NREL/TP-450-20667 · UC Category: 1320 · DE96000510

The U.S. Market for High-Temperature Superconducting Wire in Transmission Cable Applications

Conducted by Donn Forbes
as Part of the Superconductivity
Partnership Initiative under contract with
the National Renewable Energy Laboratory

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by the Midwest Research Institute
for the U.S. Department of Energy
Under Contract No. DE-AC36-83CH10093

Prepared under Task No. SC61.0101

April 1996

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling (423) 576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Printed on paper containing at least 50% wastepaper, including 10% postconsumer waste

Preface

This report relates to a series of interviews with electric utility engineers on the consideration of superconducting (SC) underground transmission cable for integration into the present underground electric power distribution system. All of the interviews were based on the response to the questionnaire provided in the Appendix. The current and future interest of the utilities in the purchase and use of SC underground transmission cable is assessed. The various performance and economic factors are also considered as part of this inspection of the utility prospects and market for SC underground transmission cable.

The program to develop SC underground transmission cable was awarded in 1995 by the Superconductivity Partnership Initiative (SPI). The SPI is a major element of the Department of Energy (DOE) Superconductivity Program for Electric Systems. It features vertical teaming of a major industrial electric power manufacturer, a producer of high-temperature superconducting (HTS) wire, and an end-user, usually an electric utility, with assistance and technical support from the National Laboratories. The intent of the SPI effort is to accelerate the development, introduction, and commercialization of HTS electric power components into the electric utility sector. These superconducting based components will show market improvement in efficiency and operate with improved system performance over conventional non-superconducting technology.

The SPI effort on SC underground transmission cable is headed by the Electric Power Research Institute (EPRI) and Pirelli Cable. American Superconductor Corporation is the HTS wire and tape manufacturer and also provides significant cost sharing in the transmission cable development. Additional technical support is provided by the nation laboratories; Los Alamos and Oak Ridge. The end-user of utility interest in represented by EPRI.

Additional information on the EPRI/Pirelli/ASC SPI program can be obtained directly from the principals involved:

- Don Von Dollen, EPRI Program Manager, (415) 466-2679
- Mujib Rahman, Chief Engineer, Pirelli Cable, (803) 951-4010
- James Daley, DOE Superconductivity Program Manager, (202) 586-1165
- Jeff Hahn, DOE/GFO SPI Project Engineer, (303) 275-4775
- R. Blaugher, NREL, technical support, (303) 384-6518.

Table of Contents

	Page
Executive Summary	iv
The Underground Transmission Market	1
Plans for Cable Replacement and Retrofits	5
Forecasts for Underground Transmission Circuits	5
The Demonstration Period for Superconducting Cable	6
The Possibility of Retrofits with Superconducting Cable	7
Percentage of Respondents' Retrofit Cable Market that HTS Cable Would Capture	8
Perceived Advantages of HTS Cable	9
Concerns about HTS Cable	11
Potential Market Share for HTS Cable	13
The Most Promising Applications for HTS Cable	16
Utility Engineers Recommending HTS Cable: The Personal Perspective	17
Support for HTS Cable Development	18
U.S. Market for HTS Cable and for HTS Wire in Cable Applications	19
List of Figures	23
Appendix A: Cable Questionnaire	24
Appendix B: Respondents	27

Executive Summary

Telephone interviews were conducted with 23 utility engineers concerning the future prospects for high-temperature superconducting (HTS) transmission cables. All have direct responsibility for transmission in their utility, most of them in a management capacity. The engineers represented their utilities as members of the Electric Power Research Institute's Underground Transmission Task Force (which has since been disbanded). In that capacity, they followed the superconducting transmission cable program and are aware of the cryogenic implications.

Nineteen of the 23 engineers stated the market for underground transmission would grow during the next decade. Twelve of those specified an annual growth rate; the average of these responses was 5.6%. Adjusting that figure downward to incorporate the remaining responses, this study assumes an average growth rate of 3.4%. Factors driving the growth rate include the difficulty in securing rights-of-way for overhead lines, new construction techniques that reduce the costs of underground transmission, deregulation, and the possibility that public utility commissions will allow utilities to include overhead costs in their rate base.

Utilities have few plans to replace existing cable as preventive maintenance, even though much of the existing cable has exceeded its 40-year lifetime. Ten of the respondents said the availability of a superconducting cable with the same life-cycle costs as a conventional cable and twice the ampacity would induce them to consider retrofits. The respondents said a cable with those characteristics would capture 73% of their cable retrofits.

The 23 respondents agreed that the utility industry would require a demonstration project. Regarding the length of the demonstration, the average of the responses was 3.65 years.

Eighteen of the 23 respondents said the ability of an HTS cable to match the ampacity of an overhead line was very important. Eighteen also said they had an application for such a cable. The engineers expressed interest in the ability of HTS cable to carry equal power at lower voltages, and in the cable's environmental characteristics. On the other hand, they expressed concerns about maintenance, repair, training, quenches, and the cryogenic system.

The engineers said HTS cable with life-cycle costs equal to conventional cable and with twice the ampacity would capture 56% of the underground transmission market 10 years after the first commercial sale. If the life-cycle costs were 20% lower, the maximum eventual market share would rise to 75%. Among the most promising applications for HTS cable, they listed applications characterized by high ampacity or high voltage, urban environments, suburban environments, long-distance links, and environmentally sensitive areas. They were unanimous in stating that the United States should develop HTS cable.

The annual market predicted for HTS wire in U.S. cable applications will reach $20 million in 2005, $150 million in 2011, and $175 million in 2020. The cumulative market predicted for HTS wire in U.S. cable applications will reach $66 million in 2006, $249 million in 2009, $1 billion in 2015, and $2 billion in 2020.

The U.S. Market for High-Temperature Superconducting Wire in Transmission Cable Applications

During the week of April 23-27, 1994, Donn Forbes, a market researcher and business consultant with clients involved in superconductivity, conducted telephone interviews with 23 utility engineers concerning the future prospects for high-temperature superconducting (HTS) transmission cables. The engineers were all members of the Electric Power Research Institute's (EPRI's) Underground Transmission Task Force. All have direct responsibility for transmission in their utility, most of them in a management capacity. The questionnaire on which the interviews were based appears in Appendix A; the interviewees are listed in Appendix B.

The engineers reported that their utilities have a total installed capacity of 2438 circuit miles of underground transmission cable ($\geq$ 69 kilovolts [kV]). Public Service Company of Oklahoma and the Salt River Project in Arizona reported only 1 circuit mile of underground cable; 10 of the respondents have more than 100 circuit miles. Consolidated Edison Company of New York reported the largest installed base, 800 circuit miles of underground cables.

The Underground Transmission Market

According to EPRI statistics, U.S. utilities install about 100 miles of underground transmission cable each year. Respondents were asked whether they expected that market to grow, remain flat, or shrink during the next decade. Figure 1 illustrates the distribution of their responses.

Pattern of Change in Total U.S. Market for Underground Transmission During Next Decade

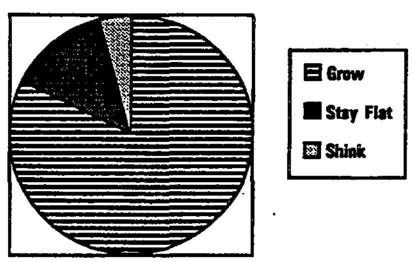

Figure 1

Of the 23 respondents, 19 said the market for underground cable would grow, driven by the need for new transmission capacity and the difficulty in acquiring overhead rights-of-way. Three said the market would remain flat; one said it would shrink.

> "The need for new transmission lines is growing, especially in urban areas, and there will be more and more environmental pressures to force them underground."
> —*James J. Pachot, Chief R&D Engineer, Bonneville Power Administration*

Of the 19 respondents who said the market would grow during the next decade, 12 were willing to quantify the average annual growth rate they expected. Figure 2 (below) specifies the annual growth rates that they forecast.

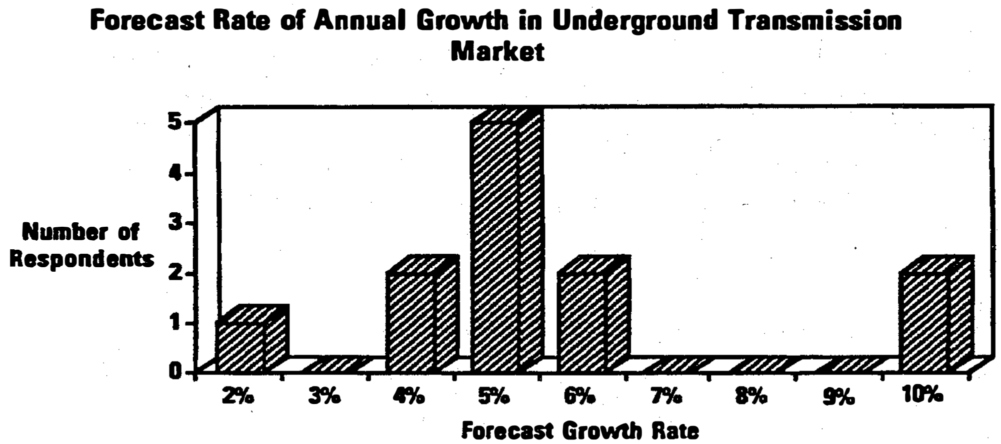

Figure 2

These 12 respondents forecast an average annual growth rate of 5.6%, which would cause the market to double in 13 years. Because the growth rate of underground transmission is a key factor in this study, it is important to derive an average rate of growth that incorporates all 23 responses, not just the 12 that forecast growth and were willing to quantify it. How, then, to include the seven responses that forecast growth but were unwilling to quantify it? To be conservative, Forbes tallied those seven responses as if they had forecast growth at 2%, the lowest growth rate cited. Likewise, he tallied the single forecast that the market would shrink as -2% growth. Figure 3 (below), which includes these conservative amendments, illustrates the distribution of all 23 responses.

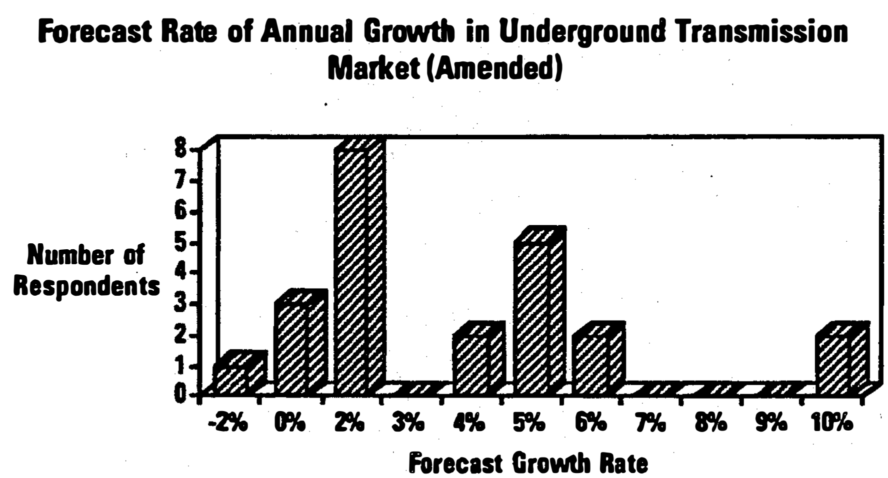

Figure 3

In this case, the average growth rate indicated by all of the responses is 3.4%. Figure 4 (below) illustrates the effect of a decade of 3.4% growth.

U.S. Market for Underground Transmission (Assuming 3.4% Growth)

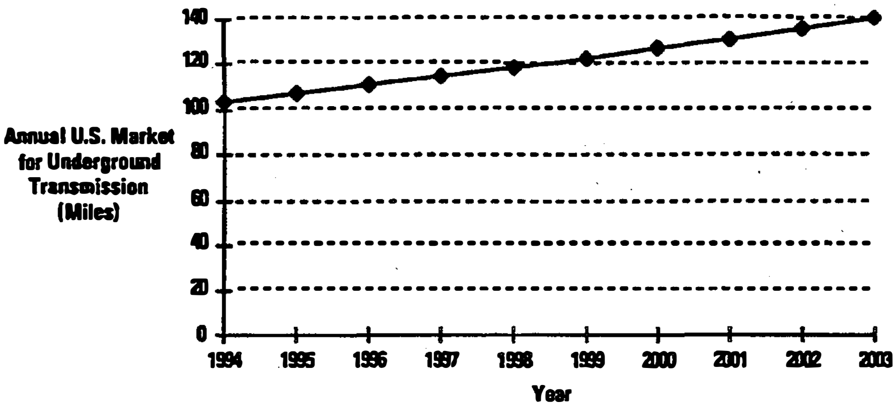

Figure 4

The anecdotal comments made by the transmission engineers clearly suggested that the market for underground transmission would grow. In some metropolitan areas, it is a foregone conclusion that installation of new overhead transmission lines is impossible.

> "In our service area, all new transmission capacity will be underground for the next 15 or 20 years. Overhead lines can go only in rural areas, and we don't have many of those. The total cable market could double in 10 years."
> —*Paul Barry, Division Manager of Transmission, Boston Edison Company*

> "Cities and counties want you to put it underground. In all the metropolitan centers in the Bay Area—San Francisco, Oakland, Milbrae, San Jose, and so on—anything over 12 kV has to go underground. They simply won't give you new rights-of-way for towers."
> —*L. Ralph Martinezmoles, Maintenance Superintendent, Pacific Gas & Electric*

> "In New York City we have committed to underground lines, and the same in Westchester. Within our service area, anything we build is going to be underground."
> —*Kenneth Maguire, Senior Engineer, Consolidated Edison*

Engineers from other metropolitan areas also report strong opposition to overhead transmission lines.

> "We're working on a system now that we decided in 1991 to put in the ground because we would be in the courts at least through 1997 to go overhead. Even to go underground, we have spent 3 years battling through a hearing process, but we did that because we needed a substation in an area that was weakly supported and had a growing load. I spend my life talking to real estate agents and lawyers. It's a continuous battle."
> —*Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company*

Even in less densely populated areas, utilities are facing the possibility that they may have to place most, if not all, of their new transmission lines underground in the future.

> "There's continuing pressure from municipalities to put underground cable in. Many municipalities would like to see us cease installing overhead lines in urban areas, but we and our customers might not be able to afford that. If cities can enforce total underground ordinances, we would have to put everything underground. EMF (Electric Magnetic Fields) may force that, because people are concerned about it, and we can get some reduction by going underground."
> —*Arthur J. Kroese, Principal Engineer, Power System Engineering, Salt River Project*

"I would hope underground transmission doesn't increase dramatically, but based on public concern about EMF, legitimate or not, I think it will increase. We will see more transmission lines in metropolitan areas placed in the ground with solid dielectric construction. Depending on how vigorously attorneys pursue this, the market might triple or quadruple if utilities get ramrodded into placing them underground."
—Daniel E. Jackman, Manager, T&D Centers, Omaha Public Power District

"At some point we are going to have to choose between putting cable underground or paying for land costs (i.e., buying everybody out along the way to put up overhead lines). People will give you an easement to go underground, but they'll make you buy the whole subdivision to go overhead. I think the courts will side with the landowners. Land value depreciation due to overhead lines is becoming a viable legal issue. Everybody's desire is to have everything underground. There's a reluctance now to pay for it. But people will start spending a lot of money to put things underground. For a utility our size, new installations of underground transmission will grow 10% per year or more."
—Michael F. Kotch, Principal Engineer, Tampa Electric Company

The respondents cited several factors that would stimulate growth of the market for underground cable. In some areas, cities and counties are sharing the installation costs.

"There are programs where we pick up some of the tab and they pick up some. I can see some of that going on. For example, starting next year, I have about 7 or 8 miles that I have to put underground at the request of city of San Jose."
—L. Ralph Martinezmoles, Maintenance Superintendent, Pacific Gas & Electric

"We have an aesthetics improvement fund. Municipalities can use the money to put overhead lines underground. They may be looking at that fund as a way to do it."
—Arthur J. Kroese, Principal Engineer, Power Systems Engineering, Salt River Project

Public utility commissions (PUCs) might make it easier to install underground cable by allowing utilities to pass on the costs to their customers.

"People are reluctant to give rights-of-way for overhead lines. At the same time, we are constrained by the public service commission to operate as economically as possible, so it will be a statewide consideration. For the good of all people in the state, the PUC will have to let us put cable underground and have that determine the rate base. Now underground cable can only influence the rate base as if it were overhead, unless underground were the only way to do the job. The PUC will have to look at that again. With superconductivity coming in, and right-of-way costs going out of sight, eventually we will get there."
—Michael F. Kotch, Principal Engineer, Tampa Electric Company

New construction technologies could expand the market for underground cable.

"I see opportunities to get the costs of underground cable down, not so much by lowering the price of the cable, although marginal improvement is available there. Significant improvement is available in reducing the construction costs by various methods. That will drive a lot of the market growth, because developers will be more willing to cover the costs."
—Arny D. Poppens, Principal Engineer, PSI Energy (Indiana)

Deregulation is another possible factor in the growth of underground transmission.

"Deregulation might be a factor. If somebody else built a 500-megawatt plant, it would change our load flows, and we might have to adjust our system. Today we operate generators and transmission lines together. If we deregulate, and the power plant owner operates his generator the way he wants to operate it instead of the way the transmission system is geared to accept it, we might have to up the transmission system."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"With the possibility of deregulation, things are in turmoil—there's a lot of confusion, and nobody wants to invest in major assets. If people start to see some profits in wheeling power, their attitude might change, and they might be willing to look at additional transmission and the benefits they could achieve. Deregulation could increase the market for underground transmission if there's a way to make money; a lot depends on the pricing. If it's unprofitable to wheel power, utilities won't go out of their way to build transmission. Everybody is talking about wheeling as if it were this great theoretical marketplace like the stock market, but it has constraints—there are physical limitations on the ratings of these lines, and superconductivity is one way to increase the underground capability. If there's money to be made in transmission, it will boost the interest in superconductivity."
—Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company

Plans for Cable Replacement and Retrofit

Only 3 of the 23 utilities have specific plans on the books to retrofit or replace existing underground cables, despite the fact that cable in many service areas has exceeded its nominal 40-year life. Philadelphia Electric Company (PECO) is operating cable installed in 1926. Utilities seem unlikely to replace underground cable for preventive maintenance.

"We have a replacement circuit going in now where the failure rate got so bad last August that we decided to pull it out over the winter. That one went too far. We have some other cable that I will try to get approval to replace proactively. Unfortunately, it's difficult to sell replacement of circuits which are performing, even if you get one or two failures per year, particularly in today's economic climate. We can show statistics and say failure is almost here. But it's a hard sell; we need a lot of data to convince our management to replace an old cable when it's still working."
—Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company

"Our oldest cable is roughly 40 years old. We're trying to squeeze out all the performance we can. Pipe-type cable is very reliable. There's no problem with the cable lasting another 30 or 40 years."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"Everything we have now is old. We have had few problems with our underground cables. I doubt whether anybody has looked at retrofitting these systems. "
—John B. Choban, Manager, Underground Cable, Centerior Energy Corporation

"Our oldest cable is a 115-kV cable installed in 1960. The youngest is a solid dielectric cable installed in 1976. We don't see them aging. At this time, we're just trying to get what we can out of that system. I don't see our cables failing for internal reasons."
—John Nierenberg, Associate Engineer, Puget Sound Power & Light

Forecasts for New Underground Transmission Circuits

Twenty of the 23 respondents expect their utilities to install underground transmission in the future. They were willing to estimate the total length of cable they expected their utility to install during the next 25 years, divided into 5-year periods. The total results appear below in Table 1.

Table 1. Unofficial Forecasts for New Transmission Circuits at 23 Utilities

Time Period	1994–1998	1999–2003	2004–2008	2009–2013	2014–2018
Forecast miles of underground cable among 23 utilities	136	182	154	138	189

If the 23 utilities actually buy cable according to this forecast, they will account for 23% of the total U.S. market that the respondents forecast for the 1994–1998 period, and also 23% of the total U.S. market the respondents forecast for the 1999–2003 period.

"It's important that the demonstration site be managed by typical utility people and the contractors they would hire."

The Demonstration Period for Superconducting Cable

All 23 engineers agreed that a demonstration would be necessary to establish reliability of superconducting cable.

> "A rule in utilities is that nobody wants to be first. In some cases, we evaluate new products with some research entity such as EPRI, and they contribute some of the money."
> *—Mohammad Khajavi, Electrical Engineering Associate, Los Angeles Department of Water and Power*

Figure 5 (below) illustrates the distribution of their statements regarding how many years a demonstration cable would have to be in service before the engineers would consider the technology reliable enough to purchase. Two of them said 1 year would suffice. Eight of them said 2 years was long enough to establish reliability. Ten of the engineers believed a 5–year demonstration would be required. The average figure cited was less than 3.65 years.

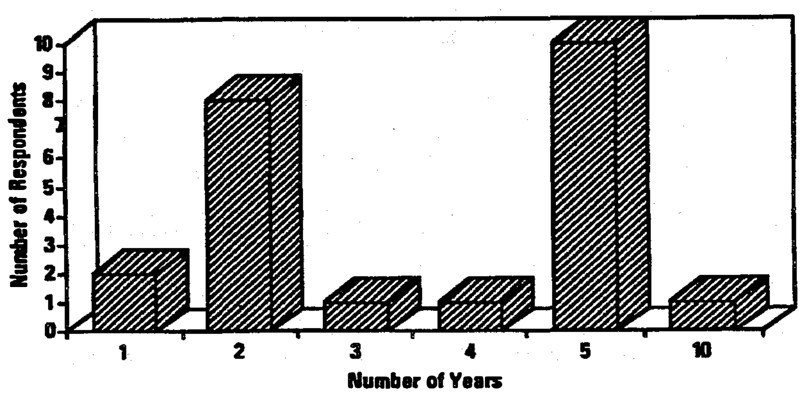

Figure 5

The respondents emphasized that the demonstration must simulate a utility environment.

> "It's important that the demonstration site be managed by typical utility people and the contractors they would hire. We don't want Ph.D.s from a research lab coming in to demonstrate cable for commercial ventures. The cable has to be a product which we can build and design and operate with the kinds of people we have available."
> *—Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company*

Although most of the engineers expressed their belief that utilities are conservative, one observed that utilities are becoming less resistant to new technology.

> "I think utilities are becoming more open to taking risks on new products that have potential benefits. Some utilities would buy a superconducting cable after a prototype had been in service for just 1 year."
> *—Larry A. Harper, Supervisor, Transmission Design and Relocation, Public Service Company of Oklahoma*

The Possibility of Retrofits with Superconducting Cable

Ten of the 23 respondents said that the availability of a superconducting cable with the same life-cycle costs as a conventional cable and twice the ampacity would lead them to consider retrofits that they would not otherwise consider (see Figure 6).

Would HTS Cable Lead You To Consider Retrofits?

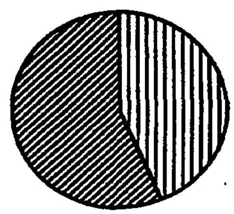

Figure 6

"Take a metropolitan area like San Francisco, New York, or Boston, where it's hard to install new cable. If you have a piece of pipe where you could double the ampacity, you will probably do that, because the big cost in installing underground is not so much cable and pulling cable, it is trenching and the hassles you go through with opening streets and things like that. I would say sure, if I have a cable right now that is old and failing, and I can increase ampacity in the same pipe with superconducting cable, we will take a close look at that."
—L. Ralph Martinezmoles, Maintenance Superintendent, Pacific Gas & Electric

On the other hand, the respondents mentioned several situations in which it would not make sense to retrofit with HTS cable.

"I don't think we would use HTS cable for retrofit. The retrofit would have to be based on overall system changes. There would have to be growth in the load. Our system is like a table with many legs, all the same size. It doesn't do us any good to put one huge leg in, unless a new generator comes on line or we need reinforcements . . . . Dielectric fluid leaks are a problem. At some point, the pipe will become the weak link. I would be concerned about putting HTS cable in a 40-year-old pipe."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"We design a system for a double-contingency outage. We can have one line out for maintenance and a second out for lightning and still maintain service to all our customers. That means we typically have three lines going to any one location. So we have actually triple capacity already in our system. When you are talking about a cable with double capacity, it wouldn't buy us a lot because we have to have those other systems with backup to give us the reliability we need."
—James J. Pachot, Chief R & D Engineer, Bonneville Power Administration

Percentage of Respondents' Retrofit Cable Market that HTS Cable Would Capture

Eleven of the survey respondents were willing to estimate the percentage of their retrofit cable that would be superconducting, provided that HTS cable had the same life-cycle costs as conventional cable and twice the ampacity. Figure 7 (below) illustrates the distribution of their responses.

Six of the 11 respondents said that HTS cable would account for 100% of their retrofits, if the HTS cable had the same life-cycle costs as conventional cable and twice the ampacity.

Percentage of Respondents' Retrofit Cable Which Would Be HTS (Assuming Equal Life Cycle Costs And Twice The Ampacity)

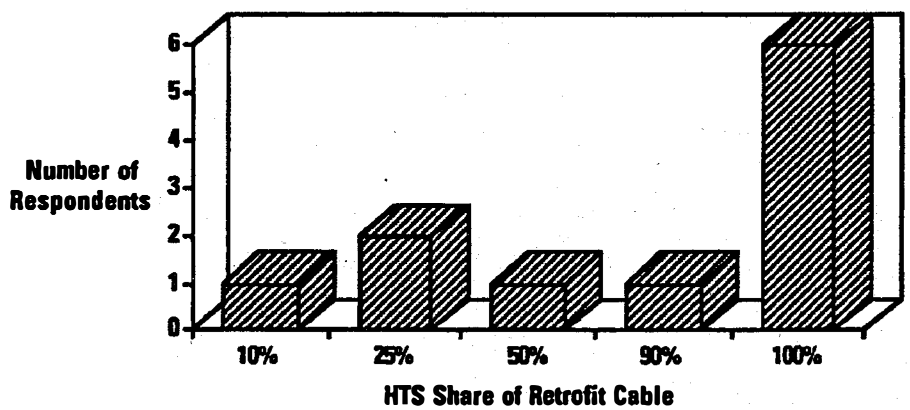

Figure 7

Six of the 11 respondents said that HTS cable would account for 100% of their retrofits. The average of 11 responses was 73%.

Figure 8 (below) shows what percentage of the respondents' retrofit cable would be superconducting if the HTS cable had life-cycle costs 20% lower than those of conventional cable and twice the ampacity. In this case, seven of the 11 respondents said that 100% of their retrofit cable would be superconducting. The average of the 11 responses was 80%.

A comparison of Figures 7 and 8 suggests that a 20% reduction in the life-cycle costs of HTS cable (down from 100% to 80% of the life-cycle costs of conventional cable) made a relatively small difference in its penetration of this market segment.

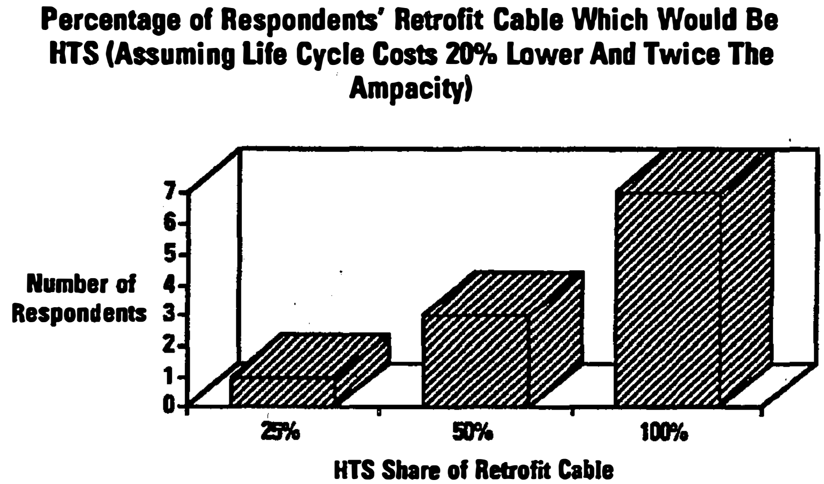

Figure 8

Perceived Advantages of HTS Cable

A well-known advantage of HTS cable is its ability to match the ampacity of an overhead line. Forbes asked the 23 respondents how important that advantage was to utilities: very important, important, somewhat important, or irrelevant. Their responses appear in Figure 9 (below).

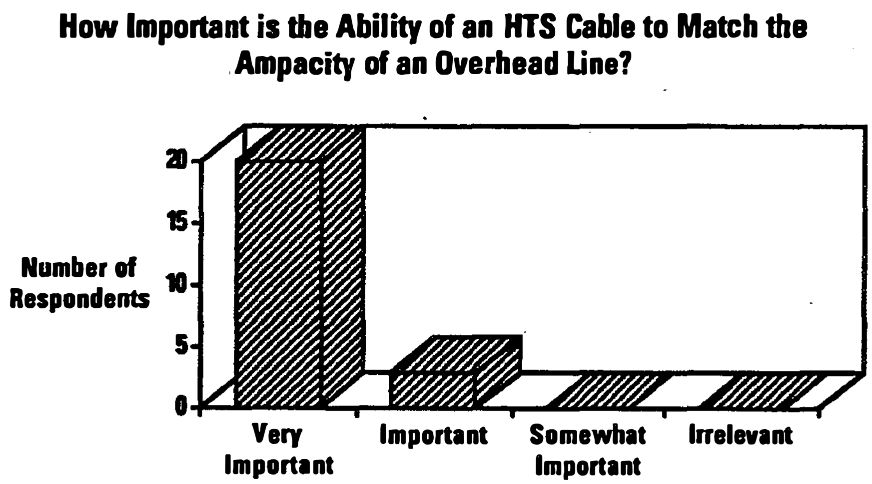

Figure 9

As Figure 10 (below) shows, 18 of the 23 respondents indicated that they had an application for a cable that could match the ampacity of an overhead line.

The respondents expressed the following viewpoints on the importance of matching the capacity of an overhead line.

> "To match the ampacity of an overhead line today, we would have to double and triple the conductor size. That sends costs through the roof."
> *—Michael F. Kotch, Principal Engineer, Tampa Electric Company*

Do You Have an Application for a Cable that Could Match the Ampacity of an Overhead Line?

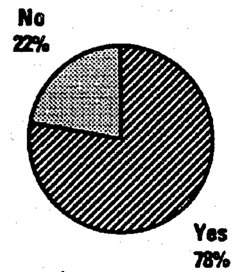

Figure 10

"Oftentimes, we have had instances in the last couple of years where we have had to put an overhead line underground. If the underground portion isn't equal in ampacity to the overhead portion, the underground becomes a weak link and decreases the capabilities of the system. We have to do it again in 1995."
—Jon R Tiemann, Supervising Engineer, Baltimore Gas & Electric Company

"Superconducting cable will be important when [an underground line] has to match the ampacity of an overhead line. With the current technology . . . you have to install two or three or four cables to match the ampacity."

"We have some areas now where we have dips in our system a mile or 2 miles long, and our biggest problem is you have to go to such a large conductor underground. The need for HTS cable is there. It would be great to have it."
—L. Ralph Martinezmoles, Mainenance Superintendent, Pacific Gas & Electric

"The ability to match the ampacity of an overhead line is very important. For example, at 115 kV an underground line carries about 600 amps of capacity per circuit, and an overhead line carries about 1500 amps. If you want to match an underground to an overhead line, you would have to put in two, almost three circuits. When you start putting in more than one underground circuit, heat builds up, so you get 100% of the rated value for the first circuit, but two circuits give you about 160% of the value of one circuit, and three circuits give you about 240% of the value of one circuit. So three would get you about 1400 amps. In many areas, utilities are having to take down overhead lines and replace them with underground lines. Southern California Edison may do that near Disneyland, and they would have to install four underground lines to match the capacity of the one that was overhead."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"Superconducting cable will be important when you have to match the ampacity of an overhead line. With the current technology, especially pipe-type or self-contained cable or XLPE, you have to install two or three or four cables to match the ampacity. We built a 345-kV line from Utica to East Fishkill, and one large section had to go under the Hudson River. We had to install six cables under the river to match the overhead line—actually, five plus one spare. That was 2400 MVA, about 4000 amps. At 115 kV or 138 kV you need two or three underground circuits."
—Edwin Hahn, Supervising Project Engineer, New York Power Authority

Some respondents stated that the ability of a superconducting cable to take the place of several conventional cables creates a need for even higher standards of reliability.

"That is what would sell the system: the ability to transmit the same amount of power at a lower, safer voltage."

"You need some flexibility. If you put all your eggs in one basket . . . say you have one big superconducting cable from the north and something happens to it, you're out of business. You could match the capacity of an overhead tower line, but what would you sacrifice in the way of reliability?"
—Kenneth Maguire, Senior Engineer, Consolidated Edison of New York

"One reason we are having a lot of problems accepting superconducting cable is that superconductivity gives you a huge leapfrogging from the capacity of conventional cable. It is likely that the superconducting cable can eliminate five or six other cables. In that case, the failure mode of the cable becomes more important, so they would look at it even more critically than standard cables. The failure of a superconducting cable might bring about a devastating power loss to the system."
—Swapan Dey, Senior Engineer, Long Island Lighting Company

One respondent voiced the opinion that the most important advantage of HTS cable is its ability to carry the same power as conventional cable at a lower voltage.

"What really helps is being able to transmit the capacity at a lower, more reliable voltage. You can transmit 3000 megawatts of power at 138 kV rather than 500 kV like we do now. That is what would sell the system: the ability to transmit the same amount of power at a lower, safer voltage. At lower voltages, substations become smaller because clearances are less, and safety and reliability seem to be better because you are talking about lower electrical stresses in all the electrical equipment. The main selling factor is a reduction in voltage for the same ampacity. You would end up with more transformers in parallel to get the power out, but the transformers would last longer because of lower electrical stresses in the equipment."
—James J. Pachot, Chief R&D Engineer, Bonneville Power Administration

Other transmission engineers pointed out that HTS cable is environmentally sound.

"I have seen this cable being developed by Pirelli Cable Company and American Superconductor Corporation. I think we as American electric utilities should continue to pursue it. There will be a need. As environmental concerns become greater, somebody will look at oil-filled cables in the future and say we can no longer install these systems. We will need an alternative."
—John B. Choban, Manager, Underground Cable, Centerior Energy Corporation

"I think the development of superconducting cables is exciting. We have to develop this technology because the backbone of our underground transmission line, the pipe-type cable system, is less environmentally acceptable because of oil leaks. So we have to find some other way. Solid dielectric cable is better environmentally, but ampacity-wise, solid dielectric is worse. Transmission lines will be the first utility application of superconductors."
—Edwin Hahn, Supervising Project Engineer, New York Power Authority

Concerns about HTS Cable

Many respondents expressed concern about the cryogenic system.

"One main concern is how well the refrigeration units operate and how easy it is to maintain them."
—Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company

"As a transmission engineer, I'm not too concerned about the superconducting cable itself, but I'm very concerned about the problem of maintaining the superconducting cable and its support apparatus."
—Swapan Dey, Senior Engineer, Long Island Lighting Company

"We have one installation, which we would potentially build in 2004, where HTS cable might be appropriate. Right now I don't think HTS cable would be appropriate because the circuit will be 12 miles long. I'm not concerned about the cable per se, but I'm very concerned about the liquid-nitrogen pumping. What scares me is that we would need pumping stations every mile or even every half mile. Can we pump liquid nitrogen for 12 miles?"
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"There's no philosophical reason not to buy superconducting cable if it's available, economical, and reliable. It's a more complex system, I suppose. I remember that old line, any fool can design something complicated, but it takes a genius to design something simple. All things being equal, we would go for the simple design."
—Allen McPhail, Senior Engineer, B.C. Hydro and Power Authority

"I'm concerned because in the city, we don't have any place to put cryogenic systems unless they make something that will fit into a manhole. We have no ability to locate it anywhere else. The cryogenic system would have to be about 4 ft x 4 ft x 6 ft."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

Several respondents wondered what would happen if the superconducting cable went normal.

"I would worry whether it would be safe. What if somebody dug into a street and broke the pipe? Would nitrogen fly up? Would the cable explode as it went from superconducting to normal?"
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"If the cable fails, it has to survive; if you drive it above critical temperature, you don't want to destroy the whole circuit. You have to let it warm to room temperature before you can work on it, then handle any cryogenic liquids or gases, repair the fault in a timely fashion, cool it back down, and then put the line back in service. Even on existing pipe-type systems, that can be a lengthy process, it can take a month or more, but you want to keep it down to days if you can. The availability of the line is a big decision factor in selecting a system, and it doesn't always show up in the cost studies. We don't put a dollar value on faults and repairs in our financial analysis, but we still think about it."
—Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company

"Will it work during faults? If there is a high current for a short period of time, the superconductor can go normal on you. It may be only for 1/10 a second, but that is enough to blow the line up. Minor wrinkles like that might affect reliability."
—Allen McPhail, Senior Engineer, B.C. Hydro and Power Authority

"What if a superconducting cable goes by a line that's leaking hot steam? There are too many ifs."
—Kenneth Maguire, Senior Engineer, Consolidated Edison of New York

Some of the engineers expressed concern that maintenance and repair costs for an HTS cable would be too high.

"Any kind of outages we can restore pretty quickly. Unless you drop a conductor, it's just a matter of hours. I don't know how long it would take to repair a superconducting cable. We don't have any experience with it."
—Kenneth Maguire, Senior Engineer, Consolidated Edison of New York

"Where we need major feeder circuits in metropolitan areas, superconducting cables would be worthwhile if their costs are reasonable. But if you need unusual construction or expensive conductors or high maintenance, the technology won't be worth the effort. If superconducting cables are going to be useful for utilities, they have to be something we can put into the ground and forget."
—Daniel E. Jackman, Manager, T&D Centers, Omaha Public Power District

Another important issue is the training of utility staff to operate, maintain, and repair HTS cable successfully.

> "Our crews are trained to handle oil-filled or extruded cables. To change over the crews and train them on superconducting cables would be expensive and time consuming. Our hourlies would consider superconducting cables to be technically more challenging. They might be reluctant to get into that. That would hold us back."
> *—James J. Pachot, Chief R&D Engineer, Bonneville Power Administration*

One respondent emphasized the importance of ancillary hardware.

> "I'm skeptical. They are coming up with a superconducting cable, but I'm not sure they have the right connections, splicing, and terminations. I think that's where the biggest problems are going to lie. There will be a lot of weak links in the system if you increase the power but stick with standard splices and terminations. If they can take care of those problems and then the cost . . . right now the way the economy is, if the cost could be comparable, we would definitely try it out."
> *—Arthur J. Kroese, Principal Engineer, Power System Engineering, Salt River Project*

Potential Market Share for HTS Cable

Twenty-one of the 23 engineers were willing to quantify the percentage of the total underground cable market that HTS cable would eventually capture, assuming it had the same life-cycle costs as conventional cable and twice the ampacity. The answers varied widely, as shown in Figure 11 (below).

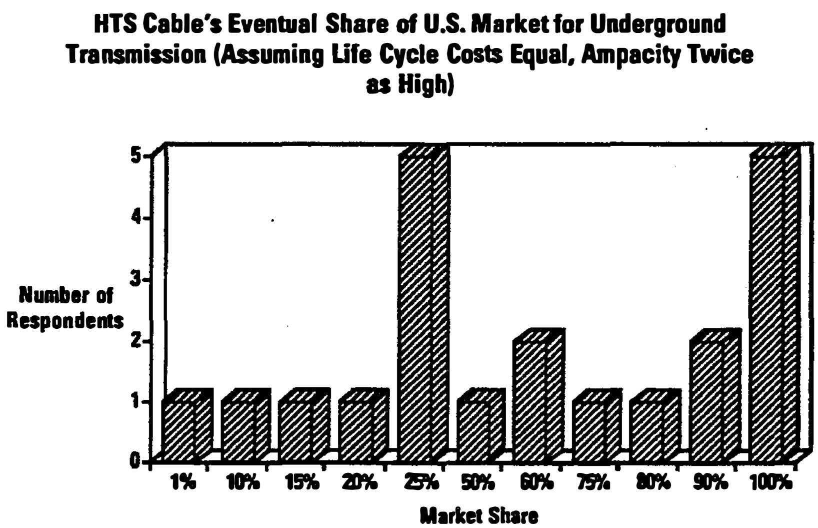

Figure 11

The most common answers were 25% (five respondents) and 100% (five respondents). The average of the 21 answers was 56%.

The 21 engineers who provided data for Figure 11 also estimated the number of years it would take after the first commercial introduction of HTS cable for it to attain the market share that they forecast. Once again, the answers varied widely, as shown in Figure 12 (below).

The most common answer was 10 years, which was given by 11 respondents. The average of the 21 responses was also precisely 10 years.

Years Required for HTS Cable To Capture Maximum Market Share

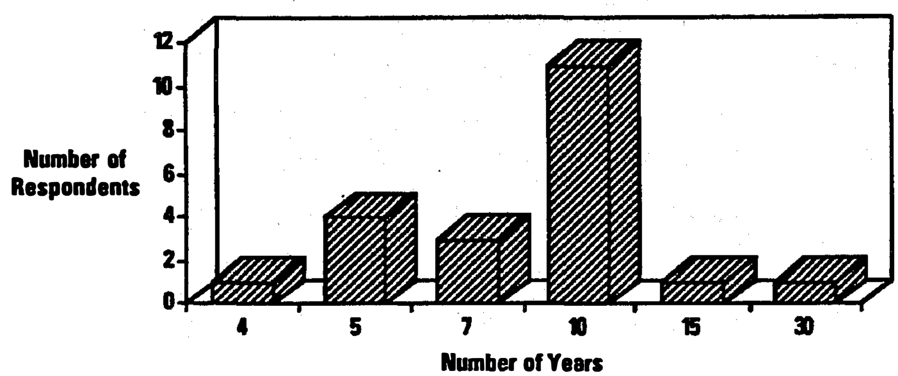

Figure 12

"Sales of HTS cable would start slowly because utilities are conservative. After the demonstration stage, you might get 10% of the market for the first year, and after those installations had been operating for a year or two sales would pick up. It would start slow and build; it would get 50% to 60% of the market within five years."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"Realistically, I think it will take 5 to 10 years to get the first stuff in the ground and then another 10 years for everybody to start using it. Once the stuff is in with 10 years of experience, everybody will be on the bandwagon."
—Michael F. Kotch, Principal Engineer, Tampa Electric Company

The 21 respondents also specified the eventual market share that HTS cable would capture under slightly different circumstances: life-cycle costs 20% lower than those of conventional cable with double the ampacity. Figure 13 (below) shows the results.

HTS Cable's Eventual Share of U.S. Market for Underground Transmission (Life Cycle Costs 20% Less; Ampacity Twice as High)

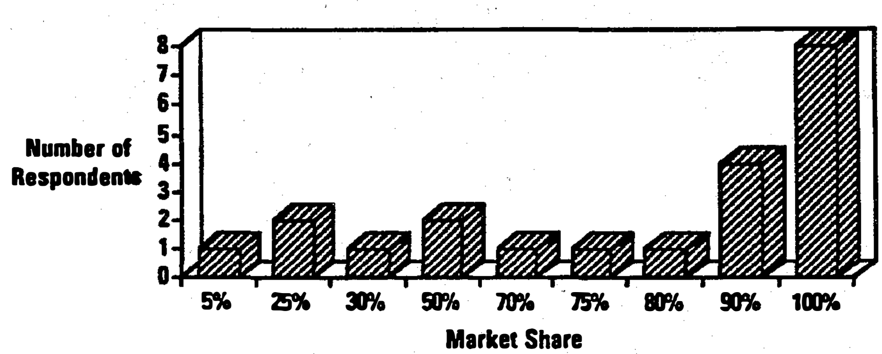

Figure 13

The respondents indicated that 20% lower life-cycle costs would allow HTS cable to gain a significantly larger market share. In this case, the most common response was 100% (eight respondents), and more than half of the respondents said either 90% or 100%. The average of the 21 responses was 75%.

Nineteen of the 23 respondents said that their utilities buy on the basis of life-cycle costs rather than initial capital costs (Figure 14).

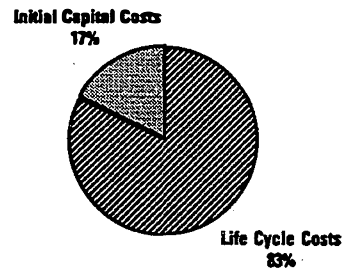

Figure 14

However, several respondents pointed out that life-cycle costs were not the sole determining factor.

> "The initial cost differential is important in any case. If life-cycle costs are equal, the HTS cable can cost 10% to 20% more than a conventional cable. If the life-cycle costs of the HTS cable are 20% lower, then you could afford a premium on the front end, but even then, the up-front cost could only be 20% or 30% higher than that of a conventional cable."
> *—Jon R. Tiemann, Supervising Engineer, Baltimore Gas & Electric Company*

> "I don't know how much larger the capital cost could be to justify lower life-cycle costs. Maybe twice as much would be feasible. Assuming environmental issues are equal; those are becoming an overriding concern."
> *—Michael F. Kotch, Principal Engineer, Tampa Electric Company*

> "Life-cycle costs 20% lower might increase the market penetration rate, but reliability is more important than life-cycle costs."
> *—Allen McPhail, Senior Engineer, B.C. Hydro and Power Company*

> "The highest-rated underground cable we have installed so far is 69 kV. We are a pretty rural utility. We might go to 138 kV, but not over that in the foreseeable future. At those voltages, we don't need superconducting cables because we can accomplish what we need with solid dielectrics. Even if the life-cycle costs were 20% lower, we wouldn't install it because we have enough freedom and flexibility to choose to do something other than the cheapest way, if we aren't comfortable with the cheapest way."
> *—Arny D. Poppens, Principal Engineer, PSI Energy (Indiana)*

One engineer pointed out that the environmental people at his utility were redefining life-cycle costs to include disposal costs:

> "We buy on the basis of life-cycle costs, which, as of recently, even include disposal costs. Environmental people within the utility are trying to get us to look at disposal costs of some types of equipment."
> *—Paul Barry, Division Manager of Transmission, Boston Edison Company*

This trend could be favorable for HTS cable suppliers because it might lead utilities to include the recycle value of silver as a benefit in their life-cycle cost equation.

The Most Promising Applications for HTS Cable

The respondents listed six promising applications for HTS cable: situations that require high ampacity, situations that require high voltage, urban environments, suburban environments, long-distance links, and environmentally sensitive areas.

High Ampacity

> "When a superconducting cable system becomes available, my gut feeling is that in the beginning growth will be very slow because a lot of people are reluctant to use new technology. Once it has been proven, everybody will use it. But it will not totally replace pipe-type cable. Where people don't need high ampacity, they will continue to use conventional cable. Here are three examples of where you would use superconducting cable:
>
> "In New York City, there are about six feeders coming into the World Trade Center. If we had a superconducting cable, you would only need one or two.
>
> "In big cities like New York, you usually have two different loops in the system. Between loops, you need a tie circuit—if you lose one loop, you can feed power from the other. But you can't supply the entire system from one loop, because it doesn't have enough capacity. That's another good application for the future. All the major cities in the United States have the same type of problem.
>
> "Most of the underground cable up to 230 kV was installed 30 or 40 years ago. Since then the load in big cities has increased tremendously, and there is no right-of-way to add more circuit. There's only one way to increase the power: pull out all the old 69 kV or 115 kV cables and replace them with superconducting cable."
> —*Edwin Hahn, Supervising Project Engineer, New York Power Authority*

High Voltage

> "Cryogenics are feasible for us only at 230 kV and above. We carry only 1000 amps on 69-kV circuits and less than that on 115-kV circuits, so there's no reason for cryogenics. At 230 kV, we have a 4000-amp requirement. That's where HTS cable starts to look fairly good."
> —*Gilbert Smith, Senior Engineer, Transmission/Substation Division, Southern California Edison*
>
> "It wouldn't surprise me if the Salt River Project had to install a new underground transmission cable every 3 to 5 years. I'm not certain we will use superconducting cables, because we may not require that level of capacity. HTS cables will have the capability to transfer tremendous amounts of power. It may present a viable option for getting large amounts of power into congested inner-city areas in Los Angeles, New York, Philadelphia, and Chicago."
> —*Arthur J. Kroese, Principal Engineer, Power System Engineering, Salt River Project*
>
> "The superconductors can carry a lot more power than overhead transmission lines. They have a lot of advantages, but they might be too expensive. I think they will be appropriate only for 230 kV and above. At lower voltages, there are many trouble-free cables you could install."
> —*Mohammad Khajavi, Electrical Engineering Associate, Los Angeles Department of Water and Power*
>
> "Superconducting cables will be limited to 230 kV and above. In this country, 230 and above is a minority percentage. If I had to guess, I'd say it's less than 25%."
> —*Arny D. Poppens, Principal Engineer, PSI Energy (Indiana)*

Urban Environments

"Growth of underground transmission will skyrocket in urban centers. It's inevitable that underground transmission will grow as places become more congested; there are no alternatives. Plus the environment—people have a fear of EMF or they want to get rid of overhead transmission for aesthetic reasons, and they are becoming more prepared to pay for it."
—John Nierenberg, Associate Engineer, Puget Sound Power & Light

"I think the government should fund the development of HTS cable. There will be applications for it in major urban utilities, where you need to deliver a large volume of power to a dense area and you're really limited in ways of getting there."
—Arny D. Poppens, Principal Engineer, PSI Energy (Indiana)

Suburban Environments

"In our latest project, we went in with the idea of building a double-circuit overhead line, and the suburb didn't want any part of it, so we had to go underground. Underground will pick up more in the suburbs. People want us to tear down some of our lines because they're building an airport. For example, we have an overhead 345-kV line that carries over 3000 amps, a double-circuit line. If we wanted to replace a mile of it, that would be a perfect application for HTS cable."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

"The value of increased ampacity depends on the installation. The ability to match the ampacity of an overhead line, one to one, will be more important in the suburbs, where you are bringing power from a distant area and you can connect a cable in series with an overhead line. In urban areas, cable is more prevalent; but you have a network system where you don't have control over the flow—the power flows are determined by the phase angle of the different substations. You can put in a high-ampacity circuit, but you might not be able to use it; it depends on the cable's position in the network."
—Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company

Long-Distance Links

"The cable is important because today's technology won't let us transmit large blocks of power underground for long distances—the impedance is too high, so you don't get any power out the other end."
—Daniel E. Jackman, Manager, T&D Centers, Omaha Public Power District

Environmentally Sensitive Areas

"We're concerned about the environmental aspect of fluid-filled cables. Ultimately we'll have to replace it with something that does not require fluid. If the government says to get rid of all the fluid in the ground, or we have a major failure we can't go in and splice, then we have this pipe in the ground, and it would be good to put a new one in. To be environmentally friendly as well as having a higher ampacity would be a big selling point."
—Michael F. Kotch, Principal Engineer, Tampa Electric Company

Utility Engineers Recommending HTS Cable: The Personal Perspective

Companies wishing to sell HTS cable to utilities should recognize that utility engineers take personal risks when they recommend new technology.

"I'm skeptical, and I'm more interested in the R&D side than most utility engineers. I worked with EPRI and the U.S. Department of Energy (DOE), and I tend to be positive toward new products, but when it comes to recommending them to PECO, you have to remember that my job depends on my recommending good, reliable products that are economical and survive the long haul."
—Stanley V. Heyer, Manager, Transmission Branch, Philadelphia Electric Company

"To a utility engineer responsible for transmission, from a selfish point of view, it means more professional risk. I have a little motto on my wall, a quote from Machiavelli, who talks about how hard it is to initiate a new order because so many want to hold onto the old and are reluctant to try something new. It's always easier to stick with the conventional. If I were to champion something like that, I would be taking more personal and professional risk, as well as opening the possibility of participating in some of the rewards for providing a better system."
—Allen McPhail, Senior Engineer, B.C. Hydro and Power Authority

Conversely, they also take personal risks when they fail to recommend new technology.

"If utilities should learn that the failure modes of superconducting cable are few and far between, and if the possibility that a superconducting cable could go normal is extremely remote, then they will have no problem going after a superconducting cable instead of a standard cable system. It would be difficult for me as a transmission engineer to present to my management that I would not prefer superconducting cable if they know it is going to cost less, and maintenance will be less also."
—Swapan Dey, Senior Engineer, Long Island Lighting Company

Support for HTS Cable Development

All 23 respondents expressed the opinion that HTS cable is an important technology and that the United States should develop it.

"I think we need to keep putting funds into HTS cable. That's why we're funding a study with EPRI. The technology will be important to the energy future of the United States if we can develop it. I'm not at the point of saying it will work, but we need to put money in to see if we can make it work."
—Gilbert Smith, Senior Engineer, Transmission/Substation Division, Southern California Edison

"The problems are not insurmountable. I think it will be one cable in the arsenal in 10, maybe 12 years. I don't know whether it will be the only cable you ever use, but I think it will be something people want to use."
—Paul Barry, Division Manager of Transmission, Boston Edison Company

" . . . if we move to electric cars or have another large electrical power load on our system, we will have to build a lot more infrastructure and our cable systems won't be able to keep up . . . that's where superconductivity can help us."

"I think superconductivity is a technology we need to look at, because it will be a viable part of our industry. I don't see any other form of energy replacing electricity. We may even see increased use of electric energy, which would mean we need greater transfer capability in the transmission and distribution system. In metropolitan areas, the increased use of electric vehicles could increase demand on our system even during daytime, not just at night. People may be driving them during the day and get a fast charge; we hear about that technology all the time: drive in, get a fast charge, keep on going. That could increase demand for electricity, which would put demands on generation, transmission, and distribution. That could drive us to higher transfer capabilities. Superconductivity allows you to get more power over the same corridor than any other technology; even overhead couldn't handle the same power that superconductivity could."
—Arthur J. Kroese, Principal Engineer, Power System Engineering, Salt River Project

"I think it's crucial to invest in superconducting technology because if we don't keep moving it until we get comfortable, it won't be a viable resource for us when our power requirements jump again. Right now power requirements slowly continue up, but if we move to electric cars or have another large electrical power load on our system, we will have to build a lot more infrastructure and our cable systems won't be able to keep up. We have a bottleneck in cables, and that's where superconductivity can help us."
—John Nierenberg, Associate Engineer, Puget Sound Power & Light

"I think superconducting cable will be the next major step in developing the underground systems for the future of utilities. I definitely think that is the direction we need to go in, and we need to devote enough money to develop a reliable system that will handle the capacities we are talking about now for major overhead projects."
—James J. Pachot, Chief R&D Engineer, Bonneville Power Administration

"I think the interest in HTS cable is there. There's almost a mandate for it. The public's expectations have been raised over the last few years. Rights-of-way restrictions will drive us underground, and we will need all the ampacity we can get."
—Michael F. Kotch, Principal Engineer, Tampa Electric Company

"I definitely feel that it's important to develop superconducting cable. Somebody has to fund the development, and we should coordinate our efforts. In a research environment, you won't hit 100% of the time, but if you don't try, you are never going to hit."
— Daniel E. Jackman, Manager, T&D Centers, Omaha Public Power District

"I definitely think the superconducting cable is worth developing. There are places where it can be used. The project looks hopeful from what I have seen. I hope the funding is not discontinued. We should keep on the same research path."
—Mohammad Kjahavi, Electrical Engineering Associate, Los Angeles Department of Water and Power

"Superconducting cable is a really important part of our strategic research program for the future. Ultimately, it might bring lower transmission costs, which you can pass on to the customer. A less expensive infrastructure helps your country compete successfully in the world economy."
—Allen McPhail, Senior Engineer, B.C. Hydro and Power Authority

U.S. Market for HTS Cable and for HTS Wire in Cable Applications

Table 2 shows how the U.S. market for HTS cable (and for HTS wire in cable applications) will grow between 2002 and 2020, based on the information provided by the 23 transmission engineers consulted in this market study. The following assumptions have been made for this table:

- The total U.S. underground cable market will grow 3.4% per year from 1994-2003. This growth rate is derived from the engineers' statements.

- The total U.S. underground cable market will grow 1.7% per year from 2004–2020. Because the survey respondents were unwilling to forecast the growth rate of the cable market for longer than one decade into the future, the growth rate has been arbitrarily cut in half for the remainder of the survey period.

- The first commercial sale of HTS cable will occur in 2002. The U.S. cable team of Pirelli, American Superconductor, Underground Systems, EPRI, Los Alamos National Laboratory, and DOE has proposed to finish testing a 30-meter cable prototype and designing a 100-meter, three-phase cable prototype by 1998. Assuming they begin testing the 100-meter cable prototype in the year 2000, the first commercial sale could occur two years later.

- HTS cable will take 56% of the total underground cable market in 10 years. The engineers specified this market share according to this timetable. The table assumes that the market share would grow according to the curve shown in Figure 15 (below), starting slowly—1% the first year, 2% the second year, and 4% the third year. This table ignores the engineers' statements that HTS cable could take 75% of the market if its life-cycle costs were 20% below those of conventional cable.

Table 2. U.S. Market Forecast for HTS Cable and for HTS Wire in Cable Applications

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Circuit Miles of Cable	135	140	142	144	147	149	152	154	157	160
HTS Cable Percentage	1	2	4	8	12	17	23	31	42	56
Circuit Miles of HTS Cable	1	3	6	12	18	25	35	48	66	89
Cumulative Circuit Miles of HTS Cable	1	4	10	21	39	64	99	147	213	303
Miles of HTS Wire	405	838	1704	3465	5286	7616	10,479	14,364	19,791	26,837
Annual Sales of HTS Wire ($000)	2,282	4,719	9,598	19,523	29,782	42,908	59,039	80,927	111,506	151,203
Cumulative Sales of HTS Wire ($000)	2,282	7,001	16,599	36,121	65,903	108,811	167,849	248,776	360,282	511,485

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Circuit Miles of Cable	162	165	168	171	174	177	180	183	186
HTS Cable Percentage	56	56	56	56	56	56	56	56	56
Circuit Miles of HTS Cable	91	93	94	96	97	99	101	102	104
Cumulative Circuit Miles of HTS Cable	394	486	580	676	773	872	973	1075	1179
Miles of HTS Wire	27,293	27,757	28,229	28,709	29,197	29,693	30,198	30,711	31,233
Annual Sales of HTS Wire ($000)	153,773	156,387	159,046	161,750	164,499	167,296	170,140	173,032	175,974
Cumulative Sales of HTS Wire ($000)	665,258	821,645	980,691	1,142,440	1,306,940	1,474,236	1,644375	1,817,408	1,993,381

Assumptions:
Total U.S. underground cable market grows 3.4%/year 1994-2003; 1.7%/year 2004-2020
First commercial sale occurs in 2002
HTS cable takes 56% of total underground cable market in 10 years
Each meter of HTS cable contains 300 meters of HTS wire (100 meters per phase)
HTS wire costs $3.50/meter

Percentage of Total U.S. Underground Transmission Market Captured by HTS Cable

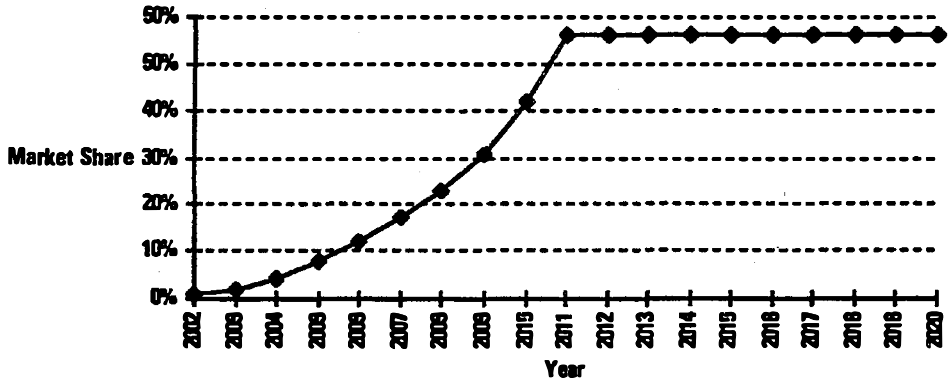

Figure 15

- Each meter of HTS cable contains 300 meters of HTS wire (100 meters per phase). This assumption is based on the configuration of early prototype cables made by Pirelli and American Superconductor, and by Sumitomo Electric Industries.

- HTS wire costs \$3.50 per meter. This is an extremely challenging goal, because HTS wire probably costs ten times that much today. However, \$3.50 per meter is the price necessary to match the life-cycle costs of conventional cable, according to a study by European cable makers. The U.S. market may allow higher costs, because the European study assumed a design that contained more superconducting material (a cryogenic dielectric design with superconducting material used in shielding as well as in the conductors). In that sense, \$3.50 is a conservative number for estimating the HTS wire market—U.S. cable applications may allow a somewhat higher cost.

Given these assumptions, the annual market for HTS wire in U.S. cable applications will grow as shown in Figure 16 (below), reaching \$20 million in the fourth year of commercial sales (2005) and \$150 million in the 10th year (2011). After the 10th year, HTS cable has reached its maximum market share of 56%, and further growth is created only by 1.7% annual growth of the total market. Sales reach \$176 million in the year 2020.

Annual Market for HTS Wire in U.S. Cable Applications (Millions of Dollars)

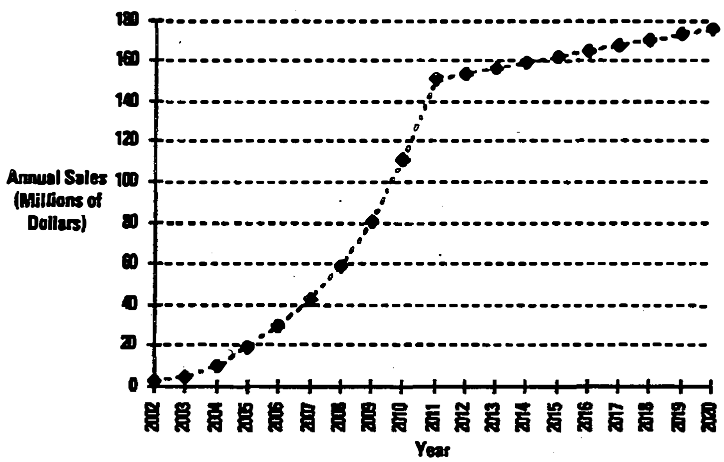

Figure 16

The total cumulative market for HTS wire in U.S. cable applications will grow as shown in Figure 17 (below), reaching $66 million in 2006, $249 million in 2009, $1 billion in 2015, and $2 billion in 2020.

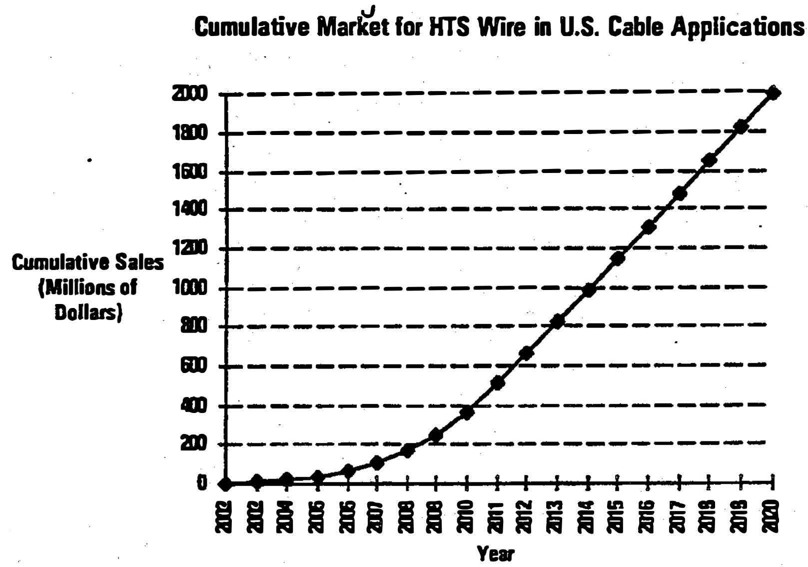

Figure 17

If the European and Japanese markets grow in a similar manner, the world market could be three times the U.S. market, in which case the annual world market for HTS wire in cable applications would exceed $500 million per year in 2020. The cumulative market during the first two decades of the 21st century would exceed $6 billion.

List of Figures

Page

Figure 1. Pattern of Change in Total U.S. Market for Underground Transmission During Next Decade 1

Figure 2. Forecast Rate of Annual Growth in Underground Transmission Market 2

Figure 3. Forecast Rate of Annual Growth in Underground Transmission Market (Amended) 2

Figure 4. U.S. Market for Underground Transmission (Assuming 3.4% Growth) 3

Figure 5. Years of Demonstration Required to Establish Reliability 6

Figure 6. Would HTS Cable Lead You To Consider Retrofits? 7

Figure 7. Percentage of Respondents' Retrofit Cable Which Would Be HTS (Assuming Equal Life-Cycle Costs and Twice The Ampacity) 8

Figure 8. Percentage of Respondents' Retrofit Cable Which Would Be HTS (Assuming Life-Cycle Costs 20% Lower And Twice The Ampacity) 9

Figure 9. How Important is the Ability of an HTS Cable to Match the Ampacity of an Overhead Line? 9

Figure 10. Do You Have an Application for a Cable that Could Match the Ampacity of an Overhead Line? 10

Figure 11. HTS Cable's Eventual Share of U.S. Market for Underground Transmission (Assuming Life-Cycle Costs Equal, Ampacity Twice as High) 13

Figure 12. Years Required for HTS Cable to Capture Maximum Market Share 14

Figure 13. HTS Cable's Eventual Share of U.S. Market for Underground Transmission (Life-Cycle Costs 20% Less; Ampacity Twice as High) 14

Figure 14. Does Your Utility Buy on the Basis of Initial Capital Cost or Life-Cycle Costs? 15

Figure 15. Percentage of Total U.S. Underground Transmission Market Captured by HTS Cable . . 21

Figure 16. Annual Market for HTS Wire in U.S. Cable Applications (Millions of Dollars) 21

Figure 17. Cumulative Market for HTS Wire in U.S. Cable Applications 22

Appendix A: Cable Questionnaire*

New Cable Installations

1. Are you considering future installation of underground transmission cables (> 69 kV)?

   ___Yes

   If so, what are your main motivations?

   - ☐ Difficulty in securing overhead rights-of-way
   - ☐ Concerns about overhead EMF
   - ☐ Retail power wheeling and deregulation
   - ☐ Other________________________________

   ________No (If you checked No, please skip to question 9.)

2. What is the total length of underground transmission capacity (> 69 kV) you expect to install during the following time frames?

	New Underground Transmission Capacity (miles)
1–5 years	
6–10 years	
11–15 years	
16–20 years	
20–25 years	

3. Superconducting cable can match the ampacity of an overhead line one-for-one (> 69 kV). How important is that advantage to you?

   ______Very Important ______Important ______Somewhat Important ______Irrelevant

4. Do you have, or will you have, any application for an underground cable that would match the capacity of an overhead line one-for-one?

   ______Yes ______No

5. Do you buy equipment on the basis of initial capital costs or life-cycle costs?

   ______Initial Capital Costs ______Life-Cycle Costs

6. If a superconducting cable had the same life-cycle costs as a conventional cable and transmitted twice the power, what percentage of your new cable would be superconducting? ______% (of total length)

*Used as a guide for telephone interviews.

7. If a superconducting cable had 20% lower life-cycle costs than a conventional cable and transmitted twice the power, what percentage of your new cable would be superconducting? ______% (of total length)

8. How long would a prototype superconducting cable have to be in service without problems before you would consider it reliable enough to purchase? ________________(length of time)

9. If a superconducting cable had the same life-cycle costs as a conventional cable and transmitted twice the power, what percentage of the total U.S. market for new cable would it capture? _______%

10. If a superconducting cable had 20% lower life-cycle costs than a conventional cable and transmitted twice the power, what percentage of the total U.S. market for new cable would it capture?_______%

Cable Retrofits

11. Do you have any underground transmission circuits (> 69 kV)?

_______Yes: Total length _________miles

_______No (If you checked No, please stop here.)

12. Are you considering replacement or retrofits for any of your existing underground cables?

_______Yes What lengths? _______ _______ _______ _______ _______

When? ___________ _______ _______ _______ _______

_______ No

13. Would you consider retrofitting with a superconducting cable that can carry twice as much current in the same size pipe?

_______Yes

Does the additional ampacity interest you because you would

- ☐ Increase the loading on the circuit?
- ☐ Use it to enhance system stability?
- ☐ Other

_______No

14. If a superconducting cable had the same life-cycle costs as a conventional cable and transmitted twice the power, what percentage of your retrofit cable would be superconducting? _______%

15. If a superconducting cable had 20% lower life-cycle costs than a conventional cable and transmitted twice the power, what percentage of your retrofit cable would be superconducting? _______%

16. Would the availability of a superconducting cable with twice the ampacity of a conventional cable cause you to consider retrofits that you would not otherwise consider (that is, retrofits not described in Question 12)?

________Yes What lengths? ________ ________ ________ ________ ________

When? ________ ________ ________ ________ ________

________ No

Appendix B: Respondents

Respondent	Utility
Barry, Paul	Boston Edison Co., Boston, MA
Basu, Sankar	Public Service Electric & Gas Co., Newark, NJ
Choban, John	Centerior Energy Corp., Independence, OH
Clark, Ross	Western Area Power Administration, Golden, CO
Dey, Swapan	Long Island Lighting Co., Hicksville, NY
Hahn, Edwin	New York Power Authority, New York, NY
Harper, Larry	Public Service Company of Oklahoma, Tulsa, OK
Hartlein, Richard	Georgia Power Co., Atlanta, GA
Heyer, Stanley	PECO Energy Co., Philadelphia, PA
Jackman, Daniel	Omaha Public Power District, Omaha, NE
Khajavi, Mohammad	Los Angeles Department of Water & Power, Los Angeles, CA
Kotch, Michael	Tampa Electric Co., Tampa, FL
Kroese, Arthur	Salt River Project Agricultural Improvement & Power District, Phoenix, AZ
Lennon, Kevin	Northern States Power Co., Minneapolis, MN
Maguire, Kenneth	Consolidated Edison Co., New York, NY
Martinezmoles, Ralph	Pacific Gas & Electric, San Francisco, CA
McPhail, Allen	B.C. Hydro, Vancouver, British Columbia
Nierenberg, John	Puget Sound Power & Light Co., Bellevue, WA
Pachot, James	Bonneville Power Administration, Portland, OR
Poppens, Arny	PSI Energy Inc., Plainfield, IN
Russell, Edward	Houston Lighting & Power Co., Houston, TX
Shupe, Robert	Niagara Mohawk Power Corp., Syracuse, NY
Smith, Gilbert	Southern California Edison Co., Rosemead, CA
Tiemann, Jon	Baltimore Gas & Electric Co., Baltimore, MD

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB NO. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 1996	3. REPORT TYPE AND DATES COVERED Technical Report	
4. TITLE AND SUBTITLE The U.S. Market for High-Temperature Superconducting Wire in Transmission Cable Applications			5. FUNDING NUMBERS (C) (TA)SC61.0101
6. AUTHOR(S) Donn Forbes and R. Blaugher			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Boulevard Golden, Colorado 80401-3393			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Energy 1000 Independence Ave., SW Washington, D.C. 20585			10. SPONSORING/MONITORING AGENCY REPORT NUMBER TP-450-20667 DE 96000510
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			12b. DISTRIBUTION CODE UC. Category: 1320
13. ABSTRACT (Maximum 200 words) This report relates to a series of interviews with electric utility engineers on the consideration of superconducting (SC) underground transmission cable for integration into the present underground electric power distribution system. The current and future interest of the utilities in the purchase and use of SC underground transmission cable is assessed. The various performance and economic factors are also considered as part of this inspection of the utility prospects and market for SC underground transmission cable.			
14. SUBJECT TERMS high-temperature superconducting wire, transmission cable applications, Superconductivity Partnership Initiative, electric power distribution			15. NUMBER OF PAGES 27 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89
Prescribed by ANSI Std. Z39-1
298-10