaii. These five designs were later evaluated in greater detail in the Federally-funded portion of the Program.

While cable designs were being evaluated, the characteristics, capabilities and availability of all known existing and planned cable laying vessels were surveyed. A preliminary conceptual design of a vessel for the HDWC Program at-sea test program was subsequently developed.

At the same time, a conceptual plan was developed for integration of the HVDC transmission linkage into the electrical grid system of Oahu. Also accomplished was preliminary identification, mapping and environmental analyses of more than forty potential commercial cable system submarine and terrestrial route segments.

To inform interested agencies and organizations about the accomplishments of the Program, an Executive Summary was widely distributed to public and private organizations providing a basic introduction to the Program. In addition, a narrated, 35 mm slide program was prepared and presented to private and public sector groups and agencies.

FINAL PROGRAM DEFINITION

Upon completion of preliminary work, Phase II began and the major tasks were divided into specific research steps that would build upon each other as work progressed. To manage and control the many diverse technical tasks in the Program, a Program Management Plan (PMP) was developed which defined the administrative, technical and fiscal functions and controls for the Program. Accomplishments within each research area are described below emphasizing work recently completed under State-funded Phase II-C.

Environmental Analyses

A detailed environmental report, including an annotated bibliography of the electromagnetic field effects of HVDC systems, was the first environmental document prepared for the HDWC Program. Federal, State and County agencies were contacted regarding their environmental concerns about the Program, permitting requirements, environmentally sensitive areas, endangered and threatened species, and other environmental and regulatory considerations. Formal briefings of all County, State and Federal agencies with environmental and land use responsibilities were conducted.

It was concluded that environmental impacts of the HDWC Program itself will be insignificant, limited to short-term ship operations and temporary disruption of small areas of marine benthic habitats during the at-sea tests. Because of their small-scale, transient and research nature, the operational aspects (at-sea testing) of the HDWC Program will face few permitting requirements. Implementation of a commercial interisland cable system, however, could have significant environmental impacts. Probable impacts include short-term negative impacts during construction of the system, long-term negative impacts in visual quality along some portions of the overland route and long-term positive impacts in the area of socioeconomics. It was determined that both State and Federal Environmental Impact Statements (EISs) as well as an extensive array of permits, would be required prior to implementation of a commercial cable system. Therefore, scoping and information gathering for a commercial cable system EIS was initiated.

In Phase II-C an environmental assessment of the "preferred route" for the commercial cable system was prepared. Both submarine and overhead route segments, as well as their nearshore interfaces, were examined for potential impacts resulting from system construction, operation, maintenance and repair. Although called an "Environmental Assessment," the document employs an EIS format to maximize its usefulness to the future developers of the commerical cable system. The "preferred route" is a broad corridor that encompasses a larger and more general area than would actually be needed for an underwater cable and overhead transmission line system (Figure 3). A detailed alignment within the corridor is not defined.

Also completed in Phase II-C were three additional studies related to interactions of the cable system and the environment. The first was a literature review of hydrogen sulfide

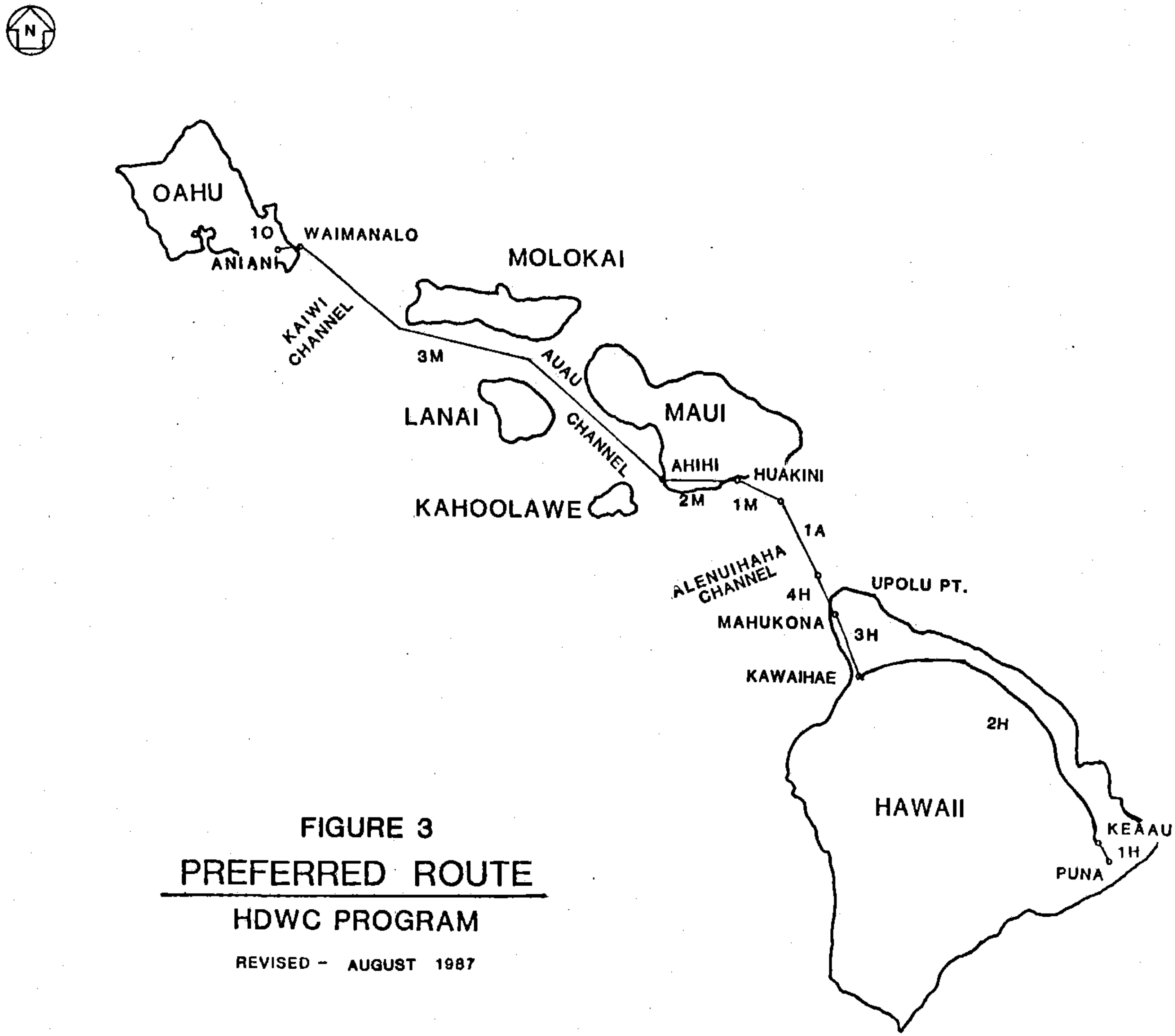


FIGURE 3

PREFERRED ROUTE

HDWC PROGRAM

REVISED - AUGUST 1987

concentrations in the seafloor along the anticipated cable route. The presence of high concentrations of hydrogen sulfide or other reduced elements and compounds along the cable route could possibly accelerate corrosion of cable components. After reviewing the available site specific literature and data, it was concluded that the cable would pass through neither of the two types of areas where sulfides could be a problem, hydrothermal vents and relatively stagnant areas with large accumulations of organic matter. Therefore, accelerated corrosion of the cable due to sulfides is not anticipated.

Second, an assessment of the potential environmental impact of using a sea return for unbalanced electrical current rather than a metallic return was carried out. Data developed in Phase II-B indicated significant technical and economic disadvantages to using a metallic return cable in the commercial system. The environmental impacts of a sea electrode system include a potential shock hazard at the electrode and accelerated corrosion of nearby metallic objects, but both are readily mitigated and expected impacts would be very minor.

Third, the potential visual impacts of the 300 kVdc overhead transmission lines which would cross portions of Hawaii, Maui and Oahu were investigated. The major components and interrelationships which would have visual impact were identified and analyzed including project, landscape, and viewer characteristics. Mitigation measures were also described.

Evaluation of the potential degree of contrast between the landscape and the proposed transmission lines for each of the study areas revealed that some portions are very capable of visually absorbing a transmission line and right-of-way and other portions are not. Significant visual intrusion into the landscape may, however, be reduced with careful alignment selection.

Electrical Grid System Integration Studies

Using the grid system integration concepts and the preliminary route survey data developed earlier, plans, designs and cost estimates to reliably link Hawaii and Oahu with and without a 50 MW power tap on Maui were developed during Phase II-C. Areas for alternative converter sites on Hawaii and Oahu were analyzed for sending and receiving the bulk dc power.

The investigations included projecting system needs on Oahu and Hawaii with and without geothermal development and the cable system, at several projected annual load growth rates. Staging of geothermal development was assumed to take place over ten and fifteen-year horizons beginning construction in 1992, and staging of the transmission system development was assumed to proceed in conjunction with this generation development scenario.

Proprietary computer software was adapted to perform reliability analyses for the overhead and submarine components and translate the results for use in production cost studies. These studies evaluated potential cost savings in power generation on Oahu using various assumptions of development scheduling, oil price escalation, system configuration, outage rates, repair times and geothermal system availability. Optimization analyses for the configuration of the overhead lines and current return flow were then performed as were other system studies including load-flow analyses for the MECO network and dynamic studies to evaluate the stability and dynamic overvoltage characteristics of the MECO system with a 50 MW tap in service.

Grid system studies in Phase II-C focused on several major issues. To allow the electrical supply to vary with daily cyclical fluctuations in demand, cycling of generating units, geothermal or oil-fired, would be necessary. Therefore possible modifications to existing HECO oil-fired units and the cycling capabilities of geothermal plants were investigated. This information was complemented by system operations studies to define operating constraints and requirements on the HVDC link resulting from existing or planned generating facilities on Oahu and planned geothermal plants on the Big Island. The constraints of required spinning reserve, maintenance of short-circut level, modification of must-run units to cycling units and loss of major blocks of dc transmitted power were identified and their impacts quantified. The maximum load change rates specified for the largest HECO units were investigated. This study complemented the cycling study by imposing the apparent control and operating characteristics of the geothermal units on the HECO system. This allowed an analysis of the expected patterns of unit commitment as governed by the incoming power and the units' own capabilities. Further, the load and generation characteristics at the HECO end of the system define the required operating characteristics of the geothermal generation. Conflicts between requirements at both ends of the HVDC link needed to be identified before significant development of the geothermal units and before the HVDC commercial venture is irreversibly tied to a 500 MW level.

In further work under this task, cable transient and dynamic behavior were researched to verify requirements and capabilities of the cable insulation and surge arrestors. This was necessary because the commercial cable system would be the longest HVDC submarine cable/overhead line combination in the world, and as such lies beyond existing technology. Those areas where technical difficulties might arise and where a significant amount of analysis and engineering effort will be needed in future design work were identified.

An equipment specification document detailing the requirements for the land-based portions of the system was drafted and will be issued to prospective bidders for comment. This document demonstrates the required format of the final specification, the data required, the studies which will need to be done to produce the final specification, the data which will need to be supplied by the bidders and the studies which they will be required to do as a condition of the bid process.

Materials Corrosion and Abrasion Testing

In Phase II-A, experiments were begun to investigate the corrosion, abrasion and cathodic protection characteristics of various types of metals which could be used as cable conductor, sheath or armor material. Specific areas of investigation included:

(1) Long-term corrosion testing of steel, copper and aluminum alloys.
(2) Crevice corrosion studies of stainless steel alloys.
(3) Corrosion and fouling of cupronickel.
(4) Abrasiveness of Hawaiian rocks to various potential cable armor steels.

This work, by the Hawaii Natural Energy Institute (HNEI), continued at the University of Hawaii at Manoa and on the Big Island at the Keahole Point, Natural Energy Laboratory of Hawaii (NELH) through Phases II-B and II-C. Long-term corrosion testing of potential cable materials, including twelve different metals and metal alloys, has utilized the unique capability of the NELH to supply seawater from both shallow (300 feet) and deep (2000 feet) depths to simulate actual conditions of environmental exposure. Samples have been exposed to flowing seawater in darkened troughs for various lengths of time. Weight loss and depth of pitting have been measured. It was found that corrosion of samples exposed to waters at NELH was slightly less than that reported at other tropical sites. Generally, samples exposed to deep waters showed less corrosion than those exposed to shallow waters, except aluminum, which corroded faster in deeper waters.

The abrasion potentials of basalt and coral rock were studied using a range of standard test materials of various hardness. The test apparatus, designed and fabricated specifically for the HDWC Program, was then employed to test actual samples of cable armor wire. Additional experimentation utilized a "U-bend" tester constructed for the Program to examine the fatigue characteristics of the cable lead sheathing material.

Investigation of the long-term survival potential of the specified cable was the focus of Phase II-C. In particular, survival of the armor wire material under accelerated, simulated service conditions was studied. This portion of the State-funded Program is being integrated with the Federally-funded laboratory test program.

Oceanographic Surveys

In Phase II-B, three major subtasks were accomplished. The Hawaii Institute of Geophysics, University of Hawaii, produced a computer-contoured bathymetric atlas of the entire HDWC Program area using newly released digitized data provided by the National Oceanic and Atmospheric Administration.

To gain a better understanding of actual bottom conditions to which a cable would be exposed, the Hawaii Undersea Research Laboratory, University of Hawaii, conducted a series of dives using the submersible Makali'i. These dives took place offshore of Kawaihae and Mahukona on the Island of Hawaii and offshore of Kaupo, Maui. During these dives, continuous videotapes and 35 mm slides were made of the ocean floor from about 200 feet deep to the submersible's maximum diving depth (about 1,200 feet).

To design a cable vessel propulsion system, the cable handling equipment and the integrated cable handling/vessel positioning system, it is necessary to understand the ocean currents which will act on the vessel and cable while the cable is being deployed. Near-surface currents at a site on the Hawaii side of the Alenuihaha Channel were measured from 1984 to 1986 and measurements of near-bottom currents at two stations farther offshore were taken from 1985 to 1986. To determine that the data generated at these sites are representative of conditions across the entire channel, another type of measurement program was funded in Phase II-B. This program employed a new technology: expendable current probes. These devices, deployed from either an aircraft or surface vessel, fall through the water column transmitting current vector data back to the deployment vessel. On three occasions, a series of these probes was deployed in the Alenuihaha Channel over a short time period to give a nearly synoptic series of current profiles across the channel. These data were then compared with data from the moored meters to examine three-dimensional variability of water currents in the channel.

In Phase II-C, information generated in Phases II-A and II-B, as well as in the Federally-funded portion of the Program, was used to plan an oceanographic cruise to gather fine-scale data necessary to identify a technically feasible route across the Alenuihaha Channel. This survey was performed during July 8-17, 1986 using the R/V Melville with the Scripps Institution of Oceanography's "Deep Tow" system. Bottom roughness data were acquired through the use of near-bottom towed survey devices with acoustic transponder navigational tracking. Principal reliance for data collection was placed on deep-towed narrow-beam echo sounding and simultaneously obtained side-looking sonar (SLS) imagery with complementary photographic coverage to document fine-scale roughness.

The objective of this cruise was to document the existence and characteristics (particularly width) of acceptable routes across the channel. **A technically feasible, but challenging, route was found across the Alenuihaha Channel.** The path width, bottom roughness and cable deployment bottom tensions for all segments were defined. In contrast to prior assumptions, it was found that the Maui side of the channel would require the more precise deployment because the path must bend around and pass between a series of otherwise impassible escarpments. These data will provide essential guidance in selection/design of the integrated vessel operations and cable laying control system required for the at-sea test program.

Overland Route Surveys

In Phase II-B, potential corridors for overhead transmission lines on Oahu, Maui and the northern half of Hawaii were identified. Data were gathered through field surveys and literature reviews, and corridors were identified using an overlay mapping technique. Four types of excluded areas and fourteen various geophysical, biological, socioeconomic and cost factors, rated by degree of constraint, were mapped and overlayed to show the composite effect of all constraints. Viable corridors were identified on each island studied, and these form the basis for future investigations of detailed alignments for the HVDC transmission lines.

In Phase II-C, the identical technique was used to identify a corridor across the remainder of the Big Island to the designated "Geothermal Resource Subzones." The results of this study indicate a major land use conflict between the Army's Pohakuloa Training Area and a corridor for the potential HVDC line. A route north of Mauna Kea would seem to present fewer constraints than a route across the saddle between Mauna Kea and Mauna Loa, and the preferred route has been adjusted to reflect this finding.

Also completed in Phase II-C was a cost comparison which examined the alternative of routing the system overland on Molokai rather than proceeding underwater from Maui to Oahu. The analysis showed that although the capital cost of a submarine segment was higher than the overland option, the indirect costs of the Molokai route alternative caused by delays associated with land use and environmental controversies would make the overland alternative considerably more expensive.

Public Information Program

Two significant informational items were produced in Phase II-B: a slide show and a scale model of the Alenuihaha Channel. During Phase II-C, three additional items were produced to aid the information dissemination efforts: a posterboard, a sample of a representative SCOF cable cut away to show its component layers, and a one-page fact sheet about the Program which was widely distributed at presentations and exhibits of Program materials.

During Phase II-C, ten special presentations, incorporating use of the exhibit and display items, were made to a variety of audiences. Dozens of Phase II-B Executive Summaries were distributed, and more than 700 fact sheets were handed out. The HDWC Program was featured in six news articles, one journal article, three HECO public newsletters, three DBED public newsletters, and one national newscast by CNN.

A June 1987 survey by SMS Research and Marketing Services, Inc. confirmed the impact of the public information program. Approximately forty percent of the 901 residents interviewed were aware of the cable program, and almost seventy-five percent of them had a favorable opinion of the program. This may be compared with only a forty-two percent awareness that oil is Hawaii's primary source of electricity.

In other areas of the country, potential health and safety issues related to high voltage direct current transmission lines have been of great concern. To provide an early opportunity for the people of Hawaii to learn about these issues, a series of expert briefings were held on Oahu, Maui and Hawaii. In addition to these public meetings, a workshop was held for HECO engineers and government agency personnel to aid assessment and management of the degree of both actual and perceived risk associated with exposure to the HVDC electrical environment. It was concluded that HVDC transmission line systems do not cause health and safety hazards to people or the natural environment.

ACCOMPLISHMENTS OF THE FEDERAL-FUNDED SUB-PROGRAM

Following State-funded Phase I, preliminary program definition, Federal funding began for design of the three major hardware subsystems - the cable, the cable vessel and the cable handing equipment. At the same time, preliminary at-sea route surveys were performed and investigations of the thermal characteristics of near-shore and on-shore soils were conducted. The paragraphs below discuss in more detail the major accomplishments of (Federally-funded) Phase II.

Cable Design and Verification

Supplementing the prototype cable design information developed in Phase I, a comprehensive cable design parametric study was completed. Over 25,000 separate calculations were made, varying some sixteen external and internal cable parameters. The results indicated that more than 251 cable designs met or exceeded all design criteria and, theoretically, were suitable for a commercial interisland cable system. Following a rigorous technical and economic analysis of all 251 candidate designs, one design was selected which is considered to be representative of an appropriate commercial cable. **The selected cable is a ±300 kVdc, 250 MW, "self-contained oil filled" (SCOF) cable.** Figure 4 illustrates the SCOF cable cross-section, and Table 1 describes the basic design characteristics of the selected cable.

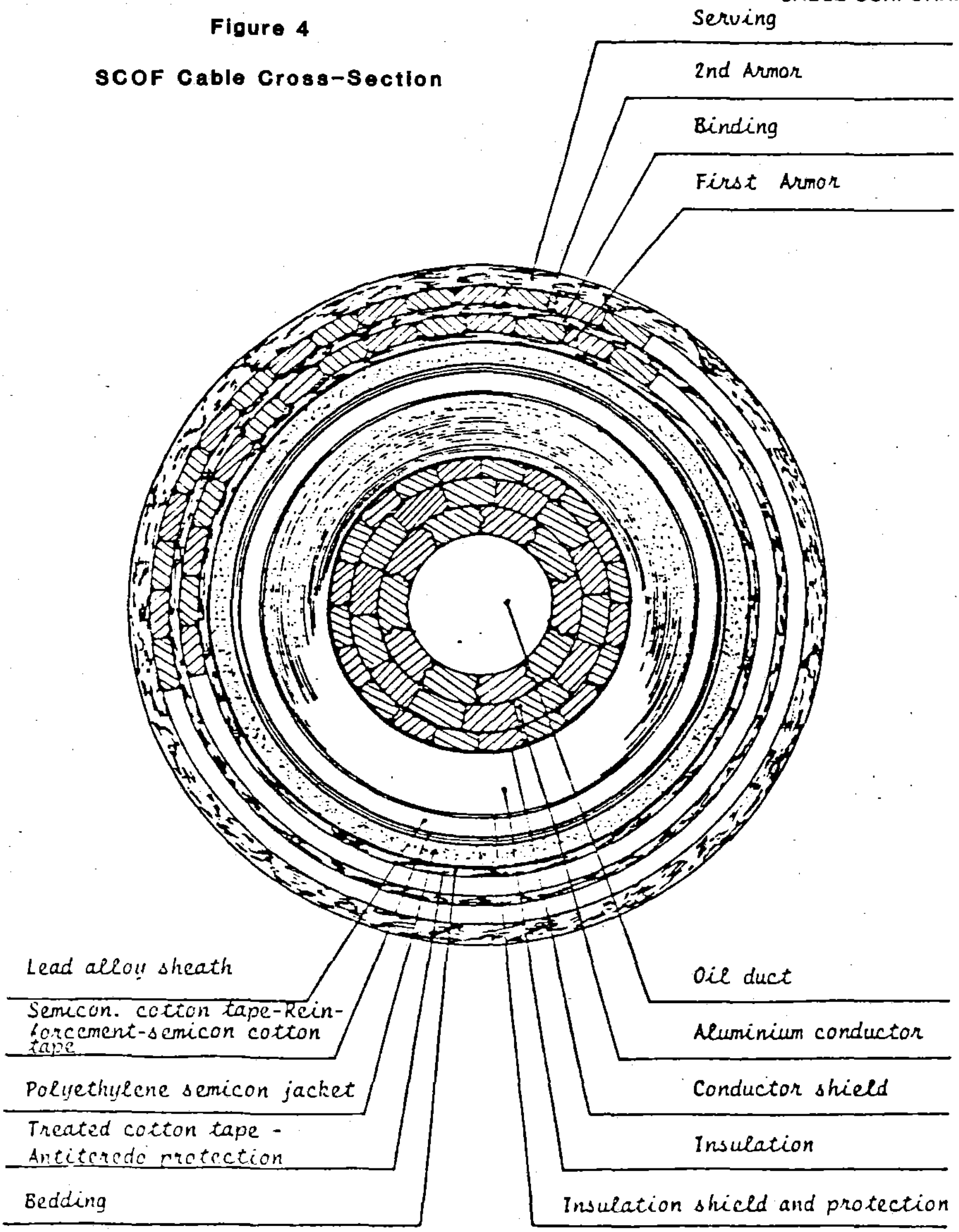
During the period of performance of State-funded Phase II-C, Federally-funded activities were focused on two major areas. The first was cable laboratory testing. A 6,000 foot length of cable was fabricated to the specifications previously produced, and a

WEIGHT OF CABLE IN AIR: 37kg/m (24.9 lb/ft)
WEIGHT OF CABLE IN WATER: 27kg/m (18.2 lb/ft)

PIRELLI
CABLE CORPORATION

Figure 4

SCOF Cable Cross-Section



Source: Pirelli Cable Corporation. 1985. <u>Hawaii Deep Water Cable Program, Phase II: Cable Construction Specification</u>. Prepared for The Ralph M. Parsons Co., Hawaiian Electric Co., Inc. and the U.S. Dept. of Energy.

Table 1

Selected Basic Design

Characteristics of Cable Design No. 116

PARAMETER	DESCRIPTION
Cable Type	SCOF
Voltage	±300 KVDC
Conductor Cross Section	1,600 sq mm (2.48 sq in)
Total Transmission Load	500 MW
Transmission Load Per Cable	250 MW
Rated Current Per Cable	833 Amps
Conductor Material	Aluminum
Oil Duct Diameter	25 mm (0.98 in)
Oil Type	High Density Synthetic Low Viscosity
Number of Cables for System	2 plus one spare
Polarity Reversal	Allowed
Conductor Diameter	51.9 mm (2.043 in)
Insulation Thickness	10.9 mm (o.429 in)
Cable Finished Diameter	118.4 mm (4.66 in)
Cable Weight in Air	37 kg/m (24.9 lb/ft)
Cable Weight in Water	27 kg/m (18.2 lb/ft)
Maximum Oil Feeding Length	190 km (118.1 mi)
Design Oil Feeding Pressure	30 atm (440 psi)
Losses at Rated Current Per Cable	12.4 kW/km
Pulling Tension for 7,000 Ft Water Depth (Based on PCC Formula)	65.1 mt (71.8 t)
Maximum Allowable Cable Pulling Tension	78.7 mt (86.8 t)
Corresponding Maximum Water Depth (Based on PCC Formula)	2,626 m (8,615.5 ft)
Minimum Allowable Bending Diameter	6 m (19.7 ft)

laboratory testing subcontract was established between Parsons Hawaii and Pirelli Cable Corporation. Simultaneously, design work continued on components of the other two subsystems, the cable vessel and the cable handling equipment.

Cable Vessel and Cable Handling Equipment

In Phase I, a cable vessel and equipment survey was conducted, and a cable vessel and equipment conceptual design prepared. Early in Phase II, cable vessel and equipment availability and applicability were reassessed, and computer modeling of dynamic and static tensions on the cable as a function of different vessel sizes and equipment configurations was performed. The model integrated the cable, cable vessel and cable handling equipment design information with statistical data on sea conditions and expected ocean bottom conditions. Results of this work indicated that a 400-foot long by 100-foot wide vessel with a stern-mounted overboarding sheave would best satisfy the criteria established for commercial cable deployment. The major cable handling machinery aboard the vessel is illustrated in Figure 5 and the subsystem components are described in Table 2.

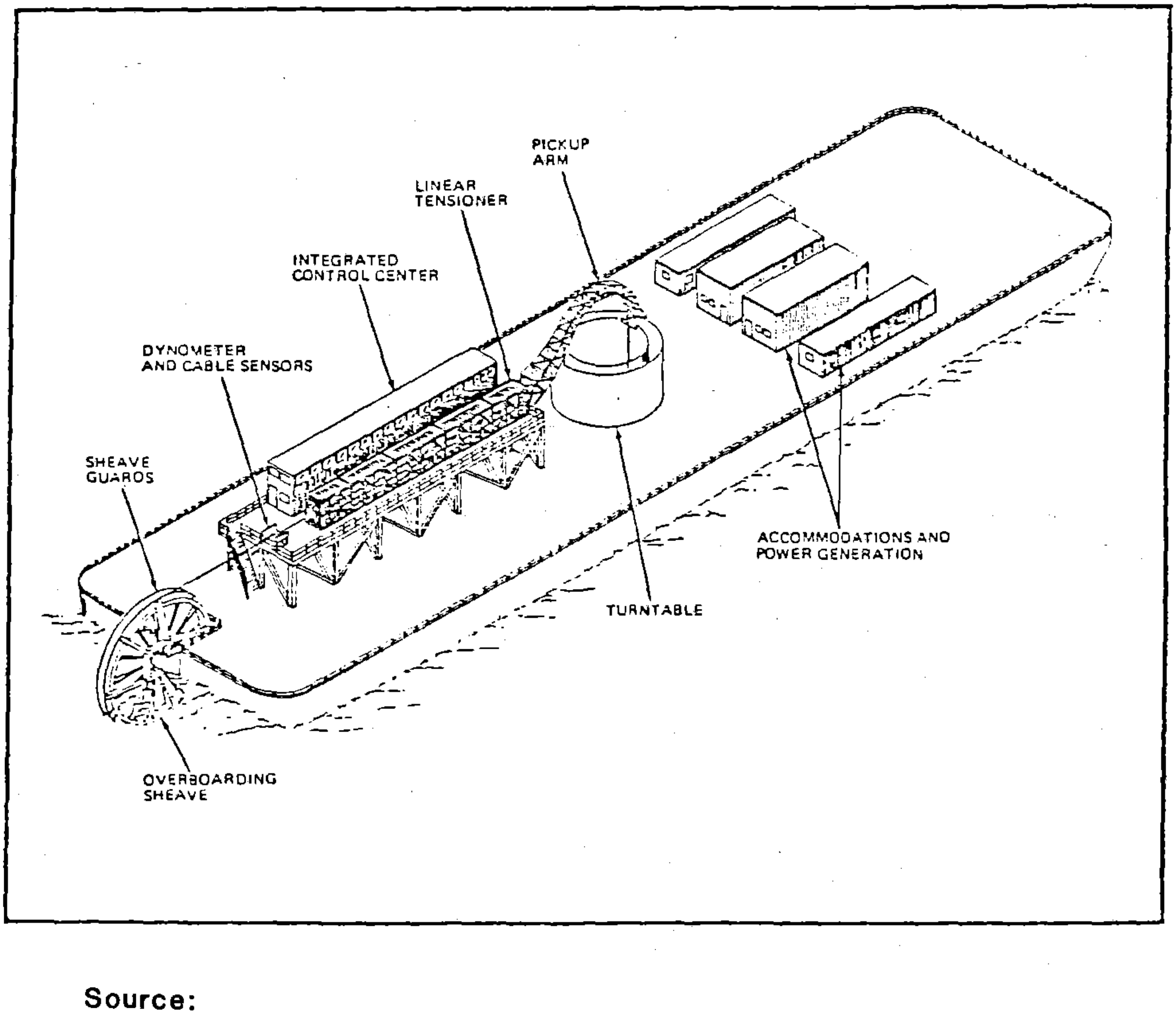
At-Sea Route Surveys

While design of the subsystems proceeded, detailed bathymetric mapping of the Alenuihaha Channel as well as deep water sediment sampling and bottom photography were performed. The data

Figure 5

Conceptual Drawing of the Major Cable Handling

Machinery for the HDWC Program



Source:

Western Gear Machinery Company. 1986. Hawaii Deep Water Cable Program, Phase II: Cable Handling Equipment Concept Study. Prepared for Hawaiian Dredging and Construction Co., The Ralph M. Parsons Co., Hawaiian Electric Co., Inc. and the U.S. Dept. of Energy.

TABLE 2

COMMERCIAL CABLE SYSTEM COMPONENTS

SUBSYSTEM	COMPONENT
Cable	Cables (possibly more than one design) Sea Return System Factory and At-Sea Splices Sheath/Grounding Joints Land/Sea Cable Joints or Terminations Cable Splicing Equipment Oil Pumps/Reservoirs - On-Board Transport and Laying Vessels and Shoreside* Spare Cable & Repair Equipment Storage
Vessel	Hull and Deck Propulsion and Maneuvering Navigation and Control Port Facilities Embedding Equipment Submersible and Support Equipment Operations and Crew Support Facilities Cable Locating Equipment (Electronic, Mechanical, Visual)
Cable Handling Equipment	Turntable Tensioner Overboarding Sheave Power Unit Control Modules Cable Orientation Guidance System
Shoreside Facilities	Rectifier/Inverter Equipment Intermediate Takeoff/Landing Facilities Overhead Lines Operations and Maintenance Facility

* If a SCOF-type cable is selected, the cable must remain pressurized while in transit from the factory and during laying.

indicated that bottom conditions in the channel vary from ideal (i.e., flat, sandy bottoms) to hazardous (i.e., steep scarps and areas of underwater landslides). The bathymetric surveys conducted were the first detailed mapping of the Alenuihaha Channel and were later supplemented with additional surveys in the State-funded portion of the Program.

As a result of preliminary analyses of the cable handling equipment and integrated control system requirements, it was necessary to gather significantly more precise information about bottom roughness in the Alenuihaha Channel. To do this, a unique precision acoustic measuring system was designed, built, tested and installed on the University of Hawaii's research vessel Moana Wave, and a survey cruise was successfully completed. Following analyses of the data gathered, it was determined that, to rigorously satisfy the Program's objective, sufficient information would be required to state conclusively that a technically feasible route across the Alenuihaha Channel exists. This would require an even more "fine-scaled" examination of the bottom, using equipment and personnel from Scripps Institution of Oceanography in State-funded Phase II-C.

FUTURE ACTIVITIES OF THE STATE-FUNDED SUB-PROGRAM, PHASE II-D

Phase II-D was made possible by an additional appropriation from the Hawaii State Legislature after the Department of Business and Economic Development concurred with the HDWC Program management that further research was necessary to conclude the program, particularly in defining an acceptable at-sea route. The one million dollar appropriation will fund the following Phase II-D tasks.

At-Sea Route Surveys

To demonstrate that at least one feasible route for a submarine electric transmission cable exists between the islands of Maui and Oahu, Seafloor Surveys International, Inc. will perform high resolution surveys using a new generation of SeaMARC technology to provide detailed coverage of areas of the submarine route not previously mapped.

Various studies of the shallow water marine geology surrounding the principal Hawaiian Islands, including those conducted for the HDWC Program, provide background information applicable to this survey. These studies suggest that most of the preferred route from Ahihi Bay, Maui to Waimanalo, Oahu will run along submerged terraces that were formed by low stands of the sea. In other areas of the state where these terraces have been studied, they have been found to have relatively smooth surfaces that are generally covered with sand-sized sediments. The areas where fossil reef material is still exposed have typically been found to contain gaps and passes in the reef, or portions of the reef surface which are sufficiently smooth that they would not constitute a barrier to a cable. The portion of the proposed route from Ahihi Bay to the western end of Molokai can be expected to have these fairly favorable characteristics.

The most serious potential obstacles along this route are the edges of the reefs where the cable must drop off into the deeper portions of Kaiwi (Molokai) Channel. The problem is similar to that identified by the surveys on the sides of the Alenuihaha Channel, although at least on the Kohala side of that channel the reefs are partly covered by sand. If the terraces and their associated reefs are not buried, they have the potential to drop nearly vertically for 300 to 400 meters. In other locations in the Hawaiian Islands where these features have been surveyed in detail, slopes as great as 30 to 40 degrees were found. Similar conditions must be anticipated in the Kaiwi Channel.

The Hawaii Undersea Research Laboratory (HURL), using the submersible Pisces V, will collect extensive photographic observations along the critical submarine sections of the cable route extending from Mahukona to Waimanalo. Detailed geological maps accompanied by photographs of the ocean floor will be produced to assist in confirming a feasible submarine cable route.

Near-bottom current measurements will continue to be collected through Phase II-D. The purpose of the near-bottom current measurement program is to obtain site specific current data at critical locations along the proposed cable route. This will allow characterization of the near-bottom flows that are essential elements in the predictive model for cable deployment and would also affect the cable in its as-deployed condition. Cable laying analysis shows that the touchdown location of the cable on the bottom is much more sensitive to near-bottom currents than other currents in the water column.

Materials Corrosion and Abrasion Testing

Testing of the armor wire component of the cable by the Hawaii Natural Energy Institute (HNEI) will continue, with corrosion and abrasion being tested under laboratory conditions using natural seawater. Earlier work concentrated on slurry abrasion, using crushed coral and basalt, with quartz sand as a reference abrasive. Materials tested included standard polymers and galvanized steel armor wire extracted from a cable sample provided by Pirelli. In Phase II-C and II-D, experiments are being conducted which more realistically approximate wear of the armor wire under natural conditions. Corrosion of a metal in seawater is typically rapid at first exposure and considerably less upon accumulation of corrosion products which serve to protect the surface from further corrosion. The submarine cable however, will be subjected to oscillating bottom currents which will move the cable, repeatedly abrading away the protective coating, thus continuously exposing fresh metal surfaces to corrosion. This could considerably reduce the cable's design life. At the end of Phase II-D, results will be compiled to describe the long-term survival of the submarine cable.

Economic Feasibility

In order to guide public and private decisions regarding commercial development of geothermal power and a submarine cable system, a report will be prepared by Decision Analysts Hawaii, Inc. to clearly address the economic feasibility of transmitting 500 MW of geothermal-generated electrical power from the Island of Hawaii to Oahu and Maui. This report will be prepared for presentation to legislators and other interested parties.

Public Information Program

HDWC Program management will continue to schedule and participate in informational events that reach the general public, such as the Pacific Business Expo and Energy Awareness Week. In addition, a brochure will be prepared to help keep the Hawaii Deep Water Cable Program in the public eye during the time between the end of the research work and the beginning of commercial development.

Also to be produced in Phase II-D is a report that discusses technology transfer activities and summarizes Program funding. This work, performed by KFC Airport Inc., is designed to assist in efforts to ensure continued federal funding for the HDWC

Program. It will include a brief review of all HDWC Program publications, both federal and state, and point out their specific technology transfer attributes. Past funding and future needs for the HDWC Program and geothermal resource development by the federal and state governments and the private sector will also be summarized.

FUTURE ACTIVITIES OF THE FEDERAL-FUNDED SUB-PROGRAM

The Federally-funded portion of the HDWC Program will continue for more than a year after the end of the State-funded portion. By the end of State-funded Phase II-D, the at-sea surveys and laboratory tests will be completed. Thereafter, the emphasis will be on preparing for the at-sea test, which is scheduled to take place in August, 1989. Preparation will include developing a navigation and control system, completing the cable handling system specifications and modifying the cable vessel to be used for the at-sea test.

CONCLUSIONS

The HDWC Program has produced a design for an electrical transmission cable for the most demanding submarine installation ever attempted. A segment was built to these specifications for electrical and mechanical testing in the laboratory. These tests will run for about a year, beginning in late 1987. Materials testing to confirm a 30-year operating life will be completed in early 1988. Following these tests, it will only remain to confirm the validity of the subsystem integration plans in the at-sea tests scheduled for 1989. By May of 1990, the HDWC Program expects to prove the technical feasibility of a commercial system.