HAWAII DEEP WATER CABLE PROGRAM

PHASE II-D

EXECUTIVE SUMMARY

partment 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 completion of all State-funded work. DOE-funded efforts will continue through completion of the At-Sea Test (AST).

At the time of this writing, interest in the HDWC Program was being spurred by two other major demonstrations of support. Hawaiian Electric Company, Inc. (HECO) had released to the private sector a request for proposal (RFP) to develop up to 500 MW of geothermal power on the Big Island and deliver it into HECO's Oahu grid. In support of this move to commercialize development, DBED requested proposals to prepare a geothermal master development plan, transmission line routing study and environmental impact statement (EIS). Consultant selection was underway.

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.

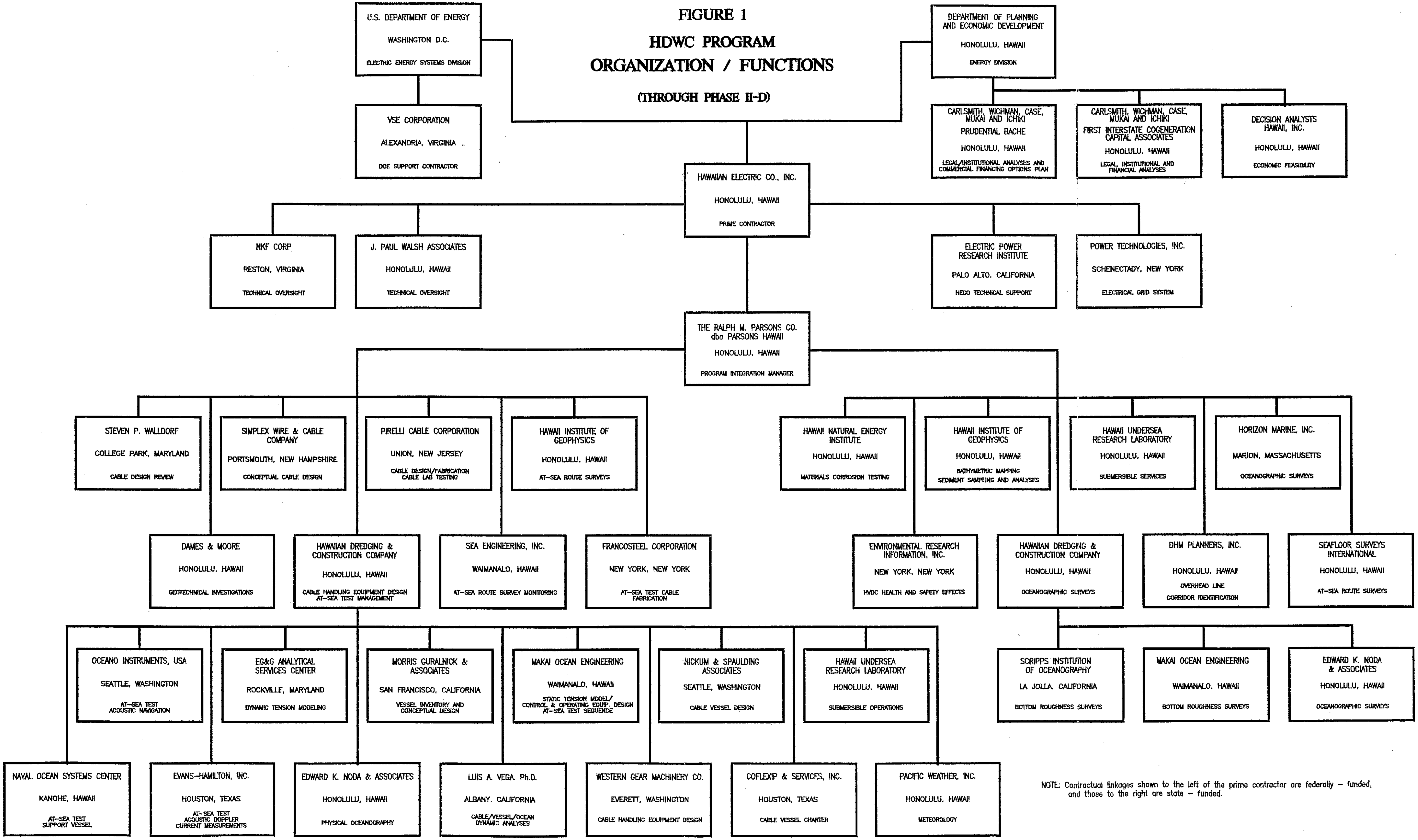
Program Phasing

The HDWC Program consists of three phases: Phase I - Preliminary Program Definition, Phase II - Final Program Definition and Cable, Cable Vessel and Cable Handling Equipment Design/Verification and Phase III - At-Sea Testing. 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. DOE funding began in Phase II which ran from 1982 into 1988. Most of the State-funded work took place in Phase II, with successive increments being termed Phases II-A through II-D, respectively. Phase III, funded solely by DOE, includes those tasks leading to and culminating in the At-Sea Test, and is scheduled to be complete in early 1990.

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, HECO is the prime contractor. The Ralph M. Parsons Company through its Honolulu

FIGURE 1
HDWC PROGRAM
ORGANIZATION / FUNCTIONS
(THROUGH PHASE II-D)



NOTE: Contractual linkages shown to the left of the prime contractor are federally – funded, and those to the right are state – funded.

office (Parsons Hawaii), is the Program Integration Manager with subcontract management and technical support responsibilities throughout the Program. Cable design, fabrication and laboratory testing was completed by Pirelli Cable Corporation. Hawaiian Dredging & Construction Co. is the lead for planning and executing the At-Sea Test. 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.

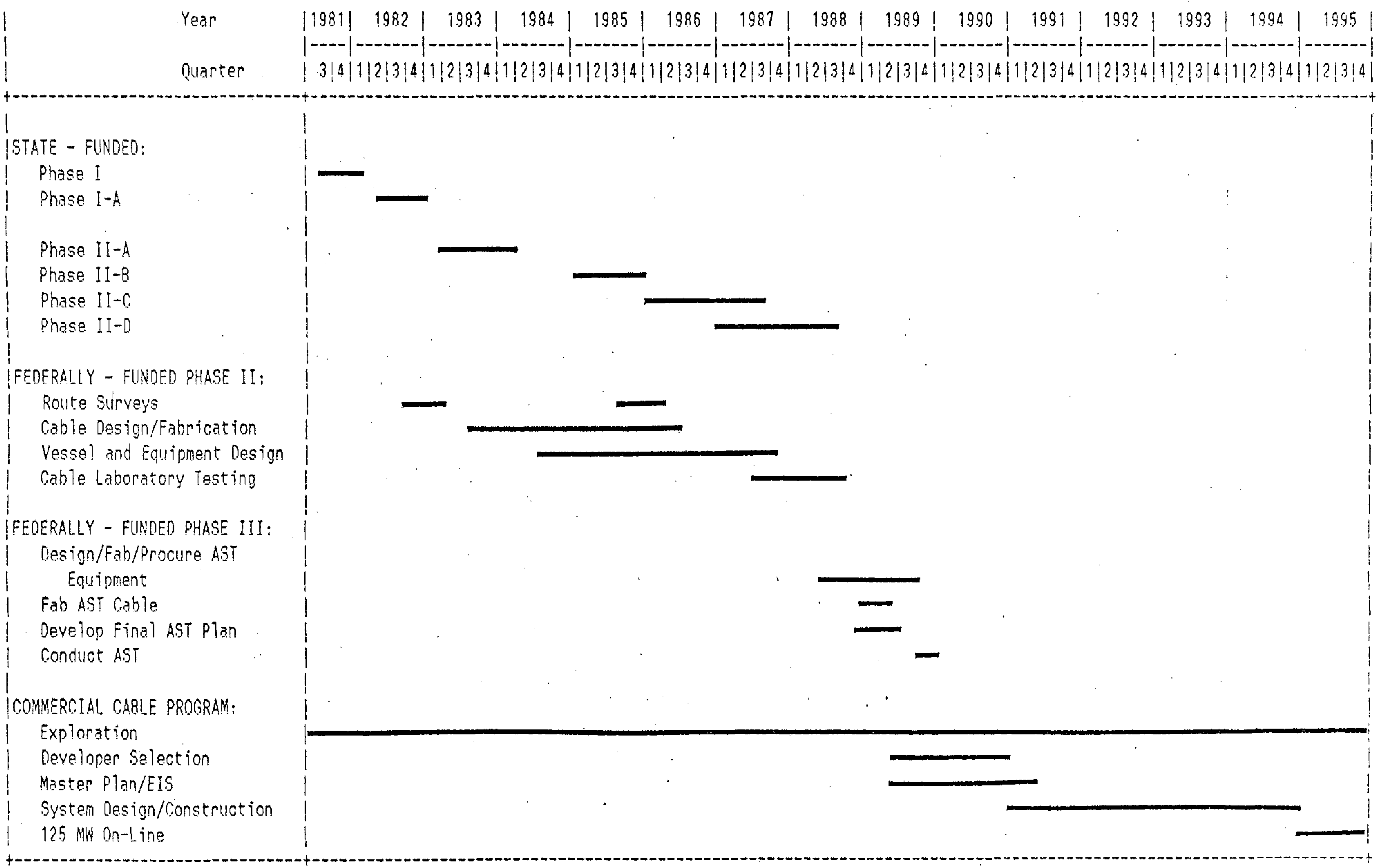
Program Schedule

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 were completed in August, 1988. At-sea testing and preparation of the HDWCP final report for the entire Federal program are scheduled to be completed in 1990.

State and Federal Focal Areas

Although the HDWC Program is being funded cooperatively by the State and Federal governments, each sponsor has its own interests. Generally, the Federally-funded portion of the Program has investigated generic aspects of the technologies involved in manufacture, testing and deployment of submarine

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



cables, while the State-funded portion of the Program has considered 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 studied included materials characteristics (type, composition and weight) and dimensions (diameter, area and thickness) of cable conductors, insulations, sheaths and armors.

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 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 prepared and widely distributed to public and private organizations. A narrated, 35 mm slide program was also prepared and used in presentations 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-D.

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 Test. Implementation of a commercial interisland cable system, however, could have significant environmental impacts including short-term impacts during construction of the system, long-term impacts in visual quality along some portions of the overland route and long-term positive impacts in the area of socioeconomics. Both State and Federal Environmental Impact Statements (EISs) as well as an extensive array of permits, may be required prior to implementation of a commercial cable system.

In Phase II-C, an environmental assessment for the commercial cable system was prepared. Both submarine and overhead route segments (Figure 3), 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.

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 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 accelerate corrosion of cable components, but no such areas were located. Second, an assessment was completed of the acceptablility of using a sea return rather than a metallic return for unbalanced electrical current flow. Significant technical and economic advantages to using a sea return were described as were the potential environmental impacts, including a potential shock hazard at the electrode and accelerated corrosion of nearby metallic objects. Third, the potential visual impacts of the 300 kVdc overhead transmission lines which would cross portions of Hawaii, Maui and Oahu were investigated.

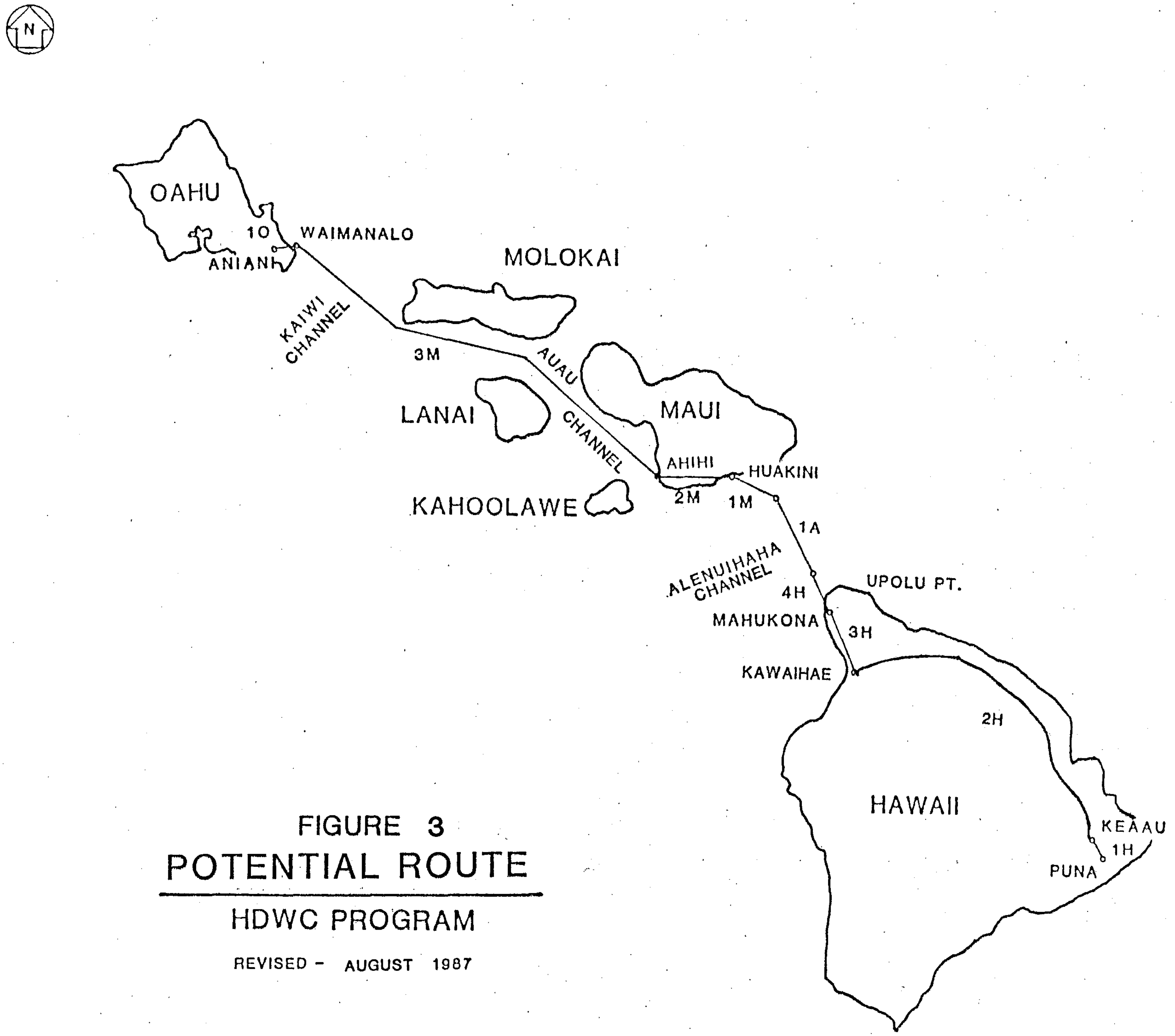


FIGURE 3

POTENTIAL ROUTE

HDWC PROGRAM

REVISED - AUGUST 1987

In Phase II-D, two additional topics having environmental implications were researched. The first of these studies was a determination of whether or not underground lines represent an economically feasible alternative to overhead lines in portions of a route where the impacts may be unacceptable, such as through residential neighborhoods. The report discusses underground cable requirements, cable system types and reliability considerations, and describes a proposed underground cable system. A comparative analysis of overhead line and underground cable hardware, land acquisition and installation costs is included. Results indicate that underground cables could meet the requirements of the land portions of a commercial intertie, but would be approximately six times more expensive than overhead lines.

The second report discusses sea electrode siting considerations. Approximately two and one half acres of land would be needed for each electrode site - one each on Hawaii, Maui and Oahu. The cost of the three electrode system is projected to be between three and five million dollars.

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.

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, will 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.

An equipment specification document detailing the requirements for the land-based portions of the system was completed. 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 commercial bidders and the studies which will be required as a condition of the bid process.

All grid system integration studies were completed in Phase II-C. No new information in this area was generated in Phase II-D.

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; and
(4) abrasiveness of Hawaiian rocks to various potential cable armor steels.

This work, by the Hawaii Natural Energy Institute (HNEI), continued through Phases II-B, II-C and II-D at the University of Hawaii at Manoa and on the Big Island at the Keahole Point, Natural Energy Laboratory of Hawaii (NELH). Long-term corrosion testing of potential cable materials, including twelve different metals and metal alloys, utilized the unique capability of the NELH to supply seawater from both shallow (300 feet) and deep (2000 feet) intakes to simulate actual conditions of environmental exposure. Samples were exposed to flowing seawater in darkened troughs for various lengths of time. Weight loss and depth of pitting were 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 hardnesses. 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 efforts under Phases II-C and II-D. In particular, survival of the armor wire material under accelerated, simulated service conditions was studied. 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 reduce the cable's service life. This possibility was investigated by abrading a sample of the design cable against lava samples collected from the shore and pillow basalt rocks dredged from a steep escarpment in the Alenuihaha Channel. The cable sample was oscillated over the abrasive surface while emersed in seawater. Damage to the cable from combining the various damage mechanisms over a worst case 30-year span totaled 5 mm of wear, 2 mm general corrosion and 2.3 mm corrosion-erosion, for a total of 9.3 mm of material loss (excluding the polypropylene serving and the bitumen bedding which was assumed to provide insignificant protection against abrasion). The radial distance from the outer wire diameter to the outer lead sheath diameter is 14.6 mm, providing a safety factor of 5.3 mm, equivalent to 17 years of service life under worst case conditions.

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 from the R/V Melville with the Scripps Institution of Oceanography's "Deep Tow" system. This system employs 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 subsequently provided essential guidance in selection/design of the integrated vessel operations and cable laying control system for the At-Sea Test.

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., in Phase II-D, performed high resolution surveys using a new generation of SeaMARC technology to provide detailed coverage of areas of the submarine route not previously mapped. The results indicate that the preferred route from Ahihi Bay, Maui to the western end of Molokai will run along submerged terraces that were formed by low stands of the sea. These terraces have relatively smooth surfaces that are generally covered with sand-sized sediments. Where fossil reef material is exposed, there are 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 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. Nevertheless, an acceptable route was found across this channel and on to Oahu.

In Phase II-D, the Hawaii Undersea Research Laboratory (HURL), using the submersible Pisces V, collected extensive photographic observations along the most critical submarine sections of the cable route. Five dives were made on the Kohala Slope and four dives were made on the Maui Slope. Detailed geological maps accompanied by photographs of the ocean floor were produced to assist in confirming a feasible submarine cable route. Comparisons of the SeaMARC II sidescan data with visual observations of the critical route segments indicated that the previously identified path is acceptable, and somewhat better than previously thought in that the winding passage up the Maui Slope is wider and has more sediment cover than was indicated by sidescan alone.

Near-bottom current measurements were collected through Phase II-D. The purpose of the near-bottom current measurement program was to obtain site specific current data at critical locations along the proposed cable route. This allowed 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.

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 provide a basis for future investigations.

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."

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.

In Phase II-D, a colorful two by three foot poster was produced to illustrate the potential land and sea route that a commercial cable system may take. This route reflects preliminary corridor analysis performed during the HDWC Program. The poster and slides of the map are available for use in future informational meetings.

Economic Feasibility

In order to guide public and private decisions regarding commercial development of geothermal power and an interisland transmission system, Decision Analysts Hawaii, Inc. evaluated the economic feasibility of transmitting 500 MW of geothermal-generated electrical power from the Island of Hawaii to Oahu. The development cost for the complete system (geothermal wells, injection wells, steam gathering and disposal systems, generating plants, overhead transmission lines, submarine cables, AC/DC converter stations, etc.) was estimated to be nearly $1.7 billion (1986 dollars), about one quarter of which was attributable to the submarine cable portion of the system. Economic feasibility was confirmed by results of several analyses. The present discounted value of the cash flow to investors is $550.7 million. The rate of return on equity is 23.8 percent. The payback period is 15 years.

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.

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, in Phase II-C, a series of expert briefings were held on Oahu, Maui and Hawaii. In addition, 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.

In Phase II-D, HDWC Program management continued to schedule and participate in informational events that reached the general public. Also, a summary of technology transfer activities and Program funding was prepared to assist in efforts to ensure continued federal funding through completion of the HDWC Program.

All reports produced in the HDWC Program, State-funded and Federally-funded, were annotated and organized in a computer database similar to the existing DBED data base for geothermal reports. The same computer software, dBase III Plus, was used for the cable program bibliography as was used for the geothermal work. The bibliography lists documents chronologically within ten subject areas.

The "Basic Design Criteria Data Book," a comprehensive reference document first produced in April 1985, was updated in Phase II-D to include important technical information regarding each of the HDWC Program subsystems. Designed more for "in-house" use by Program participants, it provides technical engineering data for those so interested.

Friction Test Specimen

In order to improve the theoretical basis for modeling internal stresses of self-contained oil-filled power cables, in Phase II-D, a friction test specimen was developed by the University of Hawaii Department of Mechanical Engineering. This specimen and its associated instrumentation is being used to validate computer models developed with other funding sources. Work under Phase II-D focused on the effects of cable laying on component stresses at the overboarding sheave where maximum tensile and bending actions occur. Improved modeling accuracy is expected to result in improved design methodology.

ACCOMPLISHMENTS OF THE FEDERALLY-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

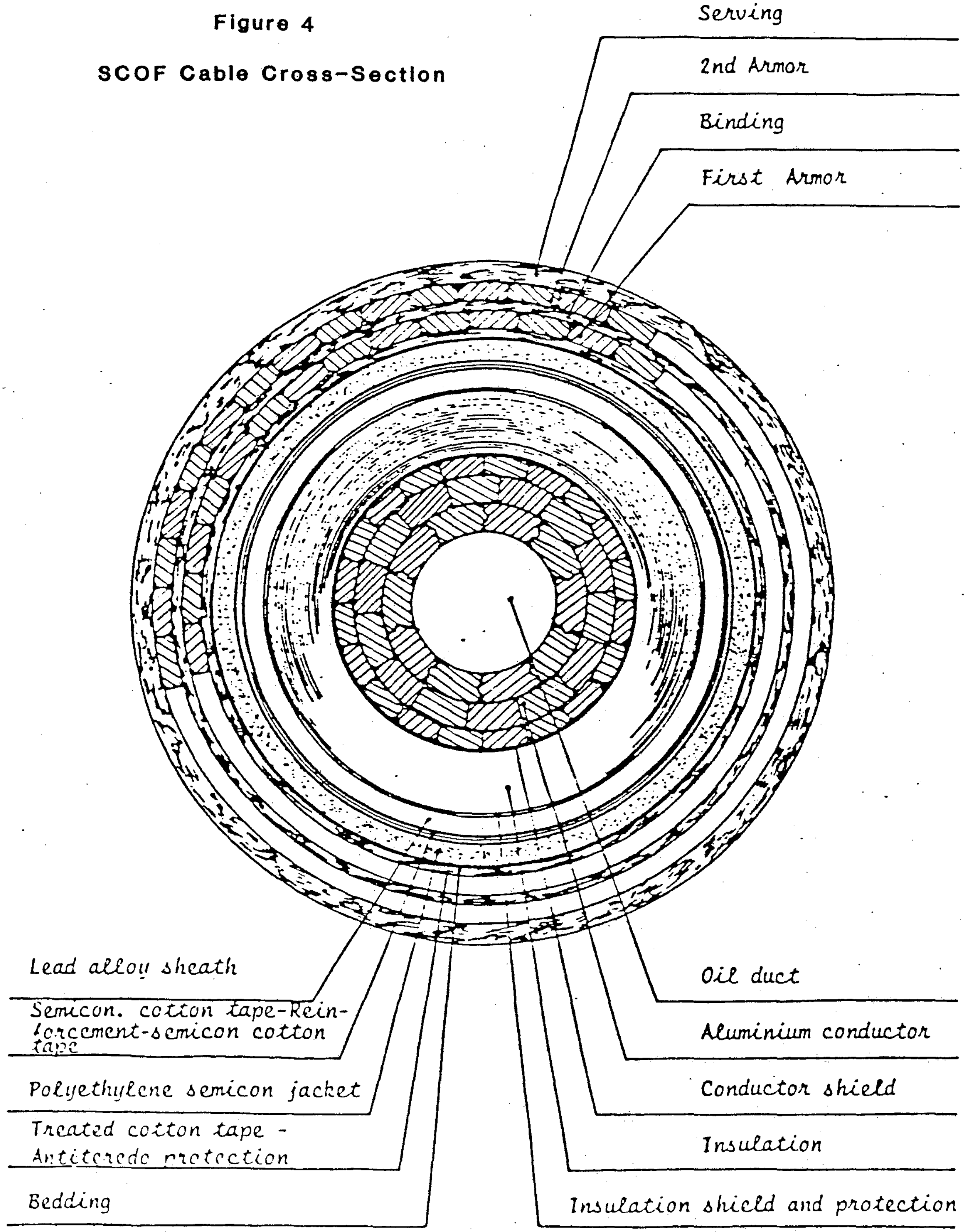
Supplementing the prototype cable design information developed in Phase I, a comprehensive cable design parametric study was completed. Over 25,000 separate calculations were made, varying some sixteen external and internal cable parameters. The results indicated that more than 251 cable designs met 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.

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. Hawaii Deep Water Cable Program, Phase II: Cable Construction Specification. 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, Bipolar	500 MW
Transmission Load Per Cable	250 MW
Rated Current Per Cable	833 amps
Conductor Material	Aluminum
Conductor Type	Hollow Core Segmental Strip (Keystone)
Design Electrical Stress	35 kV/mm (cold and hot)
Oil Duct Diameter	25 mm (0.98 in)
Oil Type	High density synthetic low viscosity
Number of Cables for System	2 plus one spare
BIL	775 kV
SIL	580 kV*
Polarity Reversal	Allowed
Conductor Diameter	51.9 mm (2.043 in)
Insulation Thickness	10.9 mm (0.429 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)
Conductor Resistance	0.0179 ohm/km
Losses at Rated Current Per Cable	12.4 kW/km
Actual Maximum Cold Screen Stress	32.1 kV/mm
Actual Maximum Hot Screen Stress	30.6 kV/mm
Ratio Between Actual & Design Stress	0.92
Electrical Design Safety Factor	3.27
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 (86.8t)
Corresponding Maximum Water Depth-Based on PCC Formula	2,626 m (8,615.5 ft)
Minimum Allowable Bending Diameter During Installation:	
a-Without Tension	7.0 m (22.97 ft)
b-With 7,000 Ft Pulling Tension	11.6 m (38.06 ft)
c-With Maximum Allowable Pulling Tension	12.0 m (39.37 ft)
Mechanical Design Safety Factor	3.02
Initial Maximum Allowable Squeeze Per Unit Length	3.00 mT/m
Total Cable Unit Cost of Which:	306 $/m
a-Material Cost	49 $/m
b-Incremental Manufacturing Costs	247 $/m
Unit Capital Transmission Cost Per Cable	1,224 $/MW km

* Assumed value.

Subsequently, 6,000 foot length of cable was fabricated to the specifications previously produced, and a laboratory testing protocol was developed. Laboratory testing equipment was designed and fabricated and cable tests completed. Testing included rigorous verification of all mechanical and electrical characteristics essential to ensure survival of the cable in deployment and operation over its 30-year design life. Because of the unusual and extreme environmental conditions to which the cable will be subjected, standard industry tests were supplemented with specially designed tests simulating (in the appropriate sequences) the strains the cable would be exposed to over its design life. In all tests, the cable performed admirably, and a minimum design life of 30 years was verified.

Cable Vessel and Cable Handling Equipment

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

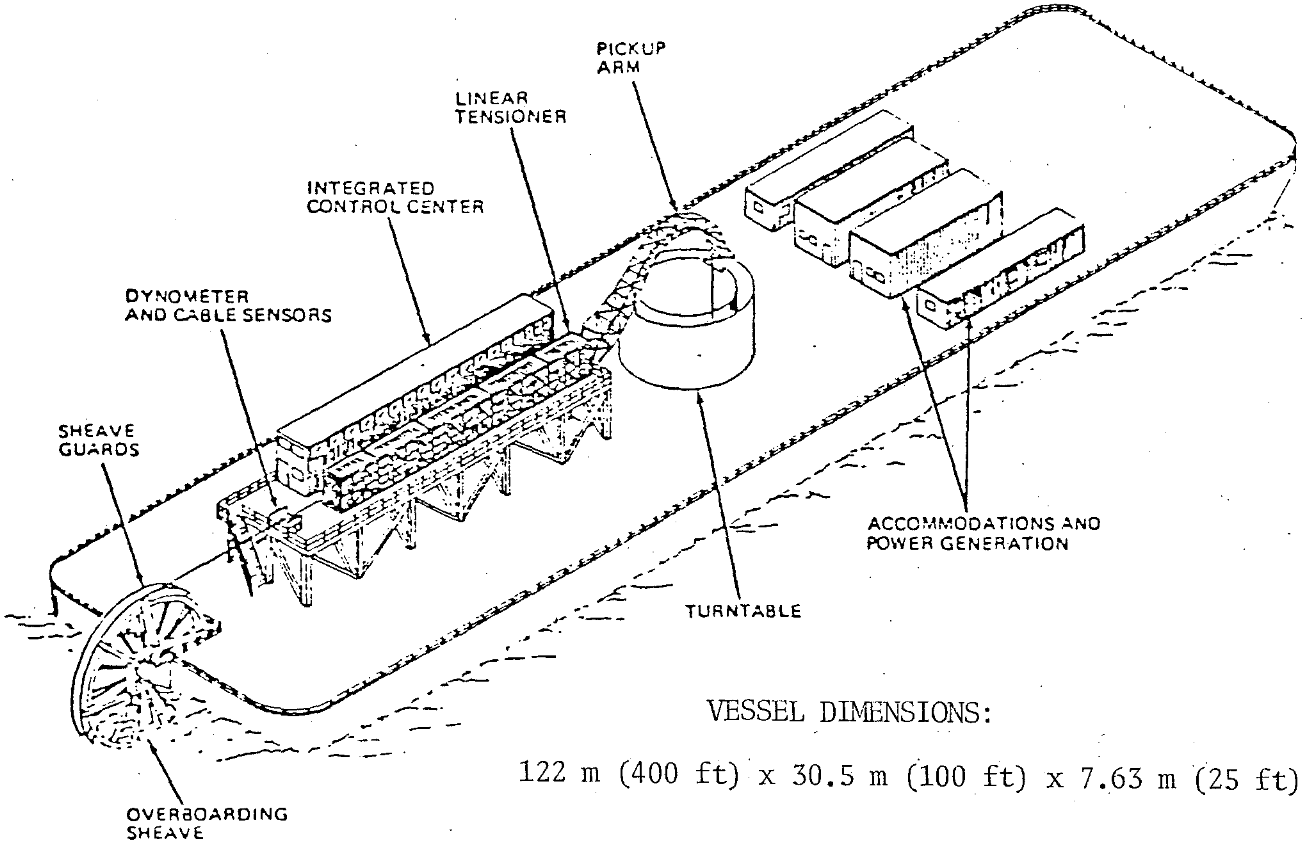
While design of the subsystems proceeded, detailed bathymetric mapping of the Alenuihaha Channel as well as deep water sediment sampling and bottom photography were performed. The data indicated that bottom conditions in the channel vary from ideal (i.e., flat, sandy bottoms) to hazardous (i.e., steep 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.

Figure 5

Conceptual Drawing of the Major Cable Handling

Machinery for the HDWC Program



VESSEL DIMENSIONS:

122 m (400 ft) x 30.5 m (100 ft) x 7.63 m (25 ft)

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

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

Subsequently, in Phase II-C, an even more "fine-scaled" examination of the bottom was completed, using equipment and personnel from Scripps Institution of Oceanography.

At-Sea Testing

Because of funding uncertainties, the federally-funded sub-program was, in 1987, divided into Phases II and III, the latter consisting of activities culminating in execution of the At-Sea Test (AST). Because an AST using the design cable would require design and fabrication (or at the very least, extensive modification) of a deployment vessel and handling equipment, a "reduced-scale" AST was designed which would satisfy all technical objectives for the test, but be much less expensive. DOE, in 1988, exercised its option to fund this test, and planning began in earnest. The concept employs a wire rope "surrogate cable" smaller, lighter and much less expensive than the designed SCOF cable. Key physical characteristics of the surrogate cable, such as the weight to diameter ratio, however, were designed to match those of the full-scale cable to accurately simulate the expected difficulties in positioning and tensioning the cable on the seafloor. Use of this surrogate cable allows use of an existing cable vessel and existing handling equipment. The principle challenge to the AST is now how to integrate (and simultaneously control) vessel propulsion and navigation with cable deployment operations. To do this, a sophisticated system of computers and custom designed software programs have been designed to receive input data on vessel position, speed and heading; cable payout rate, bottom position and residual tension; and ocean currents through the water column and, after comparison with the previously mapped cable path on the seafloor, output directions to both the helmsman and the cable handling equipment operator.

The complexity of the data gathering and support necessary for the AST will require a minimum of three surface vessels and a submersible. The test is scheduled for the fourth quarter of 1989, and all final reports will be prepared by early 1990.

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 and successfully underwent electrical and mechanical testing in the laboratory. Materials testing to confirm a 30-year operating life have been completed. It remains to confirm the validity of the subsystem integration plans in the At-Sea Test scheduled for 1989. By September of 1990, the HDWC Program expects to complete proof of the technical feasibility of a commercial system.