Application for Financial Assistance

Superconductivity Partnership Initiative

Solicitation Number DE-PS36-01GO90000

Supplemental Announcement 05

Volume I: Technical and Business Plan

"Demonstration of a Pre-Commercial Long-Length HTS Cable System Operating in the Power Transmission Network"

Submitted by:

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15 May 2001

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in Response to

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"Demonstration of a Pre-Commercial Long-Length HTS Cable System Operating in the Power Transmission Network"

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Abstract

The objective of this program is to *demonstrate a 3-phase 2500 ft long cable system based on high temperature superconductor material designed to meet the most compelling technical and economic application; retrofitting 138 kV transmission cables installed in an existing 8 in. pipe infrastructure to increase power density by at least three times and eliminating dielectric oils.* The cable will be tested at a specially prepared site operating at 69 kV and having a peak power loading of 77 MVA (650 A rms). Additionally, *methods for installation, maintenance, and repair of such a HTS system from a user's point of view will be developed and implemented in the field.* These objectives represent the logical last steps for the commercialization of HTS power cables, following the successful manufacture of a 3-phase, 400 ft cable system to operate at 24 kV and 2400 A rms.

The work described in this proposal will be realized by a unique partnership between the country's leading cable supplier and most experienced HTS cable manufacturer (PCS); a progressive utility recognized for their strong leadership in new cable system and transmission technologies (LIPA); the utility industry's research corporation (EPRI); the world's leading manufacturer of high performance long HTS tapes (AMSC); and worldwide experts in cryogenic refrigeration and technology (AL / CT).

During the proposed program, PCS will integrate HTS wire supplied by AMSC into a 3-phase cable assembly. PCS also will supply cable terminations and joints which, together with the refrigeration system supplied by AL / CT, are necessary to complete the system installation. The HTS system will be installed into LIPA's transmission network at a site provided and maintained by LIPA. PCS, EPRI, and LIPA will develop a test program and evaluate the long term performance of the system in operation.

Power transmission applications of HTS technology can most rapidly progress to the marketplace due to the benefits offered to utilities, consumers, and the environment by means of more efficient use of energy and existing infrastructure. DOE co-funding of .is program will advance market introduction and bring the benefits of the new technology by at least three years.

Selecting an application site which is part of the Transmission (≥69 kV) network is key to realizing HTS cables greatest advantages. Using HTS cables both for bulk power transmission centers can enable utilities to avoid the use of extra-high voltage systems (greater than 138 kV) without requiring multiple underground cable circuits, which in many cases is prohibited due to corridor congestion. The high capacity of HTS power cables can also be used to replace overhead lines with a single cable circuit in environmentally or aesthetically sensitive areas. Due to the amount of power to be carried by HTS cables operating in the transmission networks, a thorough understanding of the system performance characteristics and reliability is crucial for their broad use. *This demonstration will provide both advanced cable behavior models to be used in network modeling analyses and practical operating experience of a long length cable circuit in the transmission network.*

Transmission capacity and rights-of-way is already or soon will be overloaded and at a premium. Thus, the American utility industry clearly needs new technologies that deliver electricity with reduced costs, higher efficiency, and greater power levels. In addition, the digital economy demands improved power quality and stability, particularly at peak loads and in adverse environmental conditions. HTS cable technology can meet these requirements, while operating in socially and environmentally responsible ways.

I. APPLICATION ASSESSMENT

Introduction

Although the current and well-publicized "energy crisis" in California was precipitated by faulty deregulation policy rather than a breakdown in electricity infrastructure technology, the event has nonetheless highlighted potential deficiencies in the power delivery system that will certainly emerge as new regional power generation capacity becomes available over the next several years. There are strong indications the "California experience" will spread throughout the nation, particularly to the analogously heavily load-congested, generation-deficient Northeastern states.

Coupled to the need to expand power generation and delivery is the necessity to minimize societal and environmental impact to the highest degree possible. In pursuit of this goal, much of the new generation will be constructed on or close to existing power plant sites. In the same spirit, as these plants are brought on-line, ways will be sought to deliver this new electric power through existing transmission and distribution corridors, rather than attempting to obtain new rights of way with all the attendant policy and political hurdles to overcome. However, if we are to improve the capacity of these present corridors to meet future supply and demand without major public disruption, new technology will be required. Superconducting cables are that new technology.

The "obligation to serve" is the cornerstone of America's electric utilities. It is the guiding principle upon which they were founded, be they public or investor-owned, regulated or independent. Adherence to this admirable cause has historically made them naturally cautious to accept new technology without extensive evaluation and testing. Superconducting cables have not been exempt from this deliberative approach. We are now almost ten years down the road.

The industry began the journey with DOE's program in the early 1990s with EPRI and Pirelli to build and test a "warm dielectric" 50-meter prototype, as well as design a "cold dielectric" modification for future application. These efforts were followed by DOE Superconductivity Partnership Initiatives on-site demonstration projects employing superconducting cables placed in actual operation at the Frisbee Substation in Detroit, Michigan, operated by the Detroit-Edison utility company, and at Southwire Corporation's manufacturing plant in Carrolton, Georgia. These projects will complete next year and there is every reason to anticipate their success. However valuable the results obtained will be, and they will indeed be vital to future cable development, it must be noted that both efforts are occurring at tightly-controlled sites, not typically of the majority of expected future cable applications which will be in publicly exposed rights of way.

It is thus now appropriate to consider the next step on the path to utility industry deployment of superconducting cable technology…"taking it to the streets." It is just this step that Pirelli, Long Island Power Authority (LIPA), American Superconductor (AMSC), Air Liquide / Cryo Technologies, and Electric Power Research Institute will now propose to Department of Energy for its consideration as a Phase III project for the next round of its Superconducting Partnership Initiative program.

The project's utility partner, LIPA, has entered this demonstration with goals to be prepared to deploy HTS cable systems broadly throughout their network to alleviate challenges emerging due to continued load growth in areas already boasting load densities of up to 3.73 MW per square mile. LIPA projections indicate that their Eastern Suffolk region will experience 62% load growth (from 357 MW to 579 MW) over a 20 year period! Overall, they anticipate over 27% load growth for their service territory. HTS power cables offer the possibility to help meet such significant growth in a manner which results in the minimum aesthetic and civil impact. Meeting the growth in demand requires not only improved power delivery options, but also there will be significant load injection increases to the LIPA service territory. To prepare for projects already pending on the Independent System Operator's (ISO) queue, LIPA has begun to evaluate several planning alternatives, which includes the development of a 345 kV transmission system. Due to permitting restrictions for overhead transmission lines, they expect that this entire system will be composed of underground cables, and necessitate the construction of 345 kV/138 kV step down stations to connect with their 138 kV transmission network. The vailability of HTS cables capable of transmitting large amounts of power at 138 kV could greatly simplify the system design by avoiding new 345 kV substations and the associated equipment.

The current proposal, which was formulated after discussion of applications with a number of large utilities, meets the criteria for demonstrating a pre-commercial HTS cable system. This proposal pushes at the two most critical fronts in achieving market penetration. First, the application selected, that is a commercial length Cold Dielectric Coaxial cable design operating in the transmission network, will provide broad operational and economic benefits by enabling bulk power transmission through congested rights of way and suburban corridors. Moreover, it will be the first transmission voltage flexible coaxial cable specifically designed for pipe-type retrofit to be installed in the United States. Secondly, the proposal calls for the demonstration of an innovative refrigeration technology which promises to reduce initial capital costs, providing implicit standardization and minimizing system maintenance requirements.

The following pages will show how the proposed application was selected to be the *best* application to accelerate commercialization of the HTS technology after a thoroughly researched study, modeling, and analysis of utility needs, growth, market, and critical cost issues. From past experience in Phase I and Phase II SPI sponsored demonstration projects, a complete plan has been created and explained which will effectively address both the technical challenges of the program as well as demonstrating to the utility partner and to the industry as a whole the reliability of commercial length HTS cable systems while gaining valuable experience in maintenance, installation requirements, and infrastructure support of such systems. The Team has been chosen to provide the program with the most advanced materials and manufacturing experience coupled with proven innovation skills. The commitment of this Team to commercialization of HTS cable systems is demonstrated by their current substantial cost share offers as well as their ears of development investment in HTS technology.

2. Background

HTS power cables provide advantages to utility planning and infrastructure utilization through their significantly higher power density (capacity / size) than that obtainable using conventional technology. Traditionally, utility network designers have relied on a voltage-based operation philosophy, where increases in power transfer were accomplished by increasing voltage. However, the infrastructure required for extra-high voltage systems necessitates large capital investment. Also, high and extra-high voltage systems require more area to site due to the high electrical field. In heavily populated areas, gaining approval to site a high or extra-high voltage substation and lines is getting more difficult and can be impossible.

Steady growth in power consumption and the growing opposition to new high voltage projects demands technological solutions to meet consumer needs. HTS power cables offer the opportunity to transmit more electrical power at the same (or reduced) voltage in a compact cable construction. Definite benefits can be realized using this technology where the application requires very high power capacity and/or where there is pre-existing cable containment (i.e., pipes or ducts). Constrained by limits of an aging power delivery system and a growing load demand utility engineers need new tools to ensure efficient and reliable delivery of electric power. The capabilities offered by HTS cables provides network designers with new flexibility when approaching system architecture, spawning significant interest from the utility community in the field experience with HTS cable systems.

PROJECT HISTORY: In response to the growing need for advanced power delivery options, Pirelli Cables and Systems (PCS) and the Electric Power Research Institute (EPRI) began a collaboration between 1991-1994 to examine the potential designs for an upgrade of a 115 kV pipe-type cable system from a nominal rating of 200 MVA to 400 MVA. Based on the stated performance criteria, Warm Dielectric (WD) cable using oil-impregnated Polypropylene Laminated Paper insulation was selected.

In 1995, a research contract from the U.S. Department of Energy was awarded to PCS and EPRI to manufacture and test a laboratory prototype of the design reached in the 1991 study. This project resulted in a then world-record 50 m long HTS conductor assembly which carried 3300 A dc at 1μV/cm at 77 K, self-field. This conductor assembly was successfully integrated into a compact cable, including thermal and electrical insulation systems. This project was completed in early 1999 with a high voltage testing of a complete prototype system (including cable, terminations, joint, and refrigeration system) according to a program based on AEIC CS2-97 testing standard and procedure and demonstrating continuous operation at 2000 A rms.

A second project is currently ongoing where the warm dielectric cable concept is being applied to a distribution retrofit application. This project includes the supply of a complete 24 kV / 100 MVA warm dielectric cable system which will be installed by retrofitting existing 4 in. diameter ducts and operated in a Detroit Edison utility substation. The experience gained from this technological demonstration is crucial to proving the technical suitability of HTS cables in the network. The 400 ft cable system has been designed to operate independent of manual control and to withstand foreseeable network transients, such as fault current and lightning strikes. The cable and refrigeration system manufacturing activities have been completed and the equipment delivered to the project site. Installation of the system will be conducted during the summer of 2001. This project demonstrates a high capacity superconducting cable (2400 Arms through a single circuit of cables) and operation "in the field" on the utility power network. *A single circuit of HTS cables using less than 250 lbs of high performance BSCCO-2223 tape will replace three existing copper circuits which used almost 18,000 lbs of copper*. This demonstration maintains many developmental aspects, particularly the circuit length of only 400 ft. For the objectives of the Detroit demonstration, the circuit length fit the status of technology at the time of project initiation. The short length reduced the technical risk and program cost while retaining the challenges of installation and operation in the utility system, providing valuable insight into the requirements of installing a superconducting cable into a utility substation and integrating the control and monitoring of its performance with the utility SCADA system.

PROJECT PROPOSAL: The project described in this proposal has been designed to encompass elements identified as requirements for commercial entry of HTS cable systems into the market. The project embodies characteristics described as both "Phase II" and "Phase III" in the solicitation. The application and system design were selected to demonstrate simultaneously a cable construction with great technical and commercial promise and to prove the performance and reliability of HTS cables which are of lengths needed for commercial application.

Technological advancement in cable and component development has continued with great success in the past 10 years; yet no cable system demonstrations have attempted to achieve commercially interesting application lengths. The performance of long length HTS cables will continue to remain a lingering doubt for utility engineers in the absence of this experience. The proposed demonstration leveraged the perspective of the utility partner to identify a project length which will satisfy their technological questions, and maintain a reasonable project cost. The compromise achieved will *demonstrate a 2500 ft transmission cable* segment designed to be suitable for cooling lengths of up to 2.5 miles.

This program will also generate more reliability and operational experience, helping to develop confidence of system designers in the technology (another crucial impediment to commercialization). Only by incorporating HTS cables into live power delivery networks under utility operation will it be possible to evaluate the compatibility with existing system components, operational techniques, maintenance, and total system costs and benefits. Figure 1 describes the progress of HTS cable system development toward commercial deployment.

	Technical Feasibility										Operational Feasibility					Design Qualifications		
	HTS Tape Performance	Cable Conductors Fabrication	High Current Conductor Assembly	Low ac Loss Conductors	Factory Applied Cryostat / Dielectric	Accessories Design and Installation	Cooling of Cable System	Closed Cycle Refrigeration	Low Cost Refrigeration System	Long Length Cable Systems	System Reliability	Network Compatibility	Repair and Maintenance	Operational Stability	Long Term Reliability	WD – Transmission Pipe Retrofit	WD – Distribution Duct Retrofit	CDC – Transmission Pipe Retrofit
SPI Phase I	● (green)	● (green)	● (green)		● (green)	● (green)	● (green)									● (green)		
SPI Phase II	● (green)	● (green)	● (green)	● (green)	● (green)	● (green)	● (green)	● (green)			● (green)	● (green)		● (green)	● (green)		● (green)	
SPI Phase III	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)	● (red)			● (red)

FIGURE 1. Progress of HTS Cable Technology toward Commercialization

For the proposed program, the Project Team of PCS, EPRI, American Superconductor Corporation (AMSC), and Air Liquide/Cryo Technologies (AL / CT) will collaborate with a customer, Long Island Power Authority (LIPA), to install and operate the HTS cable system on the transmission network. LIPA utilizes the services of KeySpan Energy Services Co. to manage their T&D system through its Management Services Contract. The objectives of the proposed demonstration project are:

- Demonstrate the retrofit design of a cold dielectric cable system, suitable to be manufactured and installed for cooling lengths up to 2.5 miles retrofitting existing 138 kV HPFF cables installed in standard 8.0 IPS pipes.
- Prove the reliability of long length HTS cable systems.
- Verify the operation and performance of cold dielectric HTS cable systems in the transmission network. Apply actual system results to develop advanced network modeling representations for HTS cables.
- Perform maintenance and repairs on simulated system failures in the field, and develop practical procedures for management of HTS cables.

PCS, LIPA, and EPRI will continuously evaluate performance, operational issues, and economic benefits over a two year period to complete the project.

Figure 2 is a flow diagram of the program objectives and responsibilities of the Team.

The project Team expects to engage the resources and skills of the DOE's National Laboratory Superconductivity Technology Centers as appropriate throughout the course of the demonstration.

3. Energy Benefits and Technical Performance

Superconductors have the unique capability to conduct direct electrical current without generating electric losses when cooled below their critical temperature. Electrical loss has a two-fold impact on the system. First, it consumes energy and converts it to unrecoverable heat, and second, the heat generated (or more accurately the consequent temperature rise) forms the fundamental basis for the operational rating for power transmission equipment. Power transmission using superconducting materials can partially eliminate this inefficiency and create devices that are more compact and powerful. HTS power cables can transmit over three times .ie amount of current than a traditional cable of the same size.

With their high ampacity, HTS cables can match the power delivery abilities of an overhead circuit, providing a potential solution) environmental considerations and popular opposition to overhead electrical transmission projects represents. One-to-one relocation of overhead lines can require more than three conventional circuits. Buried HTS cables would not cause environmental interference, either aesthetic or physical. Further, the lack of thermal heat generation causes no de-rating of adjacent conventional cable circuits. The right-of-way for cables is also greatly reduced compared to overhead lines. This can be significant where obtaining property rights for the power line corridor faces strong objection. HTS cables can also be designed, adopting the Cold Dielectric Coaxial (CDC) configuration, to virtually eliminate magnetic fields outside the cable diameter.

Upgrading transmission (≥ 69 kV) facilities could provide the greatest overall impact and benefit from HTS power cable systems. Transmission networks are the brute laborer of the electrical power delivery world. A single circuit transports power from remote generating facilities and regional interconnections to be delivered along multiple distribution paths to tens or hundreds of thousands of people.

Typically, application development for HTS cables has originated with a need which could not be met either technically or economically with conventional alternatives. In the past six years, PCS has participated in three of these studies with U.S. utilities and one study with a local transportation authority. Starting with a requirement, cable analyses were prepared to identify the optimal design to meet the application criteria. These studies located HTS circuits within the constraints of the traditional network design. No commercial pursuit of cable applications developed from these studies for several reasons, including cost, delivery schedule, and lack of experience for critical power delivery circuits.

Other opportunities for applications of HTS cables are revealed when planning engineers look beyond traditional methods and processes. Recent unpublished work between PCS and a Northeast U.S. utility examined ways which HTS cables could be used in ɛw applications, which before have been unexplored because conventional cables could not even have been considered. This activity revealed that many new and compelling opportunities exist, which frequently ran counter to existing infrastructure development plans. A key example was recognized where HTS power cables could be used to link distribution substations which were predicted to have excess capacity over the 10 year forecasting window to substations which were forecast to be overloaded. The cases analyzed indicated that the deferral of three new substations, each with a total project budget of over $25MUSD, could be possible. Saving the company capital outlay until the forecast shows both stations exceeding capacity (a period expected to be at least 10 years). Other benefits of this configuration derive from a more heavily meshed distribution network, enabling substation reinforcement from existing substations improving reliability. Also, asset deferral reduces the risk taken by a utility when acting on extended time period plans.

The approach fits into a sub-set of a previously identified application class, termed the "virtual substation". The virtual substation uses high capacity HTS cables to serve as extended bus circuit between a large distribution substation and switchgear serving a local load. The virtual substation enables the utility to choose which substation is the most cost-effective to upgrade, and uses the HTS power cables to transfer the power to other substations for distribution. Future distribution network development could use this concept in a hub-and-spoke configuration, minimizing the number of large and obtrusive step-down substations.

This activity reveals how the increased planning flexibility offered by HTS cables can provide solutions which improve network asset utilization, resulting in more efficient, less expensive, and more reliable power transmission.

Despite these results, which indicate strong technical and economic value, the risk associated with pursuing commercial applications remains too high. Commercial use of HTS cables will not develop without indisputable evidence that long length HTS cables can be manufactured and reliably operated.

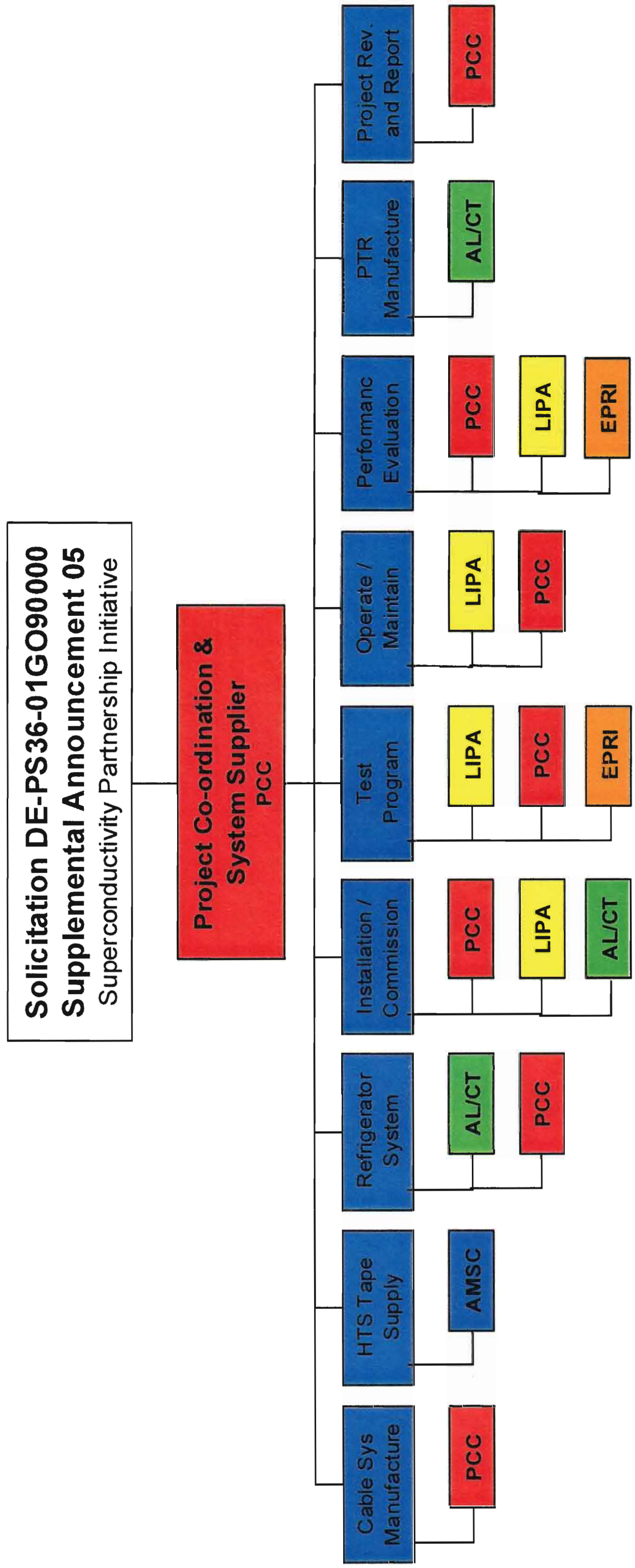

FIGURE 2: Objectives and Responsibilities of Project Team

3.1 Utility Application

Reviewing the 20-year forecast for the utility network, the partner utility, LIPA, anticipates an increase in peak load on their network from 4484 MW to 5711 MW. The installation of new superconducting cable systems as part of a 138 kV transmission reinforcement plan may provide LIPA with substantial cost savings as compared to installing a new 345 kV power transfer system, which would require the installation of new 345 kV underground cables and several new 345/138 kV step-down stations.

Bulk power transmission within the LIPA network is performed at 138 kV level. The transmission network relies heavily on pipe-type cable systems, which comprise about 35% of the total circuit miles at this voltage. Of the 175 circuit miles of pipe-type 138 kV cable installed in the LIPA network, 100 miles transport power from generation step-up stations to transmission substations on the grid. Performance limitations on these existing cables have, in at least one case, inhibited expansion of import capability to the LIPA system.

In response to interest from the utility community, the Team will consider the formation of an external observational committee composed of select utility organizations to participate in Team project meetings and witness key tests or events. Exposing more potential users to the experiences of this demonstration project should facilitate penetration of the cable market of HTS technology.

3.2 "Commercial Application" Description

LIPA has identified a retrofit application having performance characteristics representative of those needed for broad application in their network. To meet the transmission growth forecast, they anticipate the need for a new 138 kV transmission circuit with a power capacity greater than 400 MVA. Due to the suburban location of the route, overhead transmission is not a viable option. There are three (3) 138 kV pipe-type circuits along the route, as well as other subsurface utilities, including gas transmission pipes and communications cables rendering new excavation highly undesirable. The circuit will run approximately 6.5 miles in total length and is crossed at two points by overhead transmission corridors spaced about 2 miles apart. It has been anticipated that intermittent cooling stations need to be installed at the overhead corridor crossings to maintain the appropriate cable coolant flow.

Table 1. Performance Criteria for "Commercial Application" (this table contains confidential information)	
Operating Voltage	138 kV
Minimum Rated Current	1700 Arms
Installation Diameter	Nominal 8 in. dia. Pipe
Cooling Length	2.5 miles
Short Circuit / Duration	20,600 A x 117 msec

Data obtained during the course of this demonstration project will be used to develop load flow, stability and fault duty models required for selecting the power transfer corridors to be used for installing superconducting cable and the sizing of reactors, required for regulating power flow. The development of these models is essential to the commercialization of superconducting cable because the 138 kV facilities on LIPA's bulk power system consist of both conventional overhead and underground elements.

As their experience with HTS cables develops further, LIPA intends to apply the technology to bulk energy transmission applications with more than 500 MVA.

Please note that the "Commercial Application" described in the above section will not serve as the demonstration site for the current proposal. Rather, the key design characteristics and objectives will be applied (and modified as necessary) for the cable used in the demonstration program.

The specification for an HTS cable suitable to serve the commercial application is detailed in Table 1.

3.3 Cable Design Studies

To meet the characteristics identified by LIPA, the technical options for each potential cable solution were reviewed.

LIPA independently performed an analysis of conventional cables using the thermal environment and load factor for the route and determined that conventional technology cannot meet the requirements of the application. Typically (as defined in the IEEE Guide for Cable Ampacity), under the best conditions conventional HPFF 138 kV cables installed in a standard 8 in. pipe will be limited to less than 1500 A.

As demonstrated during the SPI I program, a HPFF Warm Dielectric (WD) cable system could be built to provide the desired performance levels. However, the Team considered it desirable to avoid the use of oil impregnated insulation systems, due to the potential for ground contamination. Extruded dielectric systems have a lower permitted electrical stress level, and so the total thickness of the dielectric over the cryostat system was too large to fit within the pipe. Also, as introduced earlier, WD cables, installed in steel pipes, are limited due to magnetic interactions between phases and with the steel pipe to approximately 2000 Arms. Though this exceeds the technical requirements of the Commercial Application, it could prove to be restrictive in future applications.

The best mode for meeting the stated application parameters was to use a Cold Dielectric Coaxial (CDC) cable design. This system avoids the use of environmentally unfriendly dielectric fluids and offers significant opportunities for application due to its high ampacity limit.

The CDC cable design uses superconductors to comprise both the phase conductor and the cable shield function. Using superconductors as the shield causes an equal and opposite flow of current in the shield which effectively blocks the escape of magnetic flux from the cable construction. By containing the magnetic flux, no inductive coupling between cable phases and the surrounding steel pipe occurs. This results in reduced power transmission losses in the pipe and less magnetic field influence on the ac loss and critical current capacity (Ic) of the HTS tapes.

As the cable shield must be kept at the same temperature as the phase conductor, the dielectric insulation system operates in the cryogenic environment. So, the construction of CDC places the thermal barrier around the entire system. The tape insulation is impregnated by the LN_2 coolant and maintained at the proper temperature and pressure to prevent the formation of vapor bubbles. The CDC cable designed as a pipe-type retrofit, shown schematically in Figure 3, consists of a flexible hollow former around which HTS tapes are wound to form the phase conductor. The cable may use several counter-wound layers to form a multi-strand HTS conductor. The dielectric insulation system, composed of inner semi-conducting screen, insulation, and outer semi-conducting screen, is wound directly over the phase conductor. An outer shield conductor consisting of more layers of HTS tape is applied around the insulation. A compact flexible cryostat contains the cable and provides its thermal insulation. The HTS tapes available today for demonstration applications are a metal/superconductor multi-filamentary composite. Several tapes are wound helically to minimize strain during bending and cool down of the cable to operating temperature, as well as to balance axial magnetic fields and uniformly distribute the current between the different layers of conductor to reduce ac losses. Pressurized Liquid Nitrogen (LN_2) flows through the hollow core to cool the HTS tapes and impregnate the dielectric insulation.

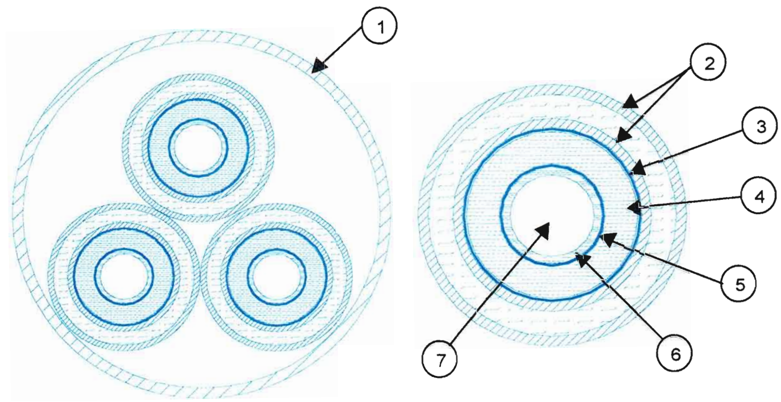

Figure 3. Cross Sectional View of CDC for 8 in. Pipe Retrofit (this figure contains confidential material)

While the CDC cable bears great similarity to conventional paper cables, the use of LN_2 to impregnate the insulation and the operation of the material at cryogenic temperatures has not been wholly characterized. Research and testing is being performed, but the acceptance levels enjoyed by conventional systems can only be achieved through the successful implementation in the field of long cable systems for a significant period of time.

PCS has previously designed and manufactured prototype cables using the cryogenic dielectric system up to 225 kV. The know-how developed during these experiences will be transferred and applied to the proposed project.

The CDC design offers the following advantages:

- The compact construction permits retrofit of standard 8 in. pipes and upgrades of the available ampacity by more than three times.
- The dielectric is impregnated by an environmentally friendly fluid.
- The coaxial configuration eliminates inductive coupling, thus increasing transfer efficiency and performance. Also, it results in zero magnetic field outside of the cable (a real factor when considering very high ampacity circuits).
- The high capacity limits of CDC designs provides the maximum flexibility to network design engineers.
- Because the cryostat is outside the cable structure, it can be remotely maintained during normal cable operation.

While the CDC design uses more HTS material than a WD cable, and thus results in a higher initial cost, the improvements in performance and efficiency can offset this cost over the life of the cable. Further, as the cost of HTS conductor falls, the economics of the system become more favorable.

4. Demonstration Project Description

The demonstration system is designed to be the world's first long length, transmission voltage, cold dielectric coaxial cable system installed and operated in a utility network. The design, manufacturing, and commissioning of this system alone will represent a significant technical achievement in the field of HTS power cables. In addition to providing an advanced technological solution, the project has been designed to demonstrate the practical viability of HTS cables in commercial applications.

APPLICATION SITE DESCRIPTION: For this demonstration project, LIPA will provide a site for installation and continuous operation of the HTS cable system. The site has been selected by balancing the technical requirements of the demonstration and regulatory / permitting obstacles.

LIPA defined criteria which the program needed to achieve in order to satisfy the lingering technical and reliability issues which they held about HTS cables. Their chief requirements are: 1) Commercial length (min length 2000 ft); 2) operating in the transmission network; 3) configuration (spatial and operational) which would permit simulated cryostat failure and repair and maintenance without interrupting load to customers (using the overhead line).

The Project Team has elected to design the cable and cable accessories for 138 kV. The superconducting cable design will include a the necessary geometric dimensions for a nominal capacity rating of 400 MVA. The outer diameter of the cable will permit the installation in a 8 in. specially coated steel pipe, which will simulate a retrofit for the 8 in. pipes used on the LIPA 138 kV system. During the term of the demonstration project, the cable will be operated by LIPA at 69 kV.

A 2,500 ft length of superconducting cable will be installed in a 8 in. pipe and manhole system on a LIPA owned 69 kV transmission right-of-way going west from Wildwood Substation, which is located north of Route 25A and west of Randall Road, in Wading River (Suffolk County). Figure 4 (see fold-out) shows the location of the proposed cable route. The 8 in. steel pipe will be installed along the right-of-way at a nominal depth of 42 in.

The LIPA owned transmission right-of-way, west of Wildwood Substation, is 150' wide and bordered by wooded areas, which will not be developed. There is one local road crossing in the project area; the permit application for this cross over will follow a normal process, without objection. The right-of-way is of level grade and consists of a sandy soil base, which will facilitate trenching and manhole installations.

The superconducting cable will operate in series with an existing 69 kV overhead transmission line, Wildwood-Ridge, Line 69-883, connecting the two substations in the local grid. The existing line construction uses 795Al phase conductors, rated at 105-N/126-LTE/137-STE MVA. Line 69-883 is part of a 19 mile, single circuit grid connection between the Holtsville Gas Turbine Station and Wildwood Substation. There are two (2) distribution substations connected midway along this route. Two bank distribution substations are located at Coram and Ridge. Ridge Substation is located approximately 5.3 miles south of Wildwood Substation at the south termination of Line 69-883. The portion of overhead transmission line paralleling the superconducting cable will remain energized, but normally carry no load. This portion of overhead line will be used when the superconducting cable is de-energized. Figure 5 shows an electrical diagram of the proposed site.

The Summer load flow on Line 69-883 will be approximately 24 MVA (24.5 MW & 0.3 MVAR's). During a contingency loss of Holtsville GT-Coram, Line 69-874 the loading on Line 69-883 will increase 76.8 MVA (76.7 MW & 3.2 MVAR's). Line 69-874 could be taken out-of-service temporarily during a planned outage if the Team wants to conduct special loading tests on the superconducting cable. The 69 kV system contribution to a superconducting cable fault will be 20,600 amperes- 3-phase and 11,500 amperes line-ground.

The HTS cable will operate at lower than design voltage and ampacity lower than typically considered appropriate for HTS cable applications. Testing a developmental technology on the transmission network introduces significant risk, as the loss of a 400+ MVA circuit can impact operation around the network. The dielectric performance of a cable system will be verified through laboratory qualification tests (typical for the industry), so the application objective remains to operate the cable on the transmission network. Reducing the ampacity of the circuit was considered an attractive solution to minimize the cost of the demonstration project, as the current cost of the HTS material remains a significant percentage of the cable cost. Earlier demonstration projects have verified that long lengths of high performance cable conductors can be reproducibly designed and manufactured.

The refrigeration unit supplying the nitrogen coolant for the superconducting cable and the auxiliary support systems will be installed inside Wildwood Substation approximately 300 ft from the east cable terminal. The perimeter of the existing substation is secured with a 8 ft fence. 12 ft fencing will be installed around the perimeter of the two (2) new cable terminals located on the transmission right-of-way. Outdoor lighting and closed circuit TV surveillance will be provided at each of the three (3) locations. A SCADA point will be installed to provide the LIPA System Operator monitoring of the superconducting cable system, including refrigeration and auxiliary support systems. Local permit applications will be made for storing the nitrogen coolants and any lubricating liquids required for the refrigeration system.

The 1000 kVA padmount transformer providing secondary service to the refrigeration unit and auxiliary equipment will be connected to a radio monitored 13 kV padmount automatic throwover switchgear (ATO) unit, The source side of the ATO unit which will be connected to two (2) separate 13 kV primary underground supplies from inside Wildwood Substation. The preferred power source will be underground. The alternate power source and second 15 kV cable will be connected an overhead fused riser, which will be tapped to the 13 kV bus supplied from Bank 2.

CABLE SYSTEM: The HTS cable system consists of three CDC cables, each having two terminations (one on each end), and two field installed joints. The maximum pulling length required for the demonstration will be 850 ft. The construction of the cable was described earlier in this proposal.

The outer diameter of the overall cable assembly, including cryostat, is approximately 86 mm and will weigh 8.5 kg/m. The cable is designed incorporating protection against damage permitting it to pass full fault current (in the case of a short circuit outside of the cable system) and one successive reclosure and remain in the normal superconducting state, permitting the cable to return to normal operation as soon as the fault is cleared.

The design of the cable will meet the dielectric, hydraulic, and installation requirements imposed by the "Commercial Application" discussed earlier. Though the operating voltage of the demonstration site is 69 kV, proving the installation haracteristics to retrofit an 8 in. pipe is a key part of the project. The cable will be manufactured in three lengths which will be jointed in the manholes located approximately 850 ft and 1650 ft from the eastern termination position.

A procedure for manufacturing HTS cables developed by PCS in earlier work will be followed for this project. Sample cables, called "mock-ups" are fabricated identically to the actual cable, except the HTS material is substituted with copper. A first mock-up will be fabricated to finalize cable manufacturing parameters focusing on the former construction, conductor deposition, the lapping chart for the electrical insulation, and the cryostat configuration. A second mock-up cable, which uses a few HTS tapes, will be manufactured to verify that no HTS performance degradation occurs due to the cable manufacturing processes. This mock-up will also be used for fitting tests with the accessories. Following successful conclusion of the mock-up activity, the conductor for the type-test (discussed later in this section) will be fabricated.

The manufacturing philosophy for the cable adopts as much as possible from the experience and infrastructure available within PCS for manufacturing of conventional cables. This has permitted the HTS system development activity within PCS to focus on developing know how and techniques for the more innovative aspects of HTS systems. Where needed, investments have been made, and will continue to be made, to purchase equipment and upgrade manufacturing facilities to accommodate the manufacturing of HTS cables. For example, a dedicated stranding line has been commissioned for the manufacture of HTS cable conductors. This line has performed perfectly in manufacturing the cable conductors used in all recent PCS development programs, including approximately 1500 ft of conductor for the Detroit Edison demonstration.

HTS TAPES: AMSC in cooperation with PCS has developed long length, high performance BiSrCaCuO(2223), also termed BSCCO-2223 (pronounced Bisco). These tapes meet strict engineering requirements, which enable demonstrations of the potential of

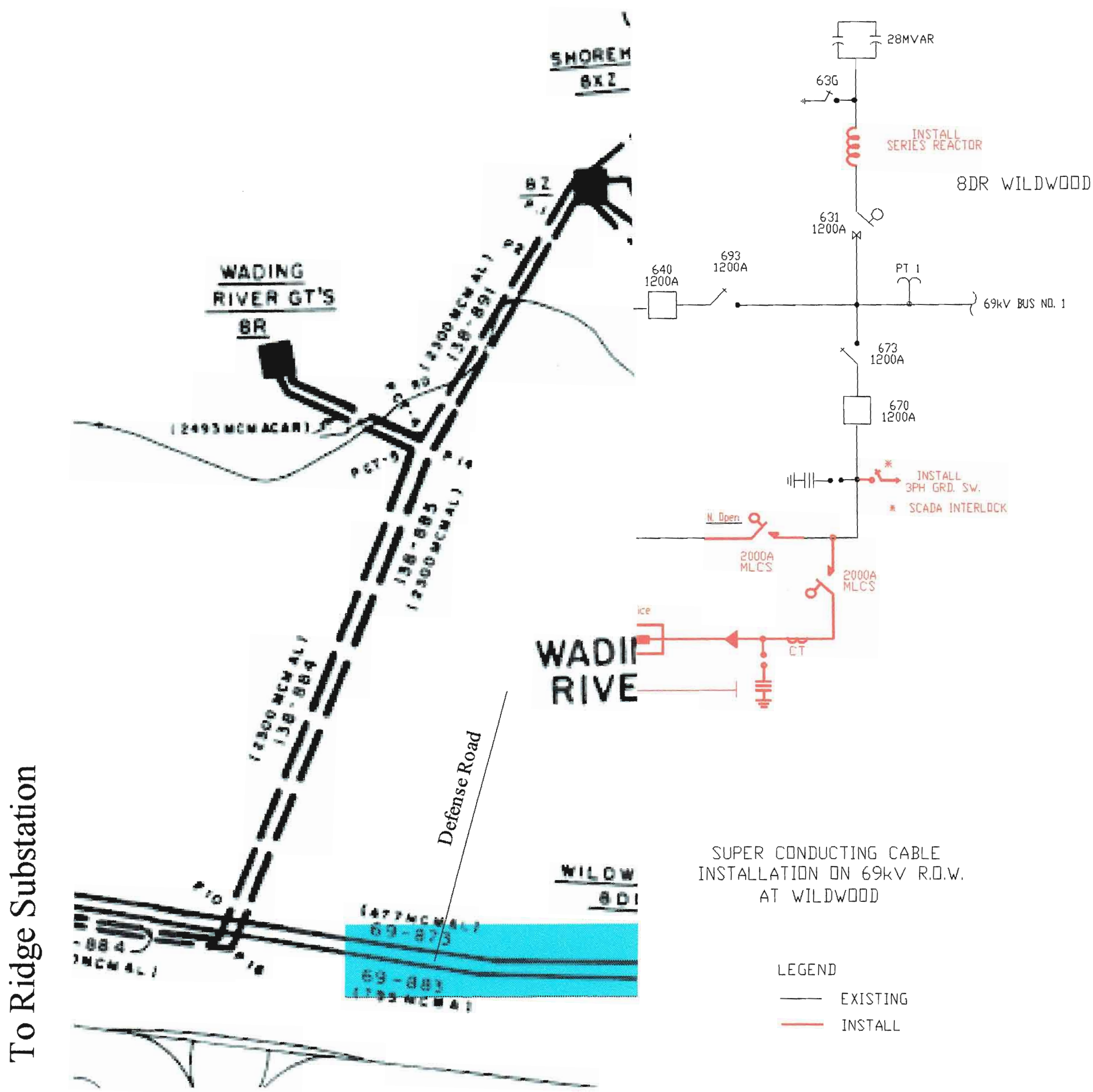

FIGURE 4. Proposed Demonstration Lostration Site

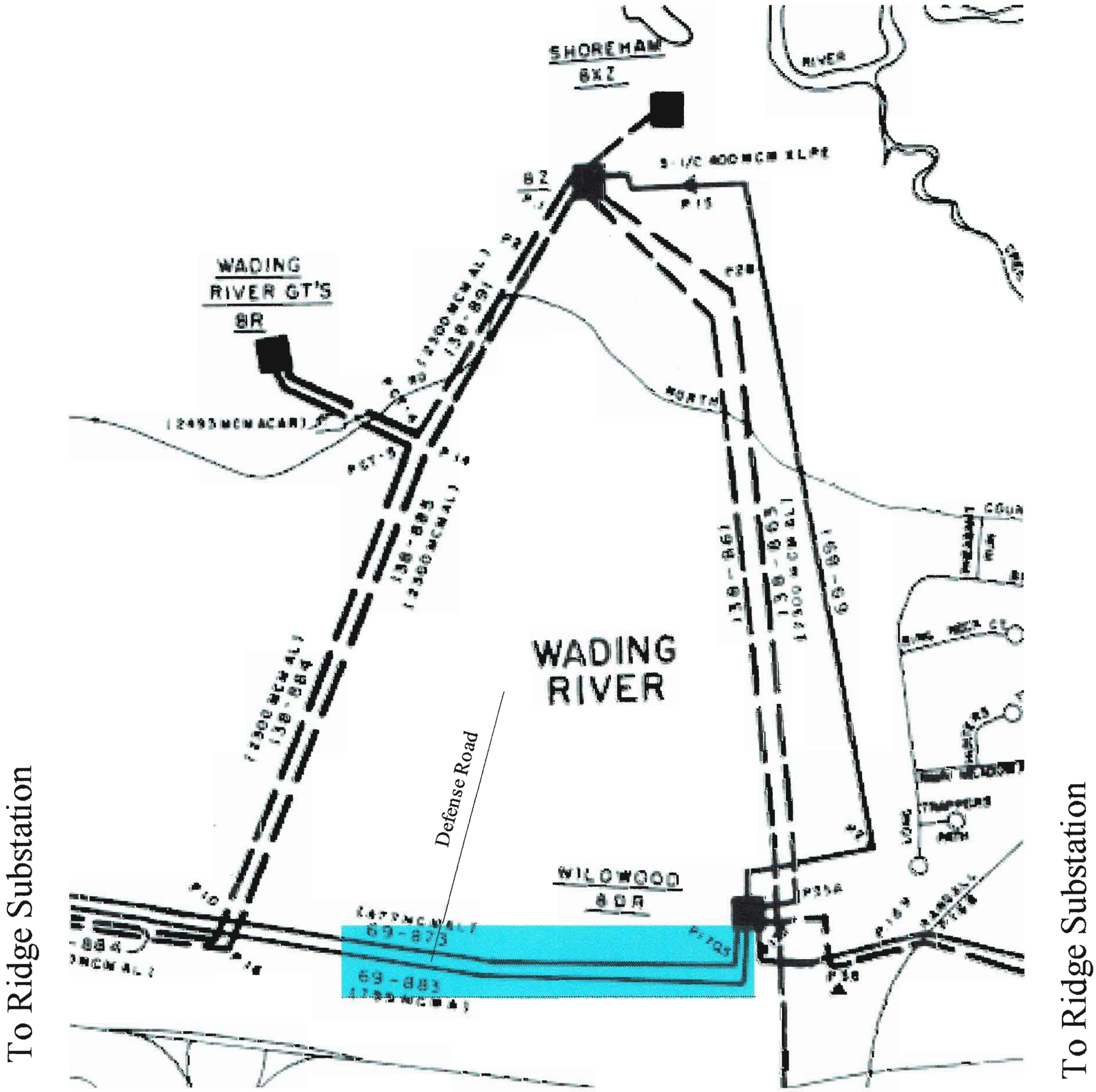

FIGURE 4. Proposed Demonstration Location and Cable Route

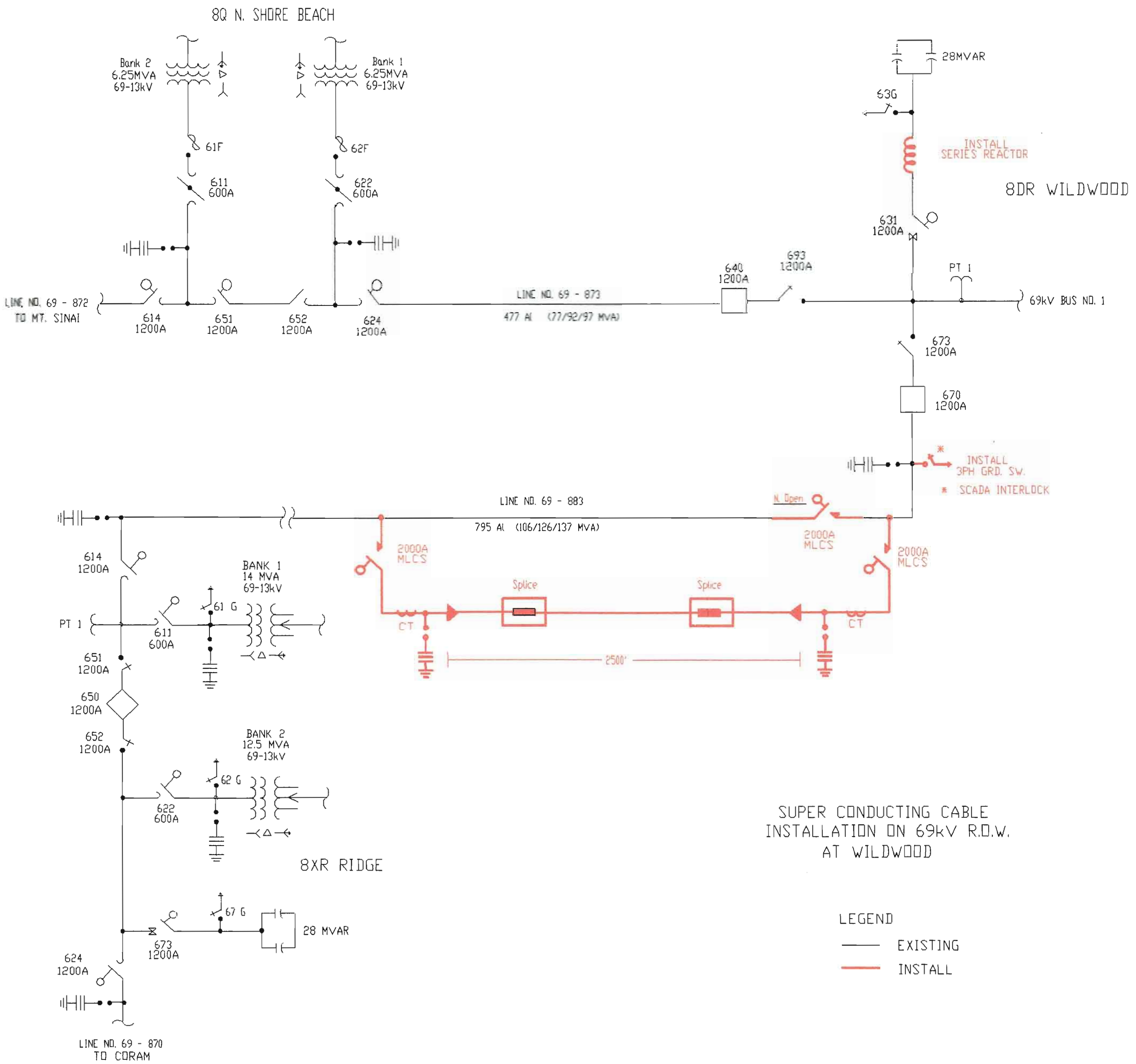

FIGURE 5. Electrical Schematic of Demonstration Site

superconducting cable technology. Tapes are manufactured according to geometric and performance (electrical, mechanical, environmental) specifications, supplied by PCS for the application.

AMSC fabricates tapes in excess of 400-m with DC engineering critical current up to 14,000 A/cm^2. The critical current densities are measured over the entire full length, using the electric field criterion of 1μV/cm at 77 K, self-field. Moreover, the critical current density of the tape is measured over each consecutive 1-m along the length. The reliability of the tapes is tested through extended exposure in the cryogenic liquid and for repeated thermal cycling between room and operating temperature.

With these tapes, retention of critical current exceeding 95% can be achieved at a tensile stress greater than 250 MPa at room temperature and at a tensile strain greater than 0.4% at operating temperature. High strength multifilamentary BSCCO-2223 made by power-in-tube process have adequate performance, both mechanical and electrical in presence of magnetic field, at 77K for the technological requirements of the program.

Using the economic models described later in this document, PCS has identified that a cost performance ratio of the superconducting tape must be below $10/kA-m for broad commercialization of the technology. The performance specifications for commercially viable HTS tapes is included as Table 2.

As already discussed in previous sections of this document, the initial market for superconducting cables using BSCCO-2223 tapes could be limited to applications where conventional solutions are technically infeasible. The primary reason for this expectation is due to the uncertainties regarding the economic viability of a superconducting solution based on today's cost for the HTS tape and the cost of the refrigeration system. In particular, the cost of BSCCO-2223 tapes, is driven by the raw material cost, mainly due to high silver content, as well as the labor intensive multi-step manufacturing process.

Table 2. HTS Tapes Performance Requirement for a Competitive Use of Superconducting Cables in High Power Transmission
(this table contains confidential information)

Operating Temperature	LN_2
J_c at Operating Temperature (A/cm^2)	10^5 @ 0.1 T
Tolerable Axial Strain at Room Temperature	> 3 x 10^{-3}
Tolerable Axial Strain at Operating Temperature	> 5 x 10^{-3}
Thermal Stability	No degradation after long term exposition to the coolant and after consecutive thermal cycles
AC Losses	Approx. = what is predicted by the elliptical Norris Fit
Continuos Fabrication Length (km)	> 1
Cost ($/kA-m)	< 10

In light of the economic limitations with BSCCO-2223 tapes, the 2nd generation of high temperature superconducting tapes YBCO Coated Conductors (CC) could represent a very promising alternative to the present BSCCO tapes in view of expected lower material and manufacturing costs and potentially higher performance. The main technical requirements to be met by HTS tape for power transmission applications are here summarized:

- high electrical transport properties, in particular critical current and engineering critical current density over the whole range of operating temperature (it should be noted that the lower critical temperature of the YBCO material adds some additional constraints on cable and refrigeration system design, as well as reducing margin in terms of maximum tape temperature increase along the cable length);

- good mechanical performance, both at room temperature, to withstand the manufacturing operations, and at low temperature to withstand the cable life operations;
- electrical stability during periods where current exceeds the Ic of the tape;
- low AC losses;
- the availability of highly uniform tapes of up to 1 km in length;
- long term electrical and thermal stability.

Concerning the ac losses, in the transport regime YBCO coated tapes should allow a significant improvement compared with the present BSCCO-2223 tapes. Over a broad current range, theoretical modeling of the AC loss behavior of cable conductors, built with YBCO tapes having critical current similar to that of BSCCO-2223 tapes, resulted in significantly reduced ac loss. The improvements become more significant using the anticipated performance of YBCO coated tapes having very high critical current density (Jc~2 MA/cm^2). Models predict that cable conductors assembling using CC tapes in a configuration optimized for low ac losses could result in reducing ac losses by one order of magnitude over conductors built using currently available BSCCO-2223 tapes.

Through significant worldwide research efforts to develop YBCO coated conductor tapes significant, very interesting results have been obtained on short samples of material prepared using various techniques. High transport performance and good mechanical performance, suitable for cable applications, have already been demonstrated – confirming the technical suitability of using coated conductors to replace BSCCO as the tape of choice for cable systems. Nevertheless, some important issues remain to be resolved:

1. Extending the performance (primarily high critical current density) of short samples to long length tapes;
2. Achieving the same engineering critical current density as BSCCO-2223 tapes, so that the same level of current can be carried using a similar tape size;
3. identifying a tape structure that guarantees:
   - adequate thermal and electrical stability;
   - resistant to coolant penetration and diffusion;
   - appropriate mechanical and handling characteristics;
   - material and component interfaces for low resistance connections for jointing, current injection, current transfer and sharing;
   - tolerance and robustness to manufacturing or cabling induced defects.

There are some strategies to overcome these issues: research and development activities are now focused on controlling and monitoring the continuous processes and on the improvement of microstructures/morphology/transport current capacity of the whole structures (substrates/buffers/superconducting films).

Concerning the second problem, a BSCCO-2223 tape commercially manufactured by AMSC can carry more than 130A on 4mm width. For a YBCO tape, this corresponds to more than 300A/cm-width of the YBCO film. To reach this performance, on a tape hundreds of meters long requires a Jc=1 MA/cm^2 on a 3 μm or Jc=3 MA/cm^2 on a 1 μm (or all possibilities that allow 300A/cm-width). These results are rare as reported in current scientific journals for YBCO on a metal substrate. A LANL sample showed Ic >500 A/cm using stacked structures but that manufacturing technique is very expensive. An alternative is represented by multi-layered structure for the tapes, but this process will cost more and the geometry will result in higher ac losses than the single thick film. Furthermore, it could introduce mechanical problems.

The final point concerns all aspects of "materials engineering", and the criteria are essential for the application of a HTS tape in HTS cable conductors.

One and half year ago PCS initiated an important research program together with AMSC. The main objective is driving the program: to find a low cost process that allows high performance long tapes. PCS's participation in this program exceeds $10MUSD over 5 years; the final goals are reliable manufacturing processes for long tapes showing uniform properties suitable for cable application. At this moment the selected technique to meet these goals is based on the following process steps:

- manufacturing cube textured metal substrates (RABiTS-like) showing adequate mechanical, structural and morphological proprieties;
- ceramic buffer layers using physical and chemical techniques have been developed on short samples. One meter long buffered samples with adequate structural and morphological properties have been already been fabricated;
- using a chemical approach (starting from trifloruroacetate-TFA precursors) depositing biaxially textured YBCO. This approach has demonstrated Jc=5 MA/cm^2 on single crystal and Jc=2 MA/cm^2 on metal substrate.

In summary, high performance, long length YBCO tapes obtained by a techno-economically optimized process will have an enormous impact on the economics and performance of superconducting cables, resulting in increased deployment of HTS cables into the transmission and distribution cable markets. PCS strongly believes in the opportunity available through the implementation of the next generation of CC tapes and participates in focused research activities in the framework of its agreement with AMSC.

ACCESSORIES: Cable systems include accessories, allowing them to be jointed for installation or repair, and connected to standard utility equipment. Accessories for CDC cables are considerably more complex than their conventional or WD counterparts.

The terminations must control the electrical field in LN_2 and realize the transition between cryogenic and ambient temperatures. Also, it withstands mechanical forces due to coolant pressure and thermo-mechanical effects.

The construction of a termination assembly designed for a separate 225 kV CDC cable program is shown in Figure 6. In this embodiment, the cable passes horizontally into a pressurized vessel containing LN_2. The LN_2 performs the same function in this vessel as SF6 in switchgear, providing dielectric insulation between the cable and the enclosure. A bushing is used to transition between the cable and the LN_2 space. Another bushing provides both thermal and electrical isolation, using a stress grading capacitor to control the electrical field, to effect the transition between the LN_2 dielectric and the ambient. This bushing contains the current lead which passes vertically outside of the LN_2 vessel. The current lead is properly designed to minimize thermal conduction and resistance losses into the low temperature system. After passing from the cryogenic environment, the current lead is contained in a standard resin-filled outdoor sealing end.

For the demonstration, the maximum pulling length for cables necessitates that two installation joints per phase be used. Joints will connect sections of cable for each phase to create the required circuit length. The joint design reconstitutes all elements of cable, while permitting LN_2 flow and providing low electrical loss jointing of the superconductor.

The dielectric part of the joint will be wrapped Polypropylene Laminated Paper, as is used for the cable insulation. The cryostat for each joint will be housed within rigid piping and have new multi-layer insulation applied.

The proposed system will be the first three-phase system CDC HTS cable developed and tested by PCS. The only significant departure from previous CDC activities is that the grounding system must be incorporated into the terminations, as suggested by U.S. patent number 6049036.

TYPE TESTING: As the demonstration represents the first time this design of a 138 kV cable system has been manufactured, a laboratory type test will be conducted. The type test will include a minimum 30 m long cable manufactured precisely per the design specification for the demonstration cable. A laboratory installation will be performed, including terminations and a joint.

Type tests will include dielectric qualifications using international testing standards (IEC 141-1 and AEIC CS2/97) as far as applicable. A specialized testing sequence, previously developed for other PCS programs to verify the mechanical and superconducting performance of the system, will also be adopted.

COOLING AND REFRIGERATION SYSTEM: Air Liquide and Cryo Technologies will engineer and supply the complete refrigeration system per the equipment specification developed by PCS. The system will be based on conventional techniques for moderate power refrigeration and include engineered subsystems needed for HTS cable application. The technique applied will be a reverse-Brayton refrigerator using either nitrogen or helium as the process fluid. Reverse-Brayton refrigerators use high-efficiency, xpansion turbines to extract energy from a high pressure process gas stream.

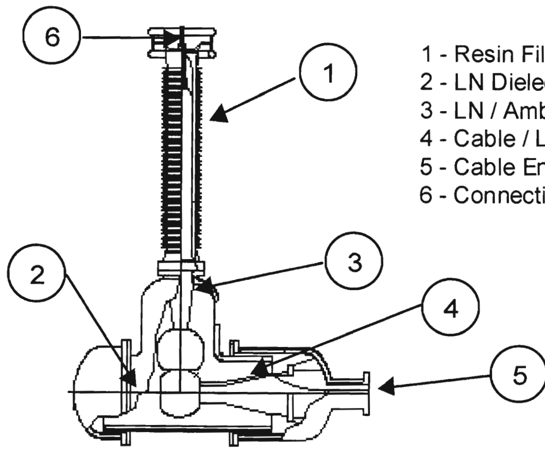

FIGURE 6: Termination Assembly for 225 kV CDC Cable System

Table 3. Performance Specification for Refrigeration System (This table contains confidential information)	
Net cold power to the HTS system	25 kW
liquid nitrogen flow rate	0.7 kg/s
LN_2 supply temperature	67 K
LN_2 supply pressure	15 bar
LN_2 return temperature (full load)	85 K
LN_2 return pressure	5 bar
Max Pressure Variation Limits $\Delta V/\Delta t = \pm 3$ L / 1 sec	+1 bar / -2 bar

The refrigeration system will be designed to provide approximately 25 kW of net "cold" power to deliver LN_2 to the cable circuit at approximately 67 K (-206 °C) and at a pressure of 15 bar. Specialized pumps will be installed to circulate the LN_2 through the cable system. LN_2 will pass outward through one phase and return through the other two. A volumetric compensation system accommodates changes in the fluid density due to varying mass-averaged temperature. All sensors needed to monitor the performance of the composite cable / accessory / refrigeration system will be incorporated with in the refrigeration system. A PLC based control system ensures reliable unattended plant operation. The performance specification for the refrigeration system is outlined in Table 3.

It is not yet clear what refrigeration system technology will prove the most economic for HTS power cables. To cool long lengths of cable, cooling capacities on the order of several 10's of kilowatts are required. This level of capacity, in fact, falls into a range where true economies and efficiencies of scale are not realized with turbine systems. However, no other existing commercial 'echnology can offer the reliability and performance range of turbine systems.

TEST PROGRAM: Following system installation at the demonstration site, it will be imperative not only to test performance of the system under load and through surges, but also to evaluate the cost benefits and reliability of the HTS system, which may not be apparent until day-to-day maintenance and operation of the system has occurred for a substantial period (2-3 years).

Evaluation of performance reliability, and cost benefits will be done in cooperation with LIPA by EPRI and PCS. This evaluation involves the development of a suitable test program which will reveal the critical aspects of system performance.

A preliminary testing agenda to be implemented following the installation of the cable system is outlined below.

1) Verification of the installed system for thermal pumping, and refrigeration losses.
    a) After the installation of the cable and accessories and connection to the refrigeration system, the system will becooled down to a stable and normal operating temperature.
    b) The key fluid flow properties (temperature, pressure, mass flow rate, etc.) and electrical efficiency of the refrigerator and pumping systems will be monitored and recorded for a subsequent analysis.
    c) The global thermal and hydraulic losses along the cable and in the terminations will be measured using differential calorimetry.

2) Electrical Testing and Evaluation of Thermal and Electrical Losses

a) The system will be energized with the operating phase-to-phase voltage (69 kV) applied to each phase conductor carrying load. After having reached a steady condition, the system losses will be evaluated. The current flowing through the cable will be monitored using suitable metering transformers, and this data monitored and stored for subsequent analysis.
b) The fluid flow properties (temperature, pressure, mass flow rate, etc.) and electrical efficiency of the refrigerator and pumping systems will be monitored and recorded for a subsequent analysis.
c) The losses calculated from 2.b. will be compared with the measurements in 1.c. to indicate the effect of load magnitude on system losses.

3) Electrical Testing on the Grid

a) The system will be connected to the grid with the natural load of the system flowing through. The cable will be subject to all of the fluctuations of the network – switching surges, lightning strikes, and load variations. The entire system will be closely monitored to evaluate total system operation.
b) The system will be kept connected to the grid for a period of time adequate to experience all of the expected variations in load conditions and to have a reasonable probability to incur non-reproducible events, such as lightning strikes or through faults. A time duration of at least two years is advised.
c) At the end of the testing period in the grid, the performance of the system will be analyzed and correlated to incurred events and compared to design data.

SIMULATED REPAIR AND MAINTENANCE: An objective of this activity is 1) to develop techniques for managing failures or malfunctions of one of the novel components of the HTS cable: the cable cryostat, and 2) to verify the performance of the installed safety, monitoring and control devices.

Particularly, this will involve vacuum and cryogenic system effects. Appropriate test procedures will be considered to simulate the loss of vacuum inside the cable cryostat. The loss of vacuum could be created either by introducing a controlled leak using an intentionally installed valve, or it could be caused by intentionally puncturing the cryostat (with the cable de-energized). These tests will be conducted at the end of the system demonstration.

Another important aspect for the commercial acceptance of HTS cables is a definition of the time required to process the system and restart before it can serve load. As the first long length demonstration cable system, this program will be used to establish these processes and techniques.

The scope of the activity will be determined between PCS and LIPA during the course of the project.

CABLE MODELING AND ANALYSIS: Because of the novel construction, high capacity, low inductance design, the performance characteristics of the CDC design in the electrical network represents an additional unknown to the utility end customer. Due to the unprecedented length of this installation, valuable information will be observed in regards to the real-world impact on the operation of electrical systems with the installation of HTS cable systems. Experience will also be gained by examining impacts on system protection and changes in system response to disturbances such as line switching and reactive power controls.

The line characteristics (i.e., inductance and reactance) will be verified and more sophisticated models of the cable system behavior will be developed for inclusion into future network modeling analyses. Load flow, short circuit, and transient stability studies are typically the first step in identifying network upgrades, and these studies will be critical to evaluate the overall efficacy of inclusion of HTS systems, as well as to determine overall impact to the network.

Prior network modeling activity has shown that the combination of high ampacity and low impedance cables can have a wide spread influence on the flow of power in a utility network. This activity, however, must be continued to develop a higher level of understanding of the mechanisms at work within large systems to ensure proper application of HTS cable systems.

COMPARISON WITH COMMERCIAL REQUIREMENTS: As emphasized earlier, the design characteristics of the cable system to be manufactured for this demonstration were based on criteria set for commercial applications. Table 4 summarizes the remaining performance and design differences between the demonstration system design and the criteria identified for the "Commercial Application".

Though the ampacity of the demonstration cable is reduced compared to the "Commercial Application", the cable design permits increasing the cable ampacity requiring only an increase in the number of tapes used. The results of previous development programs show that HTS conductors having higher ampacity ratings can be reproducibly manufactured similar in length to commercial applications. However, as shown by the "Commercial Application", longer circuits will be required.

Cryogenic cooling of the cable is performed by circulating liquid nitrogen through the cable circuit (it will flow outward in a single phase, split and return through the other two phases) and re-cooling it in a cryogenic refrigeration system. The performance of the HTS material depends strongly on its temperature, so it is desirable to minimize the maximum circuit temperature. The maximum circuit temperature depends directly on the total amount of losses into the system and the mass flow rate of the coolant. As the losses are minimized by the design of the cable system, it is necessary to increase the mass flow rate of the coolant. This has an influence on the cable system, as high flow rates require high delivery pressure.

Beyond practical issues regarding manufacturing and handling, the novel aspects of the HTS system (the cryogenic thermal insulation and system cooling) increase in complexity for longer lengths. The refrigeration system must remove all of the system losses entering the cable. As total system losses are almost entirely dependent on system length, longer cable lengths require higher capacity refrigeration systems. Cryogenic refrigeration techniques are available today with power capacity suitable for an almost arbitrarily long length of cable. (Actually, the cooling power required will be limited by the pressure drop discussed earlier than the availability of refrigerator plant capacity!) However, the efficiency and reliability of the application of these techniques to power cables must be verified through field demonstrations.

Table 4. Technical Parameters of Demonstration and Commercial Cable Systems
(this table contains confidential information)

	Demonstration	Commercial
Nominal current (A)	700	1700
HTS tape critical current @ 77 K (A)	135	170
Maximum LN pressure (bar)	15	25
Minimum LN temperature (K)	67	65
Cryostat losses (W/m)	5	2

In the cable system, the termination accessories and the cable cryostat are required to withstand the coolant pressure. Increasing the strength of these components requires more weight, challenging seal design, and the in the case of the cryostat less flexibility and more space required. Further, the pumps used to generate the flow of coolant through the cable are more complex and expensive as the mass flow rate, operating and differential pressures increase.

Minimizing the thermal inleak into the cryogenic system requires the use of a specialized thermal insulation system, called a cryostat, which relies on high vacuum levels and radiative shields. Manufacturing and maintaining long lengths of cryostat remains one of the most crucial and demanding aspects of HTS cable systems. A further challenge stems from the utility industry's lack of experience and know-how with high vacuum systems. The demonstration must prove the reliability and maintainability of long lengths of cable cryostat.

The thermal performance specified for the demonstration program can be achieved using techniques and equipment available to PCS. To reach the thermal performance level needed for commercial cable systems, a research program on material and fabrication techniques is necessary.

Utilities around the country have expressed a common thought that they need to see demonstrations of lengths of cable circuit which are similar to that needed for commercial applications. The perspective of LIPA as the partner utility was leveraged to balance the demonstration value and project cost to arrive at a suitable system length and performance.

In addition to addressing those issues remaining for commercialization, such as long length, reliability, high refrigeration power, and proving a transmission application in the field, the project also will include field simulations of mechanical cryostat failure and the application of repair and restart techniques.

II. COMPONENT AND SUB-SYSTEM DEVELOPMENT

As a "Phase III" program, the final results should be the commercial adoption of HTS power cables by the utility industry. This will be accomplished through the manufacture, installation, and operational demonstration of the long length CDC HTS transmission cable system proposed in this document. Achieving this objective relies on the successful completion of five primary technical goals.

- PCS supply of CDC HTS cable and accessories;
- Air Liquide / Cryo Technology delivers refrigeration system;
- Long length CDC cable, accessories, and refrigeration system are installed to operate in the LIPA transmission network;
- Cable performance analyzed and advanced representations for HTS cable systems developed for system modeling;
- PCS, EPRI, and LIPA evaluate performance and reliability of long length cable installed into the network and report findings, emphasizing areas recognized by LIPA as critical for commercialization.

Statement of Work

The following section will describe the various tasks, the specific Team member responsible, and the time associated with task completion.

Task 1. System Design

Task 1.1 Design Cable (PCS, Bechis; 2/28/2002)

A complete cable design will be performed considering the demonstration application requirements, as well as the commercial application requirements.

Task 1.2 Design Accessories (PCS, Ladiè; 2/28/2002)

Accessories, including outdoor terminations and installation joints will be designed based on the performance requirements of the demonstration system.

Task 1.3 Installation and Site Design (PCS, Kelley, KeySpan, Dey; 8/29/2002)

The equipment needed for installation of the cable, support of the terminations, and operation of the cable will be designed in this Task. The configuration will be representative of that anticipated by LIPA for future commercial installations. Specific components will be included to enable flexibility in operation and control for testing of the HTS cable system.

Task 1.4 Communication and Monitoring System (PCS, Wakefield; 7/1/2003)

The communication and monitoring equipment needed to monitor the cable system and initiate experiments will be designed. Focus will be paid to commercial requirements for integration with users' SCADA and operations systems.

Task 1.5 ASME Code Certification (PCS, Kelley; 8/29/2002)

The design and manufacturing processes for the cable and accessories will be reviewed for compliance with ASME code requirements. All equipment will be certified to the applicable Codes and Standards.

Task 2. Equipment and Material Specification

Task 2.1 HTS Tape Specification (PCS, Spreafico; 4/2/2002)

Based on the cable design and site requirements defined in Task 1, a detailed specification will be produced based on BSCCO tape developed as part of the joint PCS and partner American Superconductor Corporation program. The specification will be based on the characteristic necessary for the manufacture, installation, and operation of the demonstration cable system.

Task 2.2 Refrigeration Specification (PCS, Bechis; 4/2/2002)

The design of the refrigeration system will take into account the commercial application as far as the cycle and the general layout are concerned. Operating parameters (pressure, temperature, LN flow rate) will focus on the demonstration installation.

Task 2.3 Site Engineering Design (PCS, Kelley, KeySpan, Dey; 7/1/2003)

The site plan and infrastructure additions, determined in Task 1.3 will be designed. All necessary equipment will be specified and ordered.

Task 3. System Engineering and Manufacturing

Task 3.1 Tape manufacturing (ASC, Snitgen; 4/3/2003)

The tape will be manufactured by American Superconductors in accordance to the specifications defined under task 2.1.

Task 3.2 Cable Engineering and Manufacturing (PCS, Spreafico; 12/31/2003)

PCS will manufacture the cable as designed in Task 1.1 at its dedicated HTS conductor assembly facility in Italy, at an appropriate facility for the application of the dielectric insulation system and manufacturing of the outer cryostat. Various samples will be fabricated as part of this task to be used in "mock-up" testing programs for electrical qualification. As the enclosed geometry has not been previously built, tests will also be conducted to evaluate the manufacturing processes. These tests will include impregnation time, vacuum/thermal insulation performance and critical current retention.

Task 3.3 Accessory Engineering and Manufacturing (PCS, Ladiè; 12/31/2003)

The accessories designed in Task 1.2 will be manufactured according to the appropriate Codes and Standards. Type testing of the accessories under Task 3.5 will be performed using cable samples generated through Task 3.2.

Task 3.4 Refrigeration Engineering and Manufacturing (Air Liquide/Cryo Technologies, Hessinger; 12/31/2003)

The refrigeration system will be manufactured, assembled and tested by Air Liquide/Cryo Technologies per the specification developed in Task 2.2.

Task 3.5 Type Testing Cable and Accessories (PCS, Ladiè; 4/30/2003)

A type test will be performed on a short (minimum 30 m) long cable system, including joint and terminations. The test will verify the thermal, hydraulic, and electrical performance of the system.

Task 4. System Installation and Commissioning

Task 4.1 Site Preparation (KeySpan, Dey; PCS, Kelley; 1/1/2004)

Per the designs developed in Task 2.3, the demonstration site will be prepared by KeySpan. Excavation will be performed for the installation of a pipe to be "retrofitted" by the HTS cable. Two joint-bays will be supplied for the preparation of the installation joints. One additional joint-bay will be provided to enable access to the cable pipe for abnormal condition simulation tests and repair technique verification.

Task 4.2 Installation of Cable System (PCS, Kelley; 3/2/2004)

The cable designed and manufactured for this project will be installed at the demonstration site. Two joints per phase are anticipated.

Task 4.3 Installation of accessories (PCS, Ladiè; 5/3/2004)

The terminations, the joints and cable cryogenic components will be prepared and installed with the cable.

Task 4.4 Installation of Refrigeration System (PCS, Kelley; Air Liquide/Cryo Technologies, Hessinger; 5/4/2004)

The refrigeration system will be installed and tested per standard procedures.

Task 4.5 Preparation of Cable System (PCS, Kelley; 6/15/2004)

The complete cable system will be connected to the refrigeration system. The vacuum of the cryostat will be processed on site as needed. The flow channels and terminations will be cleaned and dried of adsorbed moisture.

Task 4.6 Commissioning of the Cable System (PCS, Kelley; 7/27/2004)

The cable system will be cooled down and the dielectric system impregnated. Once the cable has stabilized at the appropriate operating temperature, installation verification tests will be conducted.

Task 5. System Operation in the Network

Task 5.1 Cable Performance (PCS, Kelley; KeySpan, Dey; 10/27/2004)

The cable system will operate as part of the transmission network, and its behavior will be monitored continuously. The system will operate until it has established that the cable system has been manufactured and installed properly, and that the performance of the demonstration system have been adequately characterized

Task 5.2 Continuous Operation in the Network (KeySpan, Dey; 8/1/2005)

The system will be permitted to operate continuously in the utility network and its performance monitored to identify the system behavior in response to various operating conditions. This prolonged operation period will demonstrate the reliability of long length HTS cables, as well as provide KeySpan with experience on the O&M characteristics of the system..

Task 6. Repair and Maintenance of Cable System

Task 6.1 Simulate Cryostat Breach (PCS, Ladiè; 8/30/2005)

The effects of small gradual and sudden vacuum losses will be studied by emulating these conditions on the demonstration circuit. The line current and voltage will be removed for obvious safety reasons. The outer cryostat wall will be damaged and repaired using field techniques.

Task 7. Decommissioning

Task 7.1 System Decommissioning (PCS, Kelley; LIPA, Dey; 10/13/2005)

At the conclusions of the demonstration project, the system will be decommissioned and removed from the project site. The cable will be handled and shipped in a way to avoid disturbing its condition, so that further analysis can be conducted.

Task 7.2 Site Restoration (LIPA, Dey; 11/10/2005)

The site and network infrastructure disturbed during this project will be restored to a condition as directed by LIPA.

Task 8. Reporting

Task 8.1 Interim Reporting (PCS, Kelley)

During the course of the project, the Team will participate in periodic project review meetings, consisting of a discussion of the activities completed in the preceding period, the anticipated activities for the upcoming period, and any relevant technical points.

Task 8.2 Final Report (PCS, Kelley; 10/27/2005)

The overall evaluation of the manufacturing, installation, maintenance, operation, and testing data shall be compiled and formalized in a report. This report will summarize performance and reliability achieved during the project, as well as any issues encountered during the installation and maintenance of the system within the utility system. The procedures and experiences regarding system repair and restart will be detailed in an appended report, as they will be written in a manner for direct application in the field.

III. Application Capabilities

A. Team Capabilities

Pirelli Cables and Systems (PCS) will be the Prime Contractor for the project described in this proposal. PCS will also be supplying the CDC HTS cable system and will be the focal point for the Team. This vertically integrated Team includes the leading U.S. cable supplier and leader in HTS power cable technology, the leading U.S. HTS tape manufacturer (AMSC), a large utility (LIPA) which employs a significant transmission cable network and progressive approach to technology, a world leader in refrigeration and cryogenic technology (Air Liquide/Cryo Technologies), as well as the U.S. research organization for the electric power industry (EPRI).

Management of the project by PCS will guarantee timely and successful component and system procurement and cable manufacture. EPRI's participation focuses attention on the project from the utility industry and will provide expert input into test programs. The presence of LIPA, a utility with demonstrated technical leadership in the industry lends additional experience both from the user/operator perspective, as well as technology transfer toward commercialization.

Pirelli Cables and Systems, the U.S.-based manufacturing, marketing and research affiliate of the international Pirelli group of companies, is a major retailer of cable to the U.S. utility and industrial markets. PCS engineers have been integral in the previous development programs under the Superconductivity Partnership Initiative, including the manufacture, installation and test of a 50 m WD HTS cable tested in 1998-1999, and the design and manufacturing of a 120 meter, three-phase cable system to be installed at Detroit Edison.. Also, PCS personnel are key participants in utility standards organization working groups on HTS power equipment. PCS will lead the effort to evaluate the reliability, performance, and cost benefits of the system during and after the operational period. Certain work, related to design, construction of the cable and accessories, will be performed in Milan, Italy.

Air Liquide / Cryo Technologies is a commercial arrangement between the Advanced Technologies division of Air Liquide and Cryo Technologies, a company specializing in the advanced application of cryogenic refrigeration techniques. The inclusion of this

Team member brings world-leading expertise in the design and manufacture of refrigeration technologies and will be instrumental to the successful integration of cryogenic technologies for this project.

American Superconductor Corporation (AMSC), the leading U.S. manufacturer of HTS tape will supply tapes for the conductor assemblies and also test the tapes to ensure that they meet specifications set by PCS. Since 1989 ASMC and PCS have collaborated in a joint development project to develop HTS tapes for cables, and PCS has exclusive rights to AMSC tape in the field of power cables. PCS has strongly influenced the direction ASMC has taken in developing it HTS tapes for cables. AMSC has excelled in developing tapes that are flexible and can be fabricated for the cable application. ASMC has supplied superior tapes having high critical current densities for the 50 meter HTS cable and the 120 meter HTS cable which preceded this program. AMSC and PCS have continued their development in increasing the critical current and quality of tapes. AMSC is currently building a new HTS tape factory in order to more efficiently supply long lengths of HTS tapes.

This Team has the capability and a road map to commercialize HTS cable. PCS, EPRI, and ASC have invested significant resources and demonstrated a strong commitment to HTS Technology.

1. PCS Capabilities: PCS started HTS research activity in 1987 in Milan to investigate the performance of HTS materials, develop ways to incorporate them into practical tapes, characterize tapes for the required properties, and study the technical and economic potential related to their use, particularly in power cables. In 1990 PCC started a joint development program with American Superconductor Corporation. A significant outcome of this program has been the availability, since the early-90's, of application–tailored HTS tapes in lengths of 200+ meters, each carrying up to 20 amperes in LN_2 and suitable for stranding in a flexible conductor with electrical and mechanical performance adequate for application in an AC power cable.

PCS has completed a design study under a contract (RP 7911-24) with EPRI. This design, focused on HTS cables for etrofitting pipes presently equipped with pipe–type cables, shows that HTS cables are feasible with the materials now becoming available, and that they could be extremely attractive in some market segments. PCS was a key Team member in the first phase of this development, in manufacturing the 50 meter RTD HTS cable which was successfully tested in March of 1996 and was tested under full load in late 1997.

PCS is the Prime Contractor in the current HTS demonstration project under SPI Contract No. DE-FC36-98GO10283. This project includes the supply of a 400 foot, complete 24 kV / 100 MVA warm dielectric cable system which will be installed by retrofitting existing 4 in. diameter ducts and operated in a Detroit Edison utility substation. Installation of the system will be conducted during the summer of 2001. This project has given PCS valuable experience in manufacturing longer cable lengths and accessories for field use as well as providing valuable insight into the requirements of installing a superconducting cable into a utility substation and integrating the control and monitoring of its performance with the utility SCADA system.

PCS has designed and developed industrialized equipment for cabling HTS tapes of long lengths. In addition, both electrical and mechanical testing equipment and methods, (ac loss measurement, strain measurements, etc.), have been developed by PCS for cable characterization.

In 1997 PCS reorganized their superconductivity activities on a world-wide basis: reinforcing commitment, facilitating customer input, and optimizing the technical approach in line with world-wide market dynamics.

2. American Superconductor Corporation Capabilities: American Superconductor Corporation (AMSC), founded in 1987, is an industry leader in developing commercial applications of HTS technology for the global electric power industry. AMSC employs a total of 399 employees in four locations in Massachusetts and Wisconsin. The Westborough, MA headquarters is comprised of 100,000 square feet of offices, research laboratories and manufacturing facilities. The Electric Motors & Generators Business Unit is housed in a separate facility also in Westborough. AMSC's Superconducting Magnetic Energy Storage (SMES) Business Unit is located in Madison, WI and the Power Electronics Business Unit in Milwaukee, WI. Additionally, AMSC is in the process of building the world's first large-scale HTS tape manufacturing facility, located at Devens, MA. When completed in 2002, it will be sized to allow the future manufacture of up to 10,000 km of HTS tape in its first year. American Superconductor remains poised to increase its HTS manufacturing capacity to keep up with the anticipated demand for HTS tape. American Superconductor's common stock is traded on the NASDAQ National Market under the symbol AMSC.

The Company's mission is to create and produce high temperature superconductor tapes, coils and fully integrated systems. These are targeted for compact, cost-effective electric power and magnet systems such as power transmission cables, motors and generators, energy storage devices, power converters, current leads and transformers. With world-class expertise not only in high temperature superconductors but also in electromagnetics, cryogenic integration, power semiconductors and power engineering, the Company is driving the evolving market for advanced electric power equipment and power quality products.

Since 1990, AMSC has been developing HTS tapes for power cable applications exclusively for PCS. Furthermore over the past several years, AMSC has received contracts from several government agencies, including the Department of Energy, the US Navy, the US Air Force, the Ballistic Missile Defense Organization, the National Science Foundation, NASA, the National Institutes of Health, and NIST's ATP Program. AMSC is also currently working under Cooperative Research and Development Agreements with Department of Energy National Laboratories (Oak Ridge, Los Alamos, Argonne, and Lawrence Berkeley) and with the Department of Commerce (NIST).

AMSC has also participated in several Superconductivity Partnership Initiative projects including the on-going Pirelli Detroit Edison Project, the ABB Transformer Project, the Dupont Industrial Magnetic Separator Project, and the Reliance Motors/Rockwell nternational Motor Project.

4. LIPA Capabilities:

The Long Island Power Authority (LIPA) is a corporate municipal instrumentality of the State of New York and was created by State legislation enacted in 1986. The Long Island Power Authority was authorized under its enabling statute to acquire all or any part of the securities or assets of the Long Island Lighting Company (LILCO) on a negotiated or unilateral basis and to issue lower cost, tax-exempt debt to finance such acquisition.

In February of 1992, title to Shoreham as well as Shoreham's Nuclear Regulatory Commission (NRC) "possession-only license" were transferred from LILCO to the Long Island Power Authority. In February 1996, the Long Island Power Authority Board authorized the commencement of negotiations with LILCO to acquire the company's securities or assets as a means of substantially lowering electric rates on Long Island. In June 1997, the LIPA Board approved Definitive Agreements between LIPA and LILCO, wherby LIPA would acquire the stock of LILCO for slightly less than its book value (after LILCO has transferred its on-Island generation and gas system to subsidiaries of a new LILCO/Brooklyn Union holding company [now known as KeySpan]), and would be responsible for serving electric customers in the LIPA service area. The acquisition was completed on May 28, 1998. The Long Island Power Authority utilizes the services of KeySpan Energy to manage the T&D system through its Management Services contract.

The transmission and distribution system owned and operated by the Long Island Power Authority *(LIPA)* supplies approximately 1.05 million customers that are located within a 1206 square mile area encompassing the Rockaway Peninsula in Queens (8 square miles), Nassau County (287 square miles) and Suffolk County (911 square miles). LIPA, and its predecessor, has a ong history of leading edge research and development in the transmission area. Some of the projects include:

* Temperature Monitoring of Overhead Transmission Lines to monitor actual conductor temperatures and power data on a transmission line to determine the effects of sheltering, line orientation, and weather conditions on line ratings.
* Fluid Filled to Solid dielectric cable transition splice.
* Directional drilling using the ACCUNAV system.
* DRUMS System
* Gas in oil monitoring system
* Installed the world's longest (23 miles) 138 kV solid dielectric in record breaking time of nine months, which included design, permitting, procurement and installation.

4. EPRI Capabilities: The Electric Power Research Institute (EPRI) was founded in 1973 to enable the electric power industry to pool resources and conduct research and development that will benefit member utilities, their customers, and society. Funded through voluntary membership dues from over 1000 energy organizations worldwide, more than 700 drawn from America's electric utilities, EPRI's work covers a wide range of technologies related to generation, delivery and use of electricity, with special focus on cost effectiveness and environmental concerns. A 24–member Board of Directors composed of senior utility executives, more than 600 utility technical experts, and an Advisory Council of leaders in industry, government, academia, and the environmental community participate in program planning and review.

At EPRI's headquarters in Palo Alto, California, more than 350 scientists and engineers manage some 1600 projects throughout the world. The work is carried out by hundreds of organizations, primarily industrial and commercial firms, universities, utilities, and government laboratories. Benefits accrue in the form of products, services, and information for direct applications by the electric utility industry and its customers.

EPRI's Underground Transmission Program, formed in 1975, has participated in every major innovation in underground transmission for nearly two decades. The Underground Transmission Task Force (UTFF), an advisory group of utility underground transmission experts, assists EPRI staff in the formation, development, demonstration, and technology transfer of EPRI–funded R&D. Past accomplishments include a) extending the development of paper–polypropylene–paper (PPP) laminated cable through the commercialization stage to its current status as the preferred dielectric for high–pressure fluid–filled pipe–type cable systems, b) developing a 345 kV flexible gas–insulated cable, c) developing dynamic sensors for monitoring the condition of underground circuits, and d) introducing innovative, cost–effective construction methods for installing cable systems.

The Transmission and Substations Business Area Council and the Distribution Business Area Council, advisory groups of utility transmission and distribution experts, assists EPRI staff in the formation, development, demonstration, and technology transfer of EPRI funded R&D.

5. Air Liquide/Cryo Technologies Capabilities: Air Liquide is a world leader in refrigeration and cryogenic technology. Air Liquide is an international group specialized in industrial and medical gases and related services. Focusing on this core business, Air Liquide has served over one million customers worldwide and posted annual sales of 8.1 billion Euros in 2000.

Founded in 1902, Air Liquide operates in 60 countries through 125 subsidiaries and employs more than 30,000 people. Air Liquide currently combines the resources and expertise of a global group with a powerful local presence, based on independent customer-focused Teams.

Air Liquide research and engineering Teams have achieve major advance in the past few years in gas production technology and are developing the PTR technology for cryogenic plants. Air Liquide has R&D facilities located worldwide (Europe, North America, Asia), and all share the objective of leveraging and managing technological innovation for Air Liquide. The R&D staff is comprised of over 550 researchers (14 nationalities) at 8 centers. Air Liquide has more than 277 new inventions, leading to more than 1,500 patents in the year 2000 and more than 2,000 inventions within the last 10 years.

Cryo Technology's current staff has over 100 years of cumulative experience in the engineering and design of custom process systems, with a primary focus on helium processing. CT offers comprehensive capabilities in all engineering and design disciplines including process, mechanical, instrumentation, controls, and project management. CT's strength and versatility in the areas of process and mechanical engineering and design are augmented by the adept use of commercially available and internally developed analytical software. CT's staff has extensive field experience from on-site participation in system installation, commissioning and start-up. Equipment is manufactured in accordance with CT's detailed drawings and specifications via subcontracts with premium quality shops specializing in fabrication of cryogenic and vacuum insulated process equipment. Commercially available components such as rotating equipment, valves and instruments are purchased in accordance with detailed engineering specifications, from quality suppliers with whom CT has long-standing relationships.

Cryo Technology's staff has participated in the successful execution of cryogenic system projects for many national laboratories and universities, and most industrial gas companies. This experience was gained through projects executed by the CT staff as the core project Team at CCI Cryogenics (former employer) and since 1995 through projects executed by CT.

These Projects executed by the CT staff for the research community include numerous helium refrigerators, liquefiers and ancillary equipment supplied to universities and laboratories for superconducting accelerators; a helium refrigerator cooled, supercritical neon circulating system supplied to Argonne National Laboratory for the Continuous Wave Deuterium Demonstrator (CWDD) program; a helium refrigerator supplied to Kaman Sciences for shield cooling in an underground nuclear testing application; the ASST-B magnet test system and pump boxes supplied to the SSC; and many others.

Industrial projects include three superconducting High Gradient Magnetic Separation Systems supplied to the clay industry; production scale helium purifiers and liquefiers supplied to Air Products and Chemicals, Inc., Airco/BOC and Unocal; a turnkey helium upgrader, purifier and liquefier production plant built for Colorado Interstate Gas Company; helium recycle systems for the specialty metals industry; and many others.

B. Key Personnel Capabilities

The project Team has assembled a talented and experienced group of project managers, scientists and engineers with the skills required for developing a commercial HTS cable system.

Nathan Kelley, Senior Engineer and Area Leader for Pirelli's Superconducting Cables and Systems Team in the United States will serve as Project Manager. Dr. Marco Nassi, Department manager for Pirelli's Worldwide activities in Superconducting Cables and Systems for Pirelli Cavi e Sistemi; Swapan Dey, Section Manager, Substation and Transmission for KeySpan Energy Services / LIPA; Dr. Paul Grant, Senior Fellow whose work provides the context for EPRI's Strategic Science and Technology program; Eric Snitgen, AMSC; Rick Hessinger and Alain Ravex for Cryo Technologies and Air Liquide will form the key members of the Project Team. Key and supporting personnel experience and capabilities are outlined in the appended pages *i* to *xvii*.

IV. BUSINESS CASE

This section presents a qualitative assessment of the opportunities for HTS power cables at transmission voltages and the methods used by PCS to evaluate possible impact and direct research objectives.

BACKGROUND MARKET ANALYSIS: A review of the installed base of pipe-type cables in the United States reveals that the 115 kV / 138 kV classes of power cables account for greater than 50% of all pipe-type cables installed. A recognizable trend has occurred during the past several years, as evidenced both through direct commercial inquiries to PCS, as well as by presentations and discussions at industry conferences, that there are significant efforts underway to increase the current carrying capacity of these existing underground pipes. With more than 2300 miles of existing pipe-type cable installed in the United States, even a small percentage of cable system upgrade opportunities will be a sustainable market with broad impact on the design and operation of the utility network.

The opportunity for increasing transmission of power using HTS cables was identified early by EPRI, who initiated the original design analysis for this application, and based on these conclusions managed the program for the manufacturing and testing of a prototype cable system, as introduced earlier. The results of this activity has revealed that the WD pipe retrofit opportunity is limited to cable ampacity of around 2000 Arms. Above this level, the combination of hysteretic losses in the pipe enclosure and the incident magnetic flux between the HTS conductors due to the trefoil cable configuration begins to diminish the performance advantages of this system. Also, the power delivery losses are increased due to coupling with the pipe.

For many years, pipe-type (also frequently called High Pressure Fluid Filled or HPFF) cable systems have been the most commonly used transmission cable type in the United States due to their reliability and compact system design. Consequently, there is a very large base of existing pipe infrastructure in the United States. The pipe-type system consists of three cables (one for each phase) installed in a common steel pipe.

MARKET ASSESSMENT AND MODELING: An analysis of the market factors influencing the adoption of HTS power cables has been undertaken by PCS and refined and revisited over the past several years. The model compares the total system cost to the customer for an HTS cable system and the cost of the complete conventional alternative. Total costs consider all aspects of both solutions, not simply the capital cost of the equipment or even the specific project cost of the cable and installation. The analyses performed encompass all the existing High Voltage conventional cable markets. However, specific opportunities have been excluded from the business model including,

- Direct Current (DC) cable market;
- Medium Voltage market;
- New opportunities in Transmission and Distribution markets;
- Markets related to industrial applications;

Before describing the logic behind the business plan, we would like to emphasize that the business model is periodically updated to incorporate new experience and developments. The need for continuous updates has brought us to the decision to develop a software tool that easily allows the model to be updated with new information and rapidly obtain an updated evaluation. The first step in the development of the business plan was to identify of the more promising opportunities in the HV market segment, such as retrofit applications of existing pipe, duct, or tunnel systems; urban penetration; and bulk energy transmission Then, current and future market volumes were evaluated by the sales agents of each country in which PCS has marketing activities.

Finally, a complex software tool was developed to simulate and understand the future market trends and evolution. This software uses as input several technical and economical details. The software permits the change of technical performance/cost ratio of the HTS system, the price policy used for market penetration, and then calculates the price of the installed HTS cable and compares it to the price of the conventional solution. The program is run several times while changing the different input parameters to understand their relative weight and the areas where more focus is needed. Based on the different set of assumptions probabilistic multi-space curves are obtained in order to estimate the most probable outcomes.

The anticipation of a sustained commercial market in the field of HTS power cables has been sufficient to justify significant corporate investments over the past 12 years. As the technology approaches commercial availability, the "market pull" phase of technology introduction will be entered. As the basic components (HTS tape and refrigeration) are very expensive, collaborative funding has been sought to offset these expenses. The design of this program will bring HTS cable technology to the state of commercialization, where the material and equipment costs will be borne in a commercial manner for future projects.

CRITICAL COST ELEMENTS: As discussed earlier, the commercial objective for HTS cables is to provide a total system cost which is competitive with the total system cost of the conventional alternative. Currently, the primary costs of a retrofit cable system are the HTS tapes and the refrigeration plant. Current activities in both fields promise a reduction in costs over the next few years. The completion of AMSC's factory suitable to produce up to 10,000 km of high quality BSCCO-2223 tape should result in a six-fold reduction in BSCCO-2223 tape price (from more than $300/kA-m to about $50/kA-m). Even at the reduced price level, the commercial promise of HTS cables will stem from applications which have limited conventional technical alternatives.

The specialized nature of the cryogenic refrigeration industry has resulted in cost structures having high engineering expenses. The engineering expenses are shown not only directly by the equipment provider, but also in many specialized components and sub-assemblies used in the system. HTS power cables could provide a market where standardization across a moderate sales volume can be reasonably applied to the design and manufacture of refrigerators. The technology used for cryogenic systems has other particular characteristics which result in high costs. Examining the system from a performance and operational viewpoint could result in the identification of costs which can be eliminated from a fully price-optimized refrigeration plant. The component and specific costs for the cable system and accessories has confirmed that the previously discussed items represent the largest specific cost for a cable system, as well as areas where improvements may be made through the use of advanced technologies. A substantial reduction of these costs is a primary focus of collaborations between PCS and leaders of both industries.

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51
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495
Manorville
Commack
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Lake Grove
Yaphank
East Quogue
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Center Moriches
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Whiskey Rd
Whiskey Rd
Rocky Point Rd
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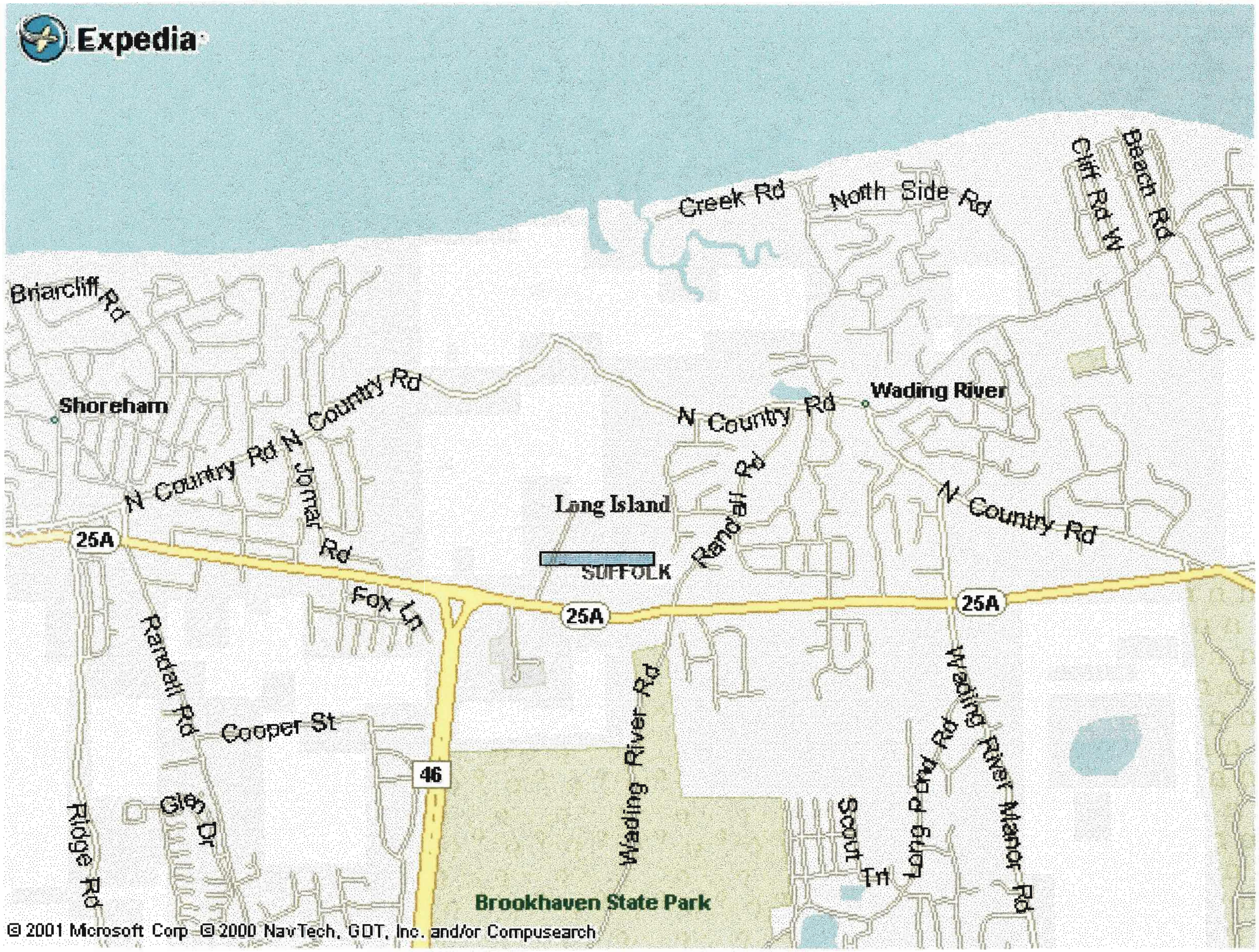
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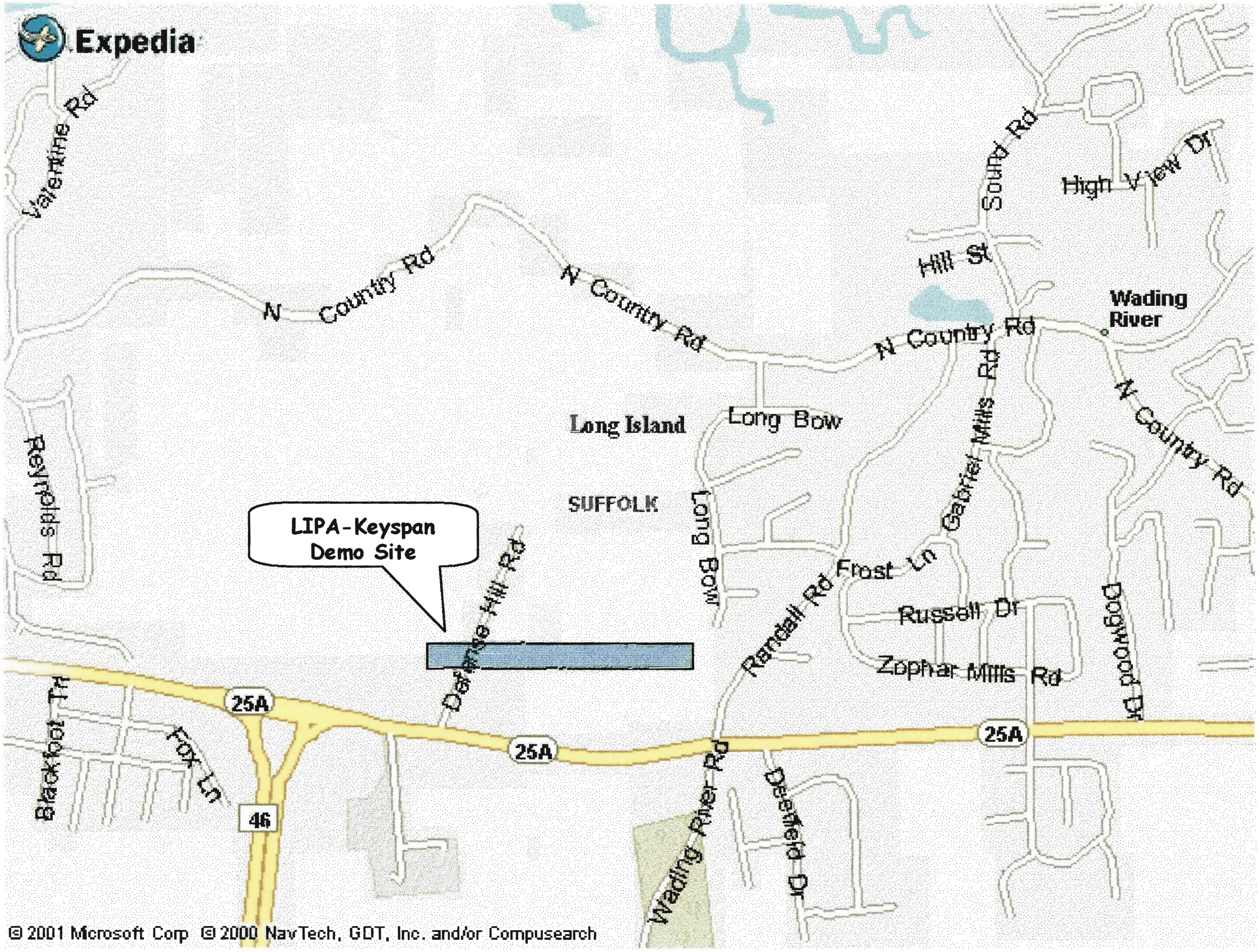
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