ORNL/Sub/97-SX339V/1

ornl

OAK RIDGE NATIONAL LABORATORY

LOCKHEED MARTIN

PROSPECTS FOR THE MEDIUM- AND LONG-TERM DEVELOPMENT OF CHINA'S ELECTRIC POWER INDUSTRY AND ANALYSIS OF THE POTENTIAL MARKET FOR SUPERCONDUCTIVITY TECHNOLOGY

Zheng Li
Bob Lawrence & Associates

MANAGED AND OPERATED BY
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-27 (3-96)

DISCLAIMER

Portions of this document may be illegible electronic image products. Images are produced from the best available original document.

ORNL/Sub/97-SX339V/1

PROSPECTS FOR THE MEDIUM- AND LONG-TERM DEVELOPMENT OF CHINA'S ELECTRIC POWER INDUSTRY AND ANALYSIS OF THE POTENTIAL MARKET FOR SUPERCONDUCTIVITY TECHNOLOGY

Prepared by
Bob Lawrence & Associates, Inc.
Alexandria, Virginia 22314
under
Subcontract No. SX339V

Funded by
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
(B&R EB5001000)

Date completed: December 1997
Date published: May 1998

Prepared for
Superconductivity Program for Electric Systems
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6195
managed by
Lockheed Martin Energy Research Corporation
for the
U.S. Department of Energy
under Contract DE-AC05-96OR22464

PROSPECTS FOR THE MEDIUM- AND LONG-TERM DEVELOPMENT OF CHINA'S ELECTRIC POWER INDUSTRY AND ANALYSIS OF THE POTENTIAL MARKET FOR SUPERCONDUCTIVITY TECHNOLOGY

Prepared By:

Zheng Li
Bob Lawrence & Associates, Inc.
Alexandria, VA 22314

December 31, 1997

TABLE OF CONTENTS

LIST OF TABLES

FOREWORD

Energy is an essential requirement for social progress and development. Electricity is an advanced and convenient energy source. The electric power industry has a foremost importance to the national economy and is an important symbol of modern social life. The development of China's electric power industry is closely linked to the nation's economic growth.

First of all, overall economic growth objectives in China are concisely and succinctly specified in this report. Secondly, this report presents a forecast of energy supply and demand for China's economic growth for 2000-2050. In comparison with the capability of energy construction in China in the future, a gap between supply and demand is one of the important factors hindering the sustainable development of China's economy. The electric power industry is one of China's most important industries. To adopt energy efficiency through high technology and utilizing energy adequately is an important technological policy for the development of China's electric power industry in the future.

After briefly describing the achievements of China's electric power industry, this report defines the target areas and policies for the development of hydroelectricity and nuclear electricity in the 2000s in China, presents the strategic position of China's electric power industry as well as objectives and relevant plans of development for 2000-2050.

This report finds that with the discovery of superconducting electricity, the discovery of new high-temperature superconducting (HTS) materials, and progress in materials techniques, the 21st century will be an era of superconductivity. Applications of superconductivity in the energy field, such as superconducting storage, superconducting transmission, superconducting transformers, superconducting motors, its application in Magneto-Hydro-Dynamics (MHD), as well as in nuclear fusion, has unique advantages. Its market prospects are quite promising.

The report analyzes the relevant research and development (R&D) situations in a number of countries, including China. Based upon this, it analyzes those technology policies pertaining to superconductivity that will possibly be adopted by China's energy industry on the basis of forecasts; it expounds that the superconducting energy industry will be one of the important high-tech industries that China will develop in the 21st century; it briefly introduces progress in both basic research and application research of superconducting electricity. In considering the prospects for the development of China's electric power industry in the 21st century, this report has optimistically revised the outlook for market development of superconductivity products in the year 2020, which was put forward by ISIC-II on May, 1993, and addresses some issues that exist in development of China's superconducting energy industry today.

This portion of the final report was authored by Zheng Li, a technically trained individual with an additional Masters in Business Administration. Mr. Li was formerly the Second Secretary for the Embassy of the Peoples Republic of China in Washington, DC, in the Science and Technology Section. In compiling this report, Mr. Li was assisted by a number of technical consultants in the PRC; relationships stemming from his days at the Embassy. The sources of information were what we considered to be the best sources possible.

As the reader will see in this report, the analysis and the way the report is written is different from the customary American way of doing similar things. Several parallel Chinese analyses are presented, with differing results, so that the range of predictions can be seen. Also, in the US, we never see reports showing projected demand, and how it will outstrip supply, but this is clearly presented in this report. Finally, the energy units addressed in this report are units adopted by the United Nations and the International Energy Agency. Such units as "Million tons of coal equivalent" (Mtce) are included, which have virtually nothing to do with a ton of coal at the mine mouth.

In order to preserve the flavor of this report, we have not changed it from the way the Chinese technical experts generated it aside from editing it to be more readily understandable, but in order to understand the numbers in traditional American terms, the following Conversion Factors are presented:

1 Ton of Coal Equivalent (tce) = 7 GigaCalories (Gcal) = 8.13 Megawatt hours (Mwhr)
1 tce = 1,000,000 grams of coal equivalent (gce)
1MWhr = .861 Gcal, 1 Gcal = 1.163 MWhr
1 MWhr = 3.412 MBTU
1 Ton of Oil Equivalent (toe) = 11.9 MWhr
1 Metric Ton of Crude Oil = 40.39MBTU = 10.18 Gcal = 7.32 "Barrels of Oil" =
1.84MWhr = 1.454 tce = 1.018 toe
1tce = 0.7 toe; 1 toe = 1.428 tce

The above conversion factors were obtained from the Energy Information Administration through Mr. Robert Lowe at (202)-426-1171. Mr. Lowe referenced the United Nations Department of International Economic and Social Affairs; Statistical Office; Report entitled: "Studies and Methods Series F, #44: Energy Statistics: Definitions, Units of measure, and Conversion Factors".

Finally, the report points out that international cooperation and exchange of science and technology is one of the most important trends at present in the development of worldwide high-tech industries. Cooperation and exchanges between China and the United States in the field of energy are mutually complementary to a certain degree, and have benefited both countries in their efforts to develop a superconducting technology industry in the 21st century.

We hope that you find the report interesting and informative.

L. R. Lawrence, Jr.
President
Bob Lawrence & Associates

A. GENERAL OBJECTIVE OF CHINA'S ECONOMIC GROWTH

Energy provides power for national economic development. It is a necessity of peoples' lives and a important industrial raw material as well. Electricity is a kind of advanced and convenient energy. The electric power industry should be in the forefront of the national economy, representing an important symbol of modern social life. The strategic objective of China's energy development, including the strategic objective of electric power industry development, is closely tied to economic growth.

The 12th Party Congress presented a strategic objective for China's economic development by the year 2000: The general objective of economic development from 1981 to 2000 is to strive to double the Gross National Product (GNP) under the premise of consistently increasing economic efficiency.

The 13th Party Congress presented a strategic objective of China's economic development by 2000: GNP would be doubled compared with that of 1980. The average standard of living will reach the lower-middle level. By the middle of the next century, the general per capita standard of living will reach a level comparable to middle-income in the developed countries. People will live more prosperously, and the Four Modernizations will begin to be realized.

The 14th Party Congress stated that China's economic growth rate was originally planned as 6% per year, but in terms of the current national development situation, it could be faster. In accordance with calculation and forecasts, 8% or 9% could be possible. We should go for this objective. From 1979 to 1994, the annual growth rate of China's GNP was 9.8% on average. During 1986 to 1994, the annual growth rate of China's GNP was 9.7% on average, greater than any country in the world. In the early 1990s, the annual growth rate of China's economy was greater than 10% on average. The forecast showed that shortly after 2000, the scale of China's economy would be doubled. Living would be more prosperous with more income and more purchasing power.

B. FORECASTS OF SUPPLY AND DEMAND OF ENERGY AND ELECTRICAL POWER IN CHINA'S ECONOMIC GROWTH

The speed-up of economic development requires corresponding energy support. Presently, some research institutes have made some forecasts of China's energy demand for 2000 as well as the demand for the middle of the next century. They also did some research on the relationship between rapid development of the national economy and energy demand, but came up with different conclusions. The main reason for this is that their ways of determining elastic coefficients of energy production and rates of energy conservation vary.

The most prevalent viewpoints for forecasting China's energy demand for 2000 are as follows:

1. National Statistics determines that the elastic coefficient of energy demand for the 1990s is 0.5, which is based upon the fact that both the elastic coefficient of energy production and consumption for the 1980s are 0.56, the energy conservation rate is 3.6% on average by the end of this century and the structure of energy consumption in China will remain almost the same. As a result, the elastic coefficient of energy demand may go down by enhancing economic development and energy conservation. Based upon that, GNP would go up by 8-9%, the general demand for energy in 2000 would be 1540 - 1600 Mtce, including hydroelectricity of 140 - 240 TWh and nuclear electricity of 30 Twh.

2. The Energy Institute, Chinese Academy of Science, sponsored by the National Planning Committee, determines that the elastic coefficient of energy that is adequate for ten years from now is 0.4 - 0.5 (0.4 is taken), based upon energy production and consumption for previous years and history of economic development. The elastic coefficient of energy consumption for electric power is about 1 (0.8 is taken). Supposing that the GNP growth rate is 9%, it is anticipated that general demand for energy in 2000 would be 1480 Mtce, including hydroelectricity of 230 Twh and nuclear electricity of 10 TWh. The total demand for electric power in 2000 would be 1360 Twh.

3. An expert group from the former Ministry of Energy forecasts that the general demand for energy in 2000 would be 1510 Mtce, including hydroelectricity of 240 Twh and nuclear electricity of 10 TWh. The total demand for electricity energy in China in 2000 would be 1350 TWh.

In terms of these three forecasts for China's energy demand by 2000, we estimate that the total demand for energy in China should not be less than 1500 Mtce, and that electricity generation should not be less than 1350 TWh (See Table 1).

Table 1. Forecasts for China's Energy Demand for the Year 2000

	National Statistics		Energy Institute	The Former Ministry of Energy Group
GNP Growth Rate (%)	8	9	9	9
The General Demand for Energy (Mtce)	1540	1510	1610	1480
Raw Coal (Mt)	1600	1500	1670	1570
Crude Oil (Mt)	200	200	165	165
Natural Gas (Million cubic m)	30,000	30,000	N/A	25,000
Electricity (TWh)	N/A	N/A	1360	1350
Hydro-electricity (TWh)	140	240	230	240
Nuclear Electricity (TWh)	30	30	10	10

TsingHua University adopts a way that analyzes sectors to determine general demand for energy in China from 2000 - 2050 (See Table 2.1 and Table 2.2), its forecasts for hydroelectricity and nuclear electricity are generally consistent with those estimates in Table 1.

The general consumption of energy in China in 1995 was 1290 Mtce, including raw coal, 75%; crude oil, 17.3%; natural gas, 1.8%; and hydroelectricity, 5.9%. Energy consumption in China primarily relies on raw coal as determined by China's natural resources. However, we can see a trend from Table 2 that the percentage of raw coal in energy consumption will decline to 67% by 2020, and be about 70% by 2050. The percentage of crude oil will decline. The percentage of natural gas will go up. The percentage of hydroelectricity will go up, accounting for 9% of the whole energy structure by 2020, but will go down to 6.46%, which has to do with the completion schedule for hydropower projects. The percentage of both nuclear and new energy in the country's energy structure will go up by 2050.

Table 2.1 Primary Energy Structure in China from 1988 to 2050

Year	Total (Mtce)	Coal (Mt)	Crude Oil (Mt)	Natural Gas (Million cubic m)	Hydroelectricity Installed Capacity (MW)	Hydroelectricity (TWh)	Nuclear Electricity Installed Capacity (MW)	Nuclear Electricity (TWh)	New Energy (Mtce)
1988	958	979.87	137	14260	32.6981	109.177	0	0	0
2000	1500	1494	200	30,000	65	247	6	36	0
2020	2400	2264	250	100,000	160	608	30	180	10
2050	5200	5160	116	200,000	260	988	240-300	1,440-1,880	250

Table 2.2 Primary Energy Structure in Percentage in China from 1988 to 2050 (%)

Year	*Coal*	*Crude Oil*	*Natural Gas*	*Hydroelectricity*	*Nuclear Electricity*	*New Energy*
1988	73.05	20.4	1.98	5	0	0
2000	71.1	19.04	2.66	6.25	0.9	0
2020	67.35	14.88	5.53	9.1	2.7	0.41
2050	68.67-70.9	3.18	5.1	6.46	9.4 - 11.77	4.8

The TsingHua study predicts the Chinese energy production capability estimates for the future:

Table 2.3 TsingHua Study Predictions of Chinese Energy Production Capability

Year	Coal (Mt)	Crude Oil (Mt)	Natural Gas (Million M^3)	Hydro Electricity (Twhr)	Nuclear Electricity
2000	1350	165	20,000	220-230	15
2010	1800	200	25-30,000	400	60

This shows that there is a gap between forecast supply and demand. This gap, including electricity, is one of those important factors that will hinder sustainable development in China. The electric power industry is important and fundamental in China, which is to be developed a great deal during the Ninth Five-Year Plan, ending in 2010, and for quite a long period of time thereafter. In addition, China will adopt high technology to utilize energy rationally.

C. CURRENT SITUATION OF THE ELECTRIC POWER INDUSTRY AND PERSPECTIVE OF MEDIUM AND LONG-TERM ECONOMIC GROWTH IN CHINA

In 1996, China's energy industry, including the electric power industry, achieved satisfactory progress. China's general production of energy in 1996 was 1260 Mtce, which is up by 4.6% as compared with the previous year; the production of raw coal was 1380 Mtce, up 4.5% compared with the previous year; the production of crude oil was 158 Mt, up 5.3% compared with the previous year; and electricity generation was 1075 TWh, up 6.7% compared with the previous year. Since The Reform, China's electric power industry developed so fast that the tight supply of electricity in most areas was alleviated. Although there were still shortages of electricity supply in some areas, some areas experienced temporary over-supplies of electricity. Examining the last few years of the 20th century, the electric power industry will provide the capability to achieve the second step of China's strategic objective: Get Chinese people to a lower-middle living standard and guarantee the sustainable, rapid, and healthy development of the national economy.

1. Current Situation of China's Electric Power Industry

By the end of 1996, the installed capacity of electricity generation in China was 236.54 GW, while electricity generation reached 1079.4 TWh. Both of these numbers represent second place in the world, trailing only the United States.

In 1995, China promulgated "The Electricity Law", which took effect on April 1, 1996. This is a significant event in the history of China's electricity development, as it provides for the protection of legal rights of electricity investors, operators, and users and for the safeguarding of the generation, supply, and utilization of electricity.

China's electric power industry is growing very rapidly; information on China's installed capacity and generation of electricity is laid out in Table 3.

China's electricity generation in 1995 reached 1006.948 TWh, up by 8.6% compared with 1994. The generation of electricity in 1995, including hydroelectricity, was 186.772 TWh, up by 12% compared with 1994; thermal power electricity, 807.343 TWh, up by 8.1%; nuclear electricity, 12.833 TWh, down by 8.6%. The consumption of fuel for electricity in thermal power plants was 412 gce/kwh (about 11,400 BTU/kwhr), down by 2 gce/kwh compared with 1994 on average nationwide; loss on power grids was 8.77% on average, up by 1.7% compared with 1994. By the end of 1995, total installed capacity was 217 GW nationwide, including hydroelectricity (24.0%), thermal power electricity (75%), and nuclear electricity (0.95%).

Table 3. China's Installed Capacity and Generation of Electricity for 1970-1995

Year	*Installed Capacity (MW)*		*Electricity Generation (TWh)*	
	Total	*Hydroelectricity*	*Total*	*Hydroelectricity*
1970	23,700	6,230	115.9	20.5
1971	26,280	7,800	138.4	25.1
1972	29,500	8,700	152.4	28.8
1973	33,920	10,300	166.8	38.9
1974	38,110	11,820	168.8	41.4
1975	43,410	13,430	195.8	47.6
1976	47,150	14,650	203.1	45.6
1977	51,450	15,760	223.4	47.6
1978	57,120	17,280	256.6	44.6
1979	63,020	19,110	282.0	50.1
1980	65,870	20,320	300.6	58.2
1981	69,130	21,930	309.3	65.5
1982	72,360	22,960	327.7	74.4
1983	76,440	24,160	351.4	86.4
1984	80,120	25,600	377.0	86.8
1985	87,050	26,420	410.7	92.4
1986	93,819	27,542	449.6	94.5
1987	102,897	30,193	497.3	100.2
1988	115,497	32,698	545.1	190.2
1989	126,639	34,583	584.7	118.4
1990	137,890	36,046	621.3	126.4
1991	151,473	37,884	677.6	125.1
1992	166,532	40,681	753.9	132.4
1993	182,911	44,593	839.5	151.8
1994	199,897	49,061	928.1	168.1
1995	217,000	52,184	1,006.9	186.8

Nationwide, there were 14 electric power networks with a capacity of more than 1 GW in 1994. The largest one is Huadong electric power network, whose capacity is 31.67 GW. The capacity of the Central China electric power network, the North China electric power network, the Northeast electric power network, and the Sichuan electric power network all surpass 25 GW, which are 27.6 GW, 27.15 GW, and 26.53 GW respectively. The capacity of the Guangdong electric power network, the Shandong electric power network, the Northwest electric power network, and the Sichuan electric power network all surpass 10 GW, which are 19 GW, 11.52 GW, 11.48 GW, and 10.09 GW respectively.

By the end of 1994, the total length of transmission lines with a capacity of above 35 KV was 539,400 km, while its transformation capacity was 5,668 GVA, including 11,197 km of transmission lines with a capacity of 500 KV, whose transformation capacity was 38.66 GVA. The country had 4,924 km of transmission lines with a capacity of 330 KV, whose transformation capacity was 8.04 GVA. There were 91,216 km of transmission lines with a capacity of 220 KV, whose transformation capacity was 1,618,100 GVA; and 142,472 km of transmission lines with a capacity of 110 KV, whose transformation capacity was 198.72 GVA. In 1995, the scale of nationwide electric power networks expanded further, and by the end of 1996, the length of transmission lines with a capacity of 500 KV reached 13,635 kilometers. In addition, great progress was made in the field of new energy, such as generation of wind power, geothermal power, and ocean energy power.

China's electric power industry is one of the industrial sectors which utilizes foreign capital most. By the end of 1994, this sector utilized $12,100,000,000 of foreign capital, establishing 64 middle or large projects with 40.7 GW of a total installed capacity of power generation, and 19.57 GW already in operation.

2. Construction of Hydroelectricity in China and Its Target Areas in Future in China

Hydropower is a clean and renewable energy resource. The total reserves of hydropower in China's rivers are 676 GW—equivalent to the annual power generation of 5,920 TWh. Water resources that can be exploited technically are 378 GW—equivalent to 1,920 TWh generated annually. Both in terms of reserves of hydropower and the water resources that can be exploited technically, China occupies the top position worldwide. The water resources that can be exploited technically in China account for one fifth of the worldwide total. It was estimated in 1992 that the installed capacity that could be exploited economically was 290 GW that could generate 1,260 TWh, excluding pumped-storage power station. In 1994, the installed hydropower capacity in China was 49.06 GW, accounting for 16.9% of the installed capacity that can be exploited economically. Annual generation of power was 168.1 TWh, which accounts for 13.3% of power that can be exploited economically. Compared with the major developed countries, the degree of exploitation and utilization of hydropower in China is quite low. The prospects for hydropower construction in China are very promising.

Although China is abundant in hydropower reserves, its distribution is not even. There is more hydropower in Western China, but less in the East. Most of the country's hydropower reserves are in the Southwest and south central regions. Among the exploitable water reserves nationwide, Hubei, Dongbei, and Huabei in the East account for 6.8%; the Northwest accounts for 9.9%; South central accounts for 15.5%; and Southwest accounts for 67.8%. In this latter area, just three provinces: Sichuan, Yunnan, and Tibet, account for 64.4% nationwide.

In the past 40 years, the construction of hydropower in China has been a great achievement. In 1994, were 7 large hydropower stations with a capacity of more than 1 GW each in China:

1. Gezhou Damp hydropower station, Yangtz River, Hubei with the installed capacity of 2.175 GW and electric power generation of 15.75 TWh;
2. Baishang hydropower station, The Second SongHua River, Jinlin with the installed capacity of 1.5 GW and electric power generation of 2.048 TWh;
3. Longyangxia hydropower station, Yellow River, Qinghai with the installed capacity of 1.28 GW and electric power generation of 5.43 TWh;
4. Geheyan hydropower station, Qing River, Hubei with the installed capacity of 1.212 GW and electric power generation of 1.684 TWh;
5. Liujiaxia hydropower station, Yellow River, Gansu province, with the installed capacity of 1.16 GW and electric power generation of 5.812 TWh;
6. Manwan hydropower station, Lancang River, Yunnan province, with the installed capacity of 1 GW and electric power generation of 3.469 TWh;
7. Guangzhou pumped storage hydropower station, Liuxi River, Guangdong, with the installed capacity of 1.2 GW and electric power generation of 0.9186 TWh.

Even though China has achieved a great deal over the past 40 years, the degree of exploitation, utilization and development of water reserves is not completely satisfactory. The proportion of the installed capacity of hydropower to that of electric power declined from 30% in the Sixth Five-Year Plan to 24% at present, and the proportion of the annual electric power generation declined from 25% to 19%. If no dedicated measures are employed, its proportion will continue to go down. In accordance with the Ninth Five-Year Plan, as well as long-term objectives, by 2010 the installed capacity of electric power will need to reach 553 GW, and the annual electric power generation will need to reach 2,500 TWh.

By that time, taking into account such an annual electric power generation and installed capacity from hydropower, coal-fired electric power generation will require an installed capacity of 420 GW and generate more than 2,000 Twh annually during this period of time, since the proportion of nuclear electric generation may be unable to provide a greater proportion of electric power generation. Therefore, the consumption of coal combustion for electric power generation will reach 900 Mt. At present, consumption of raw coal for electric power generation has risen to approximately 400 Mt, which has already caused increasingly frequent transportation problems. Consider within 15 years, 500 Mt of raw coal will be needed for electric power generation, and transportation will need to be provided, making its feasibility quite doubtful. In addition, the environmental protection issue will need to be considered, too. As a result, hydropower should be developed with a great effort.

China has targeted the upper reaches of the Yellow River, and the middle and lower reaches of the Yangtz, Hongshui, and Lancang Rivers as important areas of hydro-power construction. China will primarily establish large scale hydropower stations, selectively set up some middle or small hydropower stations, and set up some pumped storage hydropower stations, as well, in order to resolve issues for peak power adjustment of large grids. In accordance to a middle and long-term plan for hydropower development in China, by 2000 the total installed capacity of hydropower nationwide will reach 70 GW.

After 2000, there will be a 10-year period of tremendous development of hydropower. By 2010, the installed capacity of hydropower nationwide will reach 125 GW, accounting for 33.1% of what can be developed. During the Ninth Five-Year Plan, the installed capacity for each year on average was above 3.5 GW. During 2000 - 2010, installed capacity will increase 5 GW on average. Such a large scale of development will bring a gigantic market of cooperation and development to enterprises and consortiums from countries worldwide.

In early 1995, the scale of construction of hydropower projects nationwide was 44.7 GW, of which the Three Gorges Project was 18.2 GW, medium and large hydropower stations were 20.1 GW, and small and medium stations were 7.5 GW.

In order to coordinate operations of newly established large hydropower stations and nuclear power stations and to help with peak power adjustment, medium or large pumped storage power stations are being established: the Guongzhou pumped storage power station in second stage with a capacity of 1.2 GW; a pumped storage power station in Ming Tombs, Beijing with a capacity of 0.8 GW; a pumped storage power station in Tianhuangping, Zhejiang with 1.8 GW; a pumped storage power station in Yangzhuoyong, Tibet; and a pumped storage power station in Xianghongdian, Anhui.

On December 14, 1994, the Three Gorges Hydropower Station Project on the Yangtz River, which has attracted worldwide attention, officially began. This project will provide a comprehensive system of benefits, including flood control, power generation, and shipping, etc. The Three Gorges hydropower station has 26 power units installed in total, with each unit having a capacity of 0.7 GW and total installed capacity being18.2 GW. Its annual generation for years on average is 84.68 TWh, equivalent to about one seventh of China's annual power generation in 1992. After the Three Gorges Project has been established, it will become the largest hydropower station in the world for a certain period of time in terms of its installed capacity and its average annual power generation. It will provide electric power to the Central China area, the East China area, and Sichuan province. Once it is completed, a nationwide integrated power transmission network will gradually be formed, which will promote greater prosperity in the Yangtze River economic zone. The Three Gorges Project plans to block the Yangtze River on November 1997, put the first group of units into operation by 2003, and complete the entire project by 2009.

The areas where hydropower is fairly abundant in China are the Southwest and the Northwest. The capacity of the Jinshajiang Hydropower Base on Jinshajiang River is equivalent to four of the Three Gorges hydropower stations. The Jinshajiang River hydropower base is the country's largest hydropower project and has a very strategic position. The development of hydropower resources on this river is very significant to the goal of transmitting electricity from the West to the East, optimizing and improving the energy structure in parts of Huazhong and Huadong, developing the economy in the Southwest, benefiting completely from the Three Gorges Project, and reducing mud and sand sedimentation in the Three Gorges Reservoir. From now on, the target areas where China will develop hydropower are the Southwest and Northwest.

3. Construction of Nuclear Electricity and Its Development in the Next Century

The future development of China's energy industry will likely encounter three major problems:

1. The consumption of coal will increase so rapidly that the capability of coal production to keep up with the increase in demand will be difficult;
2. The demand for transportation capacity resulting from shipping coal long distances increases so quickly that the shipping capability in terms of railroad, ports, and shipping can hardly meet that demand;
3. Due to the tremendous amount of coal combustion, environmental protection will become such a important issue that it will bring unexpected harm to people's living standards and economic development.

As for nuclear electricity's high density, the pressure of shipping coal can be alleviated by generating nuclear electricity in areas far away from energy generation bases. China's economic development is planned to be led by the East. As a result, nuclear electricity is a very practical option in order to resolve those bottleneck issues that hinder economic development in these areas, such as electricity and communications.

Although China has nuclear technology, its construction of nuclear power stations began quite late, and it has chosen the pressurized water reactor as the preferred reactor. At present, there are three sets of nuclear power units in operation in Daishang and Daya Bay with a total installed capacity of 2.1 GW, which only accounts for about 1% of total nationwide power generation. Table 4 presents those nuclear power stations in operation.

Table 4. The Nuclear Power Stations in Operation in China

Stations	Type	Capacity (MW)	Provider	Start Date	Griding	Operation	First Fuel Exchange	Load Factor (1995)
Phase 1, QinShan	PWR	300	CNNC	03/1985	12/1991	05/1993	10/1994	84%
Phase 1, Daya Bay	PWR	900	CNNC	08/1987	08/1993	02/1994	12/1994	67%
Phase 1, Daya Bay	PWR	900	CNNC	04/1988	02/1994	05/1994	04/1995	N/A

During the Ninth Five-Year Plan, the nuclear power industry will not be able to develop considerably, due to the limitation of capital. The 4 nuclear power stations with 8 nuclear units and the installed capacity of 6.6 GW will be completed during the Tenth Five-Year Plan. By then, the proportion of nuclear power will account for about 2% of total electric power generation in China. In the short term, nuclear power is only a appropriate supplement to the electricity industry in China. Table 5 presents nuclear power stations that are set to begin construction before 2000.

Table 5. The Nuclear Power Stations Being Established in China before 2000

Stations	*Reactor Type*	*Capacity (MW)*	*Location*	*Operation Time*	*Current Situation*
Phase 2, QinShan	PWR	600*2 Units	QinShan Site	2001, 2002	Started in June, 1996
Phase 3, QinShan	PHWR (CANDU)	700*2 Units	QinShan Site	2002, 2003	Started in 1997
LingAo	PWR	900*2 Units	Close to Daya Bay	2002, 2003	Started in May, 1995 with French partner
LiaoNing	PWR (VVER 1000/428)	1,000*2 Units	LiaoNing Province	N/A	The feasibility report has been approved between China and Russia

The site where China and Russia are planning to establish a nuclear power station jointly has been changed from the previously selected Liaoning to Lianyung Port, Jiansu Province. The major reason why this site has been changed is that the conflict between economic development and shortage of energy in Jiansu Province has become more intense. The nuclear power station for Jiansu Province has a capacity of 2 GW, for which the Chinese and Russian governments signed an agreement in December 1996 for capitalizing on Russian capital and equipment. Power generation from this nuclear power station will be in operation and enter the power network in 2002 - 2003.

China is abundant in nuclear energy resources, including natural uranium. As its capability to process it begins to take shape, every sector in the nuclear fuel cycle industry has been meshed with each other. China has a group of nuclear technical fellows with very rich experience who can, by themselves, design and manufacture a complete set of equipment for a nuclear power station using a pressurized water reactor with a capacity of 300 MW. It is a module for a nuclear power station with a capacity of 600 MW and can be expanded to 900 MW or even 1.2 GW. This has laid out a solid foundation for independent design for nuclear power facilities and domestic manufacturing equipment. In the light of a long term, nuclear electric power industry in China this has very broad development perspective.

By the end of 1995, the total installed capacity in China's electric power industry reached 210 GW, including 2.10 GW of nuclear electricity. By 2000, the total installed capacity in China's electric power industry will reach 300 GW, including 9 GW of installed capacity for nuclear electricity. It is estimated that by 2010, the total installed capacity of nuclear electricity will reach 20 GW, accounting for about 3 - 4% of the total installed capacity. By 2020, the total installed capacity of nuclear electricity will reach 40 GW, accounting for about 5% - 6% of the total installed capacity. Refer to Table 6.

Table 6. The Nuclear Power Development in China for 1995 – 2020

Year	*Installed Capacity For Nuclear Electric Power (GW)*	*Total Installed Capacity(GW)*	*Percentage(%)*
1995	2.10	210	< 1
2000	9 - 10	300 - 400	2 - 3
2010	20	600	3 - 4
2020	40	800	5 - 6

Thanks to the safe operation of nuclear power stations in Qinshan and Daya Bay, those provinces which lack coal and hydropower resources realize that nuclear electricity provides safe, convenient, and clean energy and that establishing nuclear power stations is a solution for solving bottleneck issues, such as energy shortages and environmental and shipping problems. Some coastal provinces and autonomous regions, which are economically developed but short of energy, such as Shandong, Jiansu, Fujian, Jianxi, Hunan, Hebei, and Guangxi, all desire to establish nuclear power stations. China is doing site selections for several nuclear power stations and assessment for about 10 sites which have been preliminarily selected, such as Lenjiazhuong, Haiyang County, Shandong Province; North Bank of Qiuzhou Bay, Huaian County, Fujian Province; and Sanmen County, Zhejiang Province. These nuclear power station sites will be able to meet requirements for nuclear power stations and an installed capacity of 40 GW will be constructed in China in order to develop the nuclear electricity industry for the 21st century.

China has adopted a policy of ongoing progress to develop nuclear electricity. Its major measures are:

1. Purchase foreign technology and equipment by utilizing foreign capital for initiating China's nuclear electricity industry. The Daya Bay nuclear power station, which is a joint venture of Chinese and foreign enterprises, is a good example of success. Seventy percent of the power generated from this nuclear power station is transmitted to Hong Kong, which not only provides very good economic benefits, but also helps China learn the technology for establishing large nuclear power stations;

2. Adopt a policy of "Rolling Development" to develop nuclear power stations. Nuclear power stations need a great amount of investment, their cycle of construction is quite long, and cost of generation is comparatively low. It can bring a greater profit in a later period of return on interest, and it will generate even greater profit after the capital and interest are paid off. In this way, the profit gained can be taken advantage of to conduct "rolling development" of nuclear electricity, which is somewhat analogous to the development of hydroelectricity;

3. Conduct scalable operation. Sites for nuclear power stations should be chosen not only near the centers of electricity consumption, but should also keep such an appropriate distance from cities as to be able to be managed closely during construction operation. In addition, selected sites should have potential for further development, perhaps for a second or even third stage of expansion in order to be able take advantage of existing public utilities, reducing costs to the largest extent, shortening the period of construction, and simplifying management organizations;

4. Carry out a nuclear electricity construction policy so that safety is paramount, and perform strict quality management;

5. Keep track of development trends in international nuclear electricity technology for the next century and strengthen China's own development capabilities through the introduction of foreign capital and technology. Fully take advantage of existing capabilities of science research, design, construction, management, and equipment manufacturing of nuclear electricity in China, strive to achieve automated designs and to manufacture equipment domestically through learning, digesting and absorbing, and innovating in order to prepare for a situation of greater development in the nuclear electricity industry in China for the next century.

4. Strategy of Development of Electric Power Industry in China

(1) Strategic Position of China's Electric Power Industry

Due to the reasons mentioned below, the strategic position of electric power becomes very important in the long-term balance of energy supply and demand in China:

1. The development of energy in China must center around electric power, as shortages of electricity have hindered economic growth. Electricity is the essence of energy development in China.

2. Due to China's abundant coal resources, for a fairly long time in the future, the production structure of primary energy dominated by coal will probably not change a great deal (in 1995, raw coal accounted for 75% of total energy generation). Nevertheless, both the proportion for conversion from coal to electricity will be enhanced and hydropower and nuclear power will be developed a great deal so that development of electricity will be promoted tremendously, which eventually will impact greatly upon optimization of final consumption structure.

3. There will be more demand and more urgent requirement for the consumption of electric power in order for the comprehensive national power of China to greatly strengthen in 2000 and afterwards; for the national economy to be able to grow sustainably, rapidly, and soundly; and for people's living standards to achieve anticipated objectives; and for the economy and social life to be modernized.

4. The utilization of electric power will widely prevail through fields of production and life in order to reduce pollution caused by direct combustion of raw fuel. Wide utilization of electric power in production will benefit from the increase of power production.

Therefore, the strategy to have the energy industry center around electric power will be a long-term one which will meet the need for the sustainable development of China's economy and society.

(2) Strategic Objective for Development of Electric Power Industry in China

The level and speed of electric power development depends upon demand for electric power, which is closely tied to changes in economic growth and its structure, as well as consumption level per capita, with which the strategic objective of the electric industry development must fit in.

China's objective of economic development is that GNP will be doubled by 2000 compared with that of 1980, namely, increasing from 447,000,000 RMB (Chinese Yuan) to 1,788,000,000 RMB, and having the growth rate increase every year an average 7.2%. In fact, the growth rate for the previous 10 years was more than 9.38% every year on average. The growth rate for recent years was even higher. The growth rate of GNP in 1991 was 8%; in 1992, 13.6%; in 1993, 13.4%; and in 1994, 11.8%. If the GNP growth rate can be sustained at 9%, it is anticipated that for another 10 years, the growth rate for 20 years on average will be higher than 9%. However, the growth of power generation has been changed from 300.6 TWh in 1980 to 621.2 TWh in 1990, whose annual growth rate was 7.67%. The growth rate of electric power generation was 1.71% lower than that of GNP for the same period of time. Due to shortage of electric power for many years, supply for demand of electric power is still very tight.

The development of electric power for the middle or long term must match the growth in the economy; for example, the development of electric power must correspond with that of the economy so it can balance the supply and demand of electric power, while supporting economic development.

The demand for electric power is forecasted assuming the annual growth rate of GNP on average will be 7.2%, economic growth will be doubled, and the generation of electricity should increase accordingly as to reach 1,200 TWh. In fact, the growth rate of GNP will be above 9% so that 1,200 TWh of electricity is obviously not enough. If generation of electric power is kept in sync with the growth of economy, it should get to 1,300 TWh. Considering that China has been short of electricity for a long time ,and examining the growth of electricity consumption in communications and shipping, civil utilization, and production in rural area, which account for a small proportion in nationwide electricity consumption at present and retain considerably rapid growth from now on; as a result, demand for the growth of electric power will be greater than the growth of economy.

Therefore, during 2000-2015, the development of electric power will still need to keep in sync with that of the economy. Supposing that the economy in 2015 will be doubled, the generation of electric power also will be doubled so as to reach 2,560 TWh, and the generation of electric power per capita should reach 1,869 KWh (See forecast in Table 7).

Table 7. Forecast for Development of Electric Power Industry in China for 2000-2015

Year	Population (Billion)	GNP (Billion Yuan)	Electricity Generation (TWh)	Population Increase (%)	GNP Increase (%)	Electricity Generation Increase (%)	GNP /capital (Yuan)	Electricity Generation per capital (KWh)
1980	0.989	447	300.6				453	305
1985	1.05	723.7	410.7	1.2	10.1	6.44	689	391
1988	1.096	964.1	545.2	1.44	10	9.9	880	497
2000	1.25	1900	1280	1.1	5.8	7.37	1500	1024
2015	1.37	3800	2560	0.61	4.7	4.7	2774	1869

Taking into account the forecast for electric power in China for 2000-2015 in Table 7, the development of electric power in China for either 2000 or 2015 is made a little lower, which has been conservatively forecasted.

The development of the electric power industry in China must primarily be in sync with that of the national economy in order to achieve a strategic objective of development of the national economy in three steps and to meet the requirements of enhancing the national economy and people's living standards. In addition, it is anticipated that the installed capacity for 2000 in China will need to reach 300 GW; the generation of electric power will need to reach 1,400 TWh; by 2010, the installed capacity will reach 590 - 600 GW and the generation of electric power will reach 2,700 TWh. During 2000 - 2020, the total installed capacity in China will go up by 5% every year on average. In 2020, the total installed capacity in China will reach 800 GW. During 2020 - 2050, the total installed capacity in China will go up by 1.36%. By 2050, the total installed capacity in China will be 1,200 GW.

(3) Strategic Plans for Development of Electric Power Industry in China

1. The development of electric power production needs to be in sync with the growth of the national economy, namely, the ratio of the average annual growth rate of generation of electric power and that of GNP should be 1:1 (elastic coefficient of electricity is 1). Considering that a shortage of electricity for a long time has hindered economic development, the increase in electric power should be a little higher than that of GNP, and the elastic coefficient of electricity should be higher than 1.

2. Coal will still be a dominant energy resource. At present, the proportion of conversion from coal to electricity is only 32%, e.g., the same as in 1994. From now on, the proportion of coal used to generate electricity should be increased substantially in order to get to 30% by 2000 and about 50% by 2010. As a result, not only will the efficiency of energy utilization be increased, but also the environmental pollution caused

by direct coal combustion will be able to be decreased. In terms of thermal power generation in China at present, the thermal efficiency in thermal power stations was about 30%, which is quite low compared with that of developed countries. The major reason for that is that 0.2 GW units with large capacity and high efficiency account for a pretty small proportion of the whole unit system. The units at low and middle level should be phased out gradually or revamped. The newly installed units should have a capacity of more than 0.3 GW. With the scale of power grids enlarged, units in a capacity of above 0.6 GW should be targeted.

The scale of coal-fired generation of electric power will be enlarged more and more in the future, but the development of coal-fired generation of electric power should concentrate on improving technology, increasing thermal efficiency, and reducing the impact upon the environment caused by coal-fired power generation. Therefore, application of fluidized bed boiler with a large capacity of combined cycle should be promoted with a great effort, the research on coal gasification should be strengthened, and the key technology of integrated gasification combined cycle (IGCC) should be researched and developed. The technology of clean coal combustion for power generation should be developed considerably. In the long term, coal-fired MHD should be developed. It is an overall strategic issue in construction and development of energy bases to convert coal into electric power on site, especially building up mine mouth power stations right on coal mines and to transmit it long distances. For this reason, AC and DC transmission technology for super high voltage and long distance should be studied with greater efforts.

3. The development potential of China's hydropower resource is very substantial. The exploitable hydropower resource is 380 GW nationwide--the number one position worldwide. Southeast-oriented hydropower bases should be constructed. The Jinshajing River is the largest hydropower base with very significant strategic position, which has been planned by the State. To develop hydropower resources in this river has a significant impact on being able to transmit electricity from West to East, optimizing and improving energy structure in East China and Central China, supporting economic development in the Central East, and promoting complementary advantages in East China, Central China, and West China.

4. Development of nuclear electric power has been initiated in China. By 2000, the installed capacity of nuclear power is forecast to be 9 - 10 GW, accounting for 2% or 3% of nationwide total installed capacity. The distribution of nuclear power after 2000 will center around nuclear power stations in Gudong, Zhejiong, and Liaoning, and construction of nuclear power stations in some areas in East China, South China, Northeast China, where there is a shortage of electric power, will be sped up.

5. At present, there are about 76.56 million people who do not have access to electric power in China, with most of them living in remote and economically poor areas. Small scale hydropower stations, biogas power stations, geothermal power stations, wind

power stations, and solar power stations should be constructed with support from the government in accordance with local conditions.

6. Investments for the development of the electric power industry should be guaranteed. The installed capacity which has been planned for 2000 - 2015, cannot be achieved without adequate capital. The large scale of electric power construction needs a large amount of capital, which can be raised through multiple domestic or overseas channels.

D. THE 21st CENTURY - AN ERA OF SUPERCONDUCTIVITY

In 1911, Heike. Kamerlingh. Onnes, a Dutch physicist, observed that mercury showed the phenomenon of superconductivity at -269 ℃ (4 K). In 1914, an antimagnetic phenomenon was found. In 1930, the antimagnetic phenomenon was used as a way to detect superconductivity. With the development of science and technology, new superconductivity materials continue to be discovered, and their critical temperature keeps increasing. In light of their application property, they can be grouped into three categories:

1. Superconducting Metal Materials

There are two major kinds of superconducting materials that fall into the critical temperature range of liquid-helium-cooled:

(1) Nb_3Sn with a critical temperature: 18 K, discovered in the 1950s.
(2) NbGe with a critical temperature: 23 K, discovered in the 1970s.

The first generation of superconducting metal materials has already been in application.

2. Superconducting Oxide Materials

The superconducting materials that mostly fall into critical temperature range of liquid-nitrogen-cooled:

(1) $(LaSr)_2CuO_4$ with critical temperature: 30 K, discovered in Switzerland in 1986;

(2) $YBa_2Cu_3O_7$ with critical temperature: 90 K, discovered in the United States and China in 1987;

(3). $Tl_2Ba_2Ca_2Cu_3O_{10}$ with critical temperature: 120 K, discovered in the United States in 1988;

(4). Tl-Si-V-O with critical temperature: 130 K, discovered in Japan in 1990;

(5). Hg-Ba-Ca-Cu-O with critical temperature: 133 K, discovered in Switzerland in 1993;

(6). Bi-Sr-Ca-Cu-O with critical temperature: 250 K, discovered in France in 1993 (Unable to be repeated).

The second generation of superconducting oxide series materials have already been discovered substantially. Once process technique is available, they can be applied widely in the field of electric power.

3. The Third Generation Superconducting Materials

The third generation of organic superconducting materials with critical temperature close to room temperature, which is being studied and probed, will be able to applied into production and life. Their capability of power conservation can be about 1/3 so that the application of superconducting technology in the field of energy can rationalize utilization of energy power.

Superconducting metal series materials that are being primarily applied presently are those whose critical temperatures fall into the liquid-helium-cooled range. The application technology for oxide series superconducting materials whose critical temperature is greater than liquid-nitrogen-cooled range: 77 K, especially technology for ribbon-shaped material processing, is still in study and development. If it can be successful, not only will the engineering structure be simplified but the manufacturing cost could be reduced by 25-30%. In addition, the price for liquid-nitrogen-cooled materials is lower than liquid-helium-cooled ones, which will expedite commercialization of superconducting technology. After room temperature superconducting materials have been developed successfully, the scope of application will be expanded into wider fields of production and life. Therefore, it can be predicted that the 21st Century will be an era of superconductivity.

E. APPLICATION OF SUPERCONDUCTING TECHNOLOGY IN THE FIELD OF ENERGY

The fact that superconductivity technology, such as superconductivity storage, superconductivity transmission, superconductivity transformers, superconductivity generators, MHD, and application of superconductivity magnets in nuclear fusion; is used in energy technology, including electric power technology; will provide unique advantages. The research and development situations in some relevant countries, including China, will now be analyzed.

1. Superconducting Generators

If generators use superconducting materials instead of conventional ones, they will have the following advantages:

(1). Internal loss of generators will be reduced by 60% (See the Table 8), which will enable power generation efficiency to increase by more than 1% from 98.7%;

(2). Magnetic fields generated by rotors will be three times as much as conventional ones. Generators will take less space than conventional ones. Superconducting generators have no iron cores, enabling their axle length to be reduced by 40% and their weight by a half.

(3). Internal AC resistance in generators is so small as to be able to enhance stability of a whole electric power system and to transmit more electricity by 30-40% within 300 kilometers.

However, applications of superconducting magnets bring up a series of issues that need to be resolved in the design, manufacturing, and safe and reliable operation of generators. At present, generally, only superconducting generators with such large capacities as 300 MVA have an economic advantage.

Due to the above-mentioned advantages, all developed industrial countries are competing to exploit superconducting generators. The United States started earliest, while the former USSR and Germany are catching up. The former USSR has already developed a 300 MW unit; and Germany is being developing a 850 MW one, which plans to be commercialized in 1995. In 1997, Hitachi Institute in Japan succeeded in manufacturing a prototype of a superconducting generator with a capacity of 70 MW. It proved that when comparing superconducting technology of electric power generation with existing coal-fired ones, generation efficiency enhances to 99%, generation loss is reduced by more than 2/3, transmission capacity grows by 20% - 50%, and at the same time, weight of generators is reduced by more than 30%. The Institute of Electric Power Generation Equipment in Shanghai, China has a prototype of a superconducting generator with a capacity of 400 KVA, and has done a test for attaching it to the grid. An institute in Wuhang has succeeded in manufacturing a monopolar superconducting electric machine with a capacity of 300 KW.

Table 8. Reduction of Loss in Superconducting Generators (%)

Generator Type	Excitation Loss	Rotor Loss	Stray Reactance Loss	Iron Loss	Mechanical Loss	Loss of Refrigerants	Total Loss
Conventional	30.0	22.5	21.0	8.3	18.2	-	100.0
Superconducting	0.4	17.0	9.0	5.0	8.0	2.0	41.4

2. Superconducting Transmission and Distribution Systems

The advantages in superconducting transmission and distribution systems are as follows: Transmission losses can be reduced substantially; the electric current that goes though a unit area on superconducting transmission lines is one order of magnitude greater than that of conventional electric lines, which can increase electricity transmission quantity, or reduce diameter of transmission lines; electricity can be transmitted directly by using generating electric voltage, take away the step-up systems, simplify step-down systems at terminals; losses at the terminal can be reduced, weight can be reduced, and electric current density can be increased if superconducting materials are utilized at terminals (See Table 9).

Table 9. Comparison between Superconducting Transformers and Conventional Transformers (Three Phases, 275 KV, 300 MVA)

Transformer Type	Impedance (%)	Iron Core (ton)	Conductor (ton)	Weight (ton)	Current Density (A/mm^2)	No Load Loss (KW)	Load Loss (KW)	Electricity Loss for Apparatus (KW)	Total (KW)
Conventional	18	83	30	165	3.5	160	1,000	40	1,200
Superconducting	18	22	4	70	120	40	0.6	450	491

The key for commercialization of superconducting transmission relies on whether liquid-nitrogen-cooled superconducting materials with 100 KA/cm^2 can be exploited, as well as wire material processing technique. Japan is able to manufacture 10 m of superconducting wire material. The United States is exploiting 1000 m superconducting wire materials with a capacity of 138 KV and 4000 A. China is able to manufacture a 0.5- m high-temperature superconducting cable, which reaches the same level as the United

States and Japan, but it is confined by limitation of capital and equipment from further mastering industrializing technology for manufacturing 1000-meter superconducting cables.

At present, a high-temperature superconducting transformer has already been commercialized---the first high-temperature superconducting transformer in the world to be hooked into a transmission network is in operation. On March 12, 1997, ABB company announced that it had succeeded in connecting the world's first high-temperature superconducting transformer into a transmission network in Geneva. This transformer has a capacity of 630 KVA and can transform 18.7 KV down to 420 V.

3. Superconducting Motors

If superconducting materials are utilized as coils in motors, motors whose torque is big but rotor loss is small can be manufactured. Japan has already manufactured a low-speed, high torque DC motor that uses liquid-nitrogen-cooled superconducting material (Y-Ba-Cu-O) to make its stator magnetic pole. As a next step, they plan to use superconducting materials to make a rotor coil so that internal loss will be reduced substantially. Because AC motors have impedance loss caused by inductance and capacitance, it can only be used for small or medium sized motors with a capacity of 100 KW.

4. Coal-fired MHD

MHD is a new way to generate electricity by converting heat energy directly into electricity, whose basic principle is based on Faraday's Law of Electromagnetic induction, as conventional generators are. The difference is that the electric conducting liquid in MHD replaces the metal conductor in conventional generators. MHD is a new way to generate electricity by converting thermo-energy directly into electricity by utilizing the interaction between high-temperature (greater than 3000K) electric conducting burning gas and a magnetic field. A coal-fired MHD - steam combined cycle device that has succeeded in testing and in actual operation for electricity generation on a small-scale utilizes combustion of coal and air with high percentage of oxygen in combustion chamber to generate high-temperature burning gas (greater than 3000K), adding potash salt as ionization seed in order to increase the conductivity of the burning gas. The high-temperature, conducting, burning gas, after it is inflated and spedup, gets into the power generation canal, interacts with a strong magnetic field generated by a superconducting magnet, and converts thermoenergy into electric power. Afterwards, it generates AC power via an inverter system, and is transmitted into a power network.

MHD generators that are composed of a superconducting magnet and a power generation channel are the equivalent of conventional steam turbines and electric power generators without spinning parts. The tail gas (greater than 2200 K) jets into a waste heat boiler to generate steam used to drive a steam turbine unit for generation of electricity. The power supply of this combined cycle can reach 45% - 55%, which is 5% higher than the gas-steam combined cycle. In addition, as potash salt can desulphurize, the waste heat boiler can enable control over the generation of carbide, as its pollutant emissions are far lower than the current State standard.

Coal-fired MHD has an especially important significance to China, since China is abundant in coal. From now until 2050, coal-fired electricity generation will account for the majority of total electricity generation in China, the proportion of which is the highest in the world. The technology of coal-fired electricity generation is quite backward (average efficiency is less than 30%), and pollution control is very difficult, so study and investigations into coal-fired MHD have great significance for China's sustainable development.

China began to probe MHD in the 1960s. Within 10 years, from the early 1970s to the early 1980s, first, China adopted the long-standing combustion of oil and high-temperature preheated air (1400° C) to generate electric power. Afterwards, in consideration of its potential as an energy resource, China switched to investigating coal-fired MHD. As a result, 16 KW can be generated for as long as 5 hours. So far, China has become the fourth country after the United States, Russia, and Japan to be engaged in probing and experimentation of MHD on a large scale.

Research on coal-fired MHD has been listed as a high-tech R&D priority project in China since1986. The objective of the research --- to construct a coal-fired MHD - steam combined cycle power station --- has made rapid progress over the last 10 years. In coordination with the research work of coal-fired MHD, the Institute of Electric Engineering, (Chinese Academy of Sciences) succeeded in manufacturing a saddle-shaped superconducting magnetic system used by MHD, including a large piece of saddle-shaped superconducting magnet, an applicable horizontal low-temperature container, and a liquid-helium liquidizing device with a capacity of 150 litres/hour. The magnet consists of 34 oblate saddle-shaped coils with 17 tiers. The inner diameter of a coil is 690 mm; its outside diameter is 1210 mm, its length is 1700 mm, and it can be in operation steadily under a 4T central magnetic field. The weight of the whole magnet is 13.6 tons, and its superconducting wires weigh 3.8 tons. It demonstrates that research on MHD in China remains at an internationally advanced level.

By 2000, China will establish the first prototype of an MHD - steam combined cycle electric power station with 25 MW of thermo-input power. This trend of high-technology energy commercialization fits the current Chinese situation although there is a big gap, in terms of its scale, compared with current commercialized electric power stations with power generation efficiencies of about 0.5 - 1 GW. Taking advantage of existing power, as long as an adequate strategy is selected, with great efforts from the government, MHD in China will be commercialized in the near future. China will develop a large superconducting magnet for high power MHD with a substantial effort.

5. Superconducting Magnet in Nuclear Fusion

Nuclear fusion is an energy source which people have been dreaming of for a long time. The current way of achieving nuclear fusion is magnetic confinement, which is to confine high-temperature plasma and hang it in a vacuum. In order to do it, there must be a 10-tonne magnetic field generated in a length of tens or even hundreds of meters. This can be achieved only by using superconducting magnets. At present, the United States, Russia, Japan, and Europe are jointly probing this technology. It is estimated that the cost of electricity generation utilizing liquid-helium-cooling superconducting magnets is still higher than that of light water reactors. Therefore, liquid-nitrogen-cooling superconducting materials should be utilized.

China has been putting great efforts into studying and probing nuclear fusion equipment. A new round of physical experiments has been performed successfully in the Tokamak thermo-nuclear fusion equipment: HT-7, in the Institute of Plasma Physics, Chinese Academy of Sciences located in Hefai, Anhui province. This is the largest in China and lies in the world's forefront in terms of scale and advantage. Chinese researchers have acquired stable high-temperature plasma with features of 140 KVa of electric current, 11,000,000-13,000,000° C and 1.4 second of electric discharge pulse width. The China National Tokamak Superconducting Laboratory is also located in Hefai, Anhui Province.

6. SMES

The efficiency of pumped-storage power stations that are used for peak power adjustment is 70%. The stations are always far away from central areas where electricity is utilized so that transmission loss is increased. Utilizing superconducting storage, efficiency can reach 90% (10% for electricity consumption of liquid-helium-cooling accessory equipment's), thus reducing some limitations on sites for stations as well.

The United States and Japan have paid great attention to the research and development of superconducting storage. So far, the United States has set up a prototype with a capacity of 20,000 KWh, targeting one with a capacity of 5,000,000 KWh, which will not only be used for daily peak power adjustment in cities, but also for an electric source for strategic weapons. The Japan Superconducting Storage Research Society is testing a prototype of superconducting storage with a capacity of 1,000 KWh. The cost for a storage device for households with a capacity of 10 KWh equipped with photovoltaic equipment is almost the same as a lead storage battery, so, it may have priority in the commercialization process. Considering the future development trends for distributed electricity sources, China also pays special attention to the research work for superconducting storage devices.

F. FORECASTS FOR TECHNOLOGY POLICY PERTAINING TO SUPERCONDUCTIVITY IN CHINA'S ENERGY INDUSTRY

China, like developed countries worldwide, places new materials, including superconductivity materials, into target industries of new technology that have development priority.

China began to conduct research into the superconductivity of electricity in the mid-1950s. The spectacular prospects for superconductivity technology applications were realized in the 1970s, so a research and development team for superconductivity was organized, which included specialized research institutes, universities and colleges, and industrial sectors. This team made great progress on application research and development of superconductivity in China and made China an important international competitor.

As mentioned before, in terms of research and development on superconductivity technology of energy, China mainly focuses on superconductivity cables, superconductivity generators, application of superconductivity magnets on MHD and in nuclear fusion, etc. In addition, the development of tremendous amounts of distributed electricity storage in the 21st century is considered so likely that SMES is going to become a priority in development of superconductivity energy technology in China in the future. Not withstanding, progress in these aspects depends primarily upon research and development of high temperature superconductivity materials and improvement of materials manufacturingtechniques. Therefore, policies for the research and development of superconductivity technology for the energy industry are directly related to policies for research and development of superconductivity materials.

In China, R&D on high temperature superconductivity material is categorized into an R&D field of newly functional materials or materials for energy conservation, belonging to an R&D field of high tech industry. In light of the policy on R&D for superconductivity of electricity, it can be divided into three tiers:

1. Basic research on superconductivity of electricity;
2. Application R&D of superconductivity of electricity;
3. Transfer of lab research achievement into industrial products.

In respect to basic research of superconductivity of electricity, as early as April 1987, the Chinese government promulgated "A Determination for Organizing Research on Superconductivity Electricity Technology of High Critical Temperature". The main contents of this determination are that for speeding up development of superconductivity technology in China, the limited human power, materials, and capital must be organized effectively, bringing existing research power and resource advantages in China into full play; have a centralized leadership; and attack major target areas in a cooperative way. At present, research into superconductivity of electricity, namely, basic research of high temperature superconductivity of electricity, is supported by a national key project plan for basic research, the "Climb Project", which was initiated in 1991. In addition, a national high-tech R&D project, the "863 Project", also supports the R&D of superconductivity materials.

Thus, it is emphasized in China that special attention should be paid to basic research of superconductivity and R&D of superconductivity for application. A National Superconductivity Experts Committee and a National United Superconductivity Technology Research Center were established respectively to organize and coordinate issues in attacking major problems in superconductivity in accordance with the national "Climb Project" and "863 Project."

From these facts, we can see that the major points in policy for R&D of superconductivity technology in China are: Unified operation; Bring advantages into play; government takes lead; promote it positively; pay special attention to application; and the market is quite large.

G. ANALYSIS OF THE POTENTIAL MARKET FOR SUPERCONDUCTIVITY TECHNOLOGY IN CHINA'S ELECTRIC POWER INDUSTRY

Research into superconductivity of electricity and the application of superconductivity materials has been in the forefront of Chinese and worldwide attention for the past 10 years. With the development of economic construction and enhancement of peoples' living standards in China, a gap between electric power supply and demand will appear in China. However, application of superconductivity technology in the electric power industry will help to conserve tremendous amounts of energy, thus helping optimize utilization of energy. Economic growth in China will go in the direction of conserving natural resources and energy resources; the application of superconductivity technology in the electric power industry will benefit and facilitate this direction of development. In light of the current situation in China, it has adopted a policy: "Catch up with the worldwide leading edge for some, but not with respect to development of critical science and technology projects and newly developed enterprises." In terms of the current development situation, the trend of development of newly developed international industries, and the existing foundation in China, the science and technology of superconductivity has been selected as a critical science and technology project in China.

It is expected that in the next century, China will become a major competitor in the arena of superconductivity technology in worldwide superconductivity high-tech industries, including superconductivity high-tech enterprises of energy and electric power as well. It is quite obvious that research into superconductivity is a field where China is qualified to rank equally with the world's developed countries.

The formation of the superconductivity electric power industry is related to the progress in the basic research of superconductivity. The Chinese government pays great attention to basic research of superconductivity and R&D for application of superconductivity. As early as 1987 in China, a special project for superconductivity was set up, a national committee of superconductivity technology experts and national center for research and development of superconductivity technology were set up, and a national lab for superconductivity technology was set up, which is on the list of national critical labs. For the Seventh Five-Year Plan, some 20 million RMB were delegated to support the conduct of research into superconductivity technology. In the "Climb Project " and the "863 Project" in the Eighth Five-Year Plan, a superconductivity project was set up and some 40 million RMB were delegated to support research of superconductivity technology. Important government agencies, such as State Science Technology Committee, Chinese Academy of Sciences, State Planning Committee, State Education Committee, State Defense Science Committee, National Natural Science Foundation, Ministry of Metallurgy, Ministry of Electronic Industry, all are very concerned about and support superconductivity R&D work. Generally speaking, China has invested 130 million RMB to support basic research into superconductivity and R&D for application of superconductivity in the Seventh, Eighth and Ninth Five-Year Plans.

Over the past 10 years, China has made some fairly good achievements in superconductivity R&D, in the areas of exploring new superconducting materials, studying the electric magnetic property of high temperature superconducting materials as well as weak linkage effect of high temperature superconductors, developing application technology that can make copper oxide into useful materials and membrane technology, and developing electronic equipment of high temperature superconductivity, etc.

In the light of application of superconductivity in strong electricity, high temperature superconductivity cables that are being researched in China have reached the same level as in the United States and Japan. In 1996, the Beijing Institute of Nonferrous Metals made great progress in high temperature superconductivity materials, having manufactured a big piece of single domain YBCO in a diameter of 20 mm, whose magnetic floating power is $10N/mm^2$ and it is at a very advanced level internationally. It also manufactured a 160 mm tube-shaped wire with a inside diameter of 9 mm, an outside diameter of 12 mm, its critical electric current under liquid nitrogen being 117 A, and its critical electric current under liquid helium 430 A, and a 120 mm stick-shaped wire with an inside diameter of 10 mm; its critical electric current under liquid nitrogen 2000 A. These research achievements that the Institute has achieved have been published for the first time worldwide; these are new achievements after the United States and Japan.

In the Ninth Five-Year Plan, China will construct an applicable cable in experimentation so that research on both transmission cables of superconductivity and on manufacturing transmission cables of superconductivity will be strengthened in the projects of application of superconductivity. Research for applications in fields of non-electric power superconductivity will be strengthened as well, such as superconductive magnetic flow meters, trains using superconductive magnetic floating power, and superconductive microwave equipment, etc. Once these research projects can be transferred and applied to industry, the economic benefits coming from these gigantic superconductivity industries will be fairly spectacular.

In addition, China has made significant progress in the basic research of high critical temperature superconductivity of electricity. The work in this project during the Eighth Five-Year Plan has enabled China to keep up with or catch up with the research frontier worldwide in several aspects in this field. A lot of creative work has been done deeply and systematically in new high critical temperature superconductivity materials; mechanism of high temperature superconductivity; phase relationship and crystal structure in copper oxide superconductive materials; manufacturing technology for copper oxide superconductive materials of Y series (Yttrium), Bi (Bismuth) series, and Tl (Thallium) series; basic research on material science for membrane technology; and some basic issues in magnetic flux motion and magnetic pinning of high critical temperature superconductors.

It is here that we would like to discuss an issue about how to promote the formation and development of high-tech superconductivity industries in China, including the electric power industry. The application of superconductivity technology in energy technology has unique advantages, and market prospects will be very promising. In light of the international situation, the superconductivity high-tech industry that has been spawned and developed since the 1960s has grown up to a high-tech industrial sector with some 1.5 billion USD of annual sales worldwide as progress has been made in research fields of application technology of superconductivity, applicable superconductivity materials, and low temperature technology. In May 1995, the second session of the International Superconductivity Industrial Convention (ISIC-II) was convened in Japan, where a forecast of market development for superconductivity products worldwide in 2020 was made under the assumption that present prices for products would not be changed (See Table 10).

Table 10. Forecasts for the Worldwide Superconductivity Market

YEAR	*Electronics (%)*	*Energy (%)*	*Transportation (%)*	*Medicine (%)*	*Other (%)*	*Total Market (Billion USD)*
1993						1.5
2000	23	15	9	30	23	8 - 12
2010	32	16	6	24	22	60 - 90
2020	46	18	9	11	16	150 - 200
Products examples	Microwave equipment, computers.	Storage device, generators.	Maglev trains, Electromagnetic propulsion boats.	SQUID, MRI, and MRS for medicine	Magnet, magnetic shield.	

In accordance with the forecast from ISIC-II, from 2000 on, the proportion of high-temperature superconducting products in the market will increase. By 2020, the ratio between high temperature superconducting products (superconductivity in liquid nitrogen temperature range) and low temperature superconducting products (superconductivity in liquid helium temperature range) will be approximately 70% to 30%. It was predicted at this meeting that storage devices of high temperature superconductivity and low temperature superconductivity would come onto the market in 2000 and 2020 respectively, and that these will be fairly critical application technologies. Superconductivity motors, superconductivity transmission cables, and superconductivity transformers will come out into the market one after another after 2000. By 2020, the market share for energy technology using superconductivity will by one rough estimate be worth 27 - 36 billion USD every year, in which high temperature superconductivity will account for about 78%. It is very hard to confirm these data, but it does show for sure that the superconductivity high-tech industry will be very, very promising and lucrative in the future.

In China, it is very difficult to assess the development of a high-tech industry concretely and accurately when it is so young and has just begun to grow, especially for a high-tech industry like superconductivity, as the science and disciplines relevant to it are still growing and developing rapidly. For instance, the forecast on its development will be totally different once a superconductivity material with higher critical temperature, or even room temperature conductivity will be found or a class of materials that will be easier to manufacture than found with oxide. Besides, the invisible hand of the market will also play a very important role in this area.

China's special situation should be taken into consideration. Examining some issues in Table 10 for instance, the forecast about application of energy primarily is primarily based upon estimates for developed countries. As for China, it has a huge population, its economy is growing rapidly, and its electric power industry will make great progress in the 21st Century. Its energy development will go in the direction of conservation and sustainable development of energy, as superconductors are a kind of new material with the capacity for electricity conservation. Its utilization will conserve a lot of electricity, enabling energy use to be rationalized, and high temperature superconductivity transmission cables and superconductivity storage systems will be commercialized in the 21st century. The market distribution for energy applications in Table 10 may not be adequate if we thoroughly consider the above-mentioned factors. It is reasonable to estimate that the market proportion of superconductivity technology applied to the energy industry field in 2000, 2010, and 2020 will be even larger, so we can say that by the next century, China will be a primary competitor in the arena of superconductivity high-tech industry worldwide.

As for achieving this objective, several possible major breakthroughs in science and technology of superconductivity in China should be selected by studying and analyzing them carefully. In light of research work, the basic research and application research of high-temperature superconductivity electricity should be the primary focus. However, as China has quite a good foundation and the advantage of resources in low-temperature superconductivity technology, in the future, the application of low-temperature superconductivity technology is obviously going to play a very crucial role. At the same time, application of utility electricity to high-temperature superconductivity should not be ignored, such as transmission and storage. It is imperative to take into account the real need in China, to arrange research on manufacturing the materials of high-temperature superconductivity that lay out a good foundation for application of utility electricity, and to plan some projects for application to intense electrification, such as establishing applicable cables for experimentation in the Ninth Five-Year Plan.

Research on application conversion of superconductivity material in China is at an internationally advanced level. Research and manufacturing of high temperature superconductivity cables have kept abreast with that of United States and Japan. Block-shaped superconductivity materials in terms of maglev and magnetic property lie at an advanced level worldwide as well. From the perspective of industrialization, especially from the perspective of relevant techniques, technique equipment, and system technology, there will still be big gaps compared with the worldwide advanced level, and there will be a tendency that the gaps will widen rapidly so that the formation and development of a superconductivity industry in China will be restricted by that. The difference in capital and equipment makes application conversion of superconductivity technology lag behind the United States.

In the area of superconductivity cables, the technological level in manufacturing half-meter superconductivity cables in China is not less than the United States. Nevertheless, to master manufacturing technology for 1000-meter superconductivity cables is inevitably hindered by limitation of capital and equipment. It is very hard for China to compete against developed countries in a lot of high-tech fields, in other words, China does not have a strong capability to compete with overseas high-tech industries. Quite obviously, one of the reasons is that the research task force is comparatively weak. In most cases, China embarks on basic research for a given technology once it has already been industrialized abroad.

The situation is not optimistic as to whether superconductivity technology can be industrialized in China in the future, including whether superconductivity will be applied to the energy and electric power industry. Even so, China will keep focusing on some basic research fields that will play a critical role in providing a fundamental foundation for forming a superconductivity high-tech industry and mastering some critical technology. The foundation of basic research must be solid. Only if the foundation is solid will China be able to have a position in the arena of the superconductivity technology worldwide, once a superconductivity industry is formed to a certain scale. At present, change and development in the market need to be examined closely in order to foster China's superconductivity industry.

In light of the current situation, whether industries and enterprises in China can participate in the R&D of superconductivity earlier becomes a key issue for the formation of China's high-tech industries. The prevailing trend in high-tech industries in overseas developed countries is to stress a linkage to the market. For instance, as soon as technology for superconductivity cables comes out, the United States brings it into the market right away and issues stocks to leverage capital from society in order to push the technology toward maturation. Right now, the United States leads in the technique of manufacturing 1000-meter superconductivity cables. Technically speaking, the United States possesses the technical capability to manufacture thousands of meters of transmission lines with a high electric current capacity and low electric voltage.

A lot of weaknesses will always appear in China whenever high technology needs to be industrialized. A very critical issue for commercializing superconductivity technology should be defined, namely, that the key to commercializing superconductivity technology is superconductivity materials; other issues mostly are relevant technology. However, what Chinese entrepreneurs are looking for are projects that can give rise to economic benefits immediately. For instance, the maglev train that is being studied by the

Institute of Electric Engineering, Chinese Academy of Science is quite outstanding, none-theless, there is neither an enterprise nor a department in China that has an interest in it.

International exchange and cooperation in science and technology is an important trend in the development of high-tech industries and enterprises. As for China, the prospect for applications of superconductivity technology in the energy industry is very promising. By the 21st century, application of superconducting transmission cables, superconducting storage, superconducting generators, superconducting magnets, and MHD in China will all show magnificent market prospects; thus, application of HTS in utility scale electricity will have a spectacular prospect so that a high-tech industry with a certain scale will be formed. What is more important is that China has quite a technical foundation in this field. Looking overseas, the United States has quite a few technological advantages in this aspect. Therefore, there is a very broad development prospect in scientific and technological cooperation for studying and probing HTS utility scale electricity and exchanges for key technologies in the superconducting industry. By doing so, China and the United States will be able to complement their mutual advantages so as to achieve the objective of development collectively and simultaneously.

MAJOR REFERENCES

1. China Statistics Yearbook, 1996, China Statistical Publishing House.

2. Yan, Chang-le, The Report on Development of China Energy, Economics Management Publishing, 1994.

3. Proceedings from Conference on: European Union-China energy co-operation, Beijing, China, October 13 - 15, 1996.

4. Li, Peng, China Energy Policy, Science & Technology Daily, May 29, 1997.

5. "Speed Up the Development of Hydropower and Optimize the Structure of Energy," China Science Association Daily, October 6, 1996.

6. "It is Still Thriving for China to Develop Nuclear Power," Economics Reference, August 11, 1996.

7. Hua, Zhi-nian, "Impact of Superconducting Technology Upon the Future and Assessment and Anticipation of High-Tech Development," Beijing Post and Telecommunication College Publishing House, 1988, p.101 – 104.

8. "Promote Technological Progress of Electric Power Industry and Contribute to Sustainable Development," Science & Technology Daily, August 15, 1997.

9. Lin, Liang-zhen, "Application of Superconducting Magnet," Physics, 1993, v22n10, p.604-610.

10. Gan, Zi-zhao, "Promote the Forming and Developing of Superconducting High-Tech Industry in Our Country," Physics, 1995, v24n11, p.694-696.

11. "Hot Spot on S & T Frontier: High Temperature Superconductivity," China High-Tech Industry Magazine, March 12, 1997.

12. Yiu, Xiao-han, "Superconductivity Experts Talk About the Superconducting Industry," Science & Technology Daily, March 13, 1997.

13. Yian, Lu-guang, "Who Will Fill the Energy Gap," Science & Technology New Era, 1997, Issue 4, p.48 – 49.

14. State Superconductivity Central Office, "2020 World Superconducting Market," Physics, 1993, v22n12, p.761 - 762.

INTERNAL DISTRIBUTION

1. M. A. Brown
2. D. K. Christen
3. D. F. Craig
4. L. M. Dickens
5. L. B. Dunlap
6. R. G. Gilliland
7. M. J. Gouge
8. G. R. Gruzalski

9-28. R. A. Hawsey

29. D. M. Kroeger
30. L. A. Langley
31. B. W. McConnell
32. D. P. Norton
33. M. Paranthaman
34. J. B. Roberto
35. A. C. Schaffhauser
36. J. Sheffield
37. J. P. Stovall
38. J. VanCoevering

39-40. Laboratory Records Dept.

41. Laboratory Records—RC
42. Central Research Library

EXTERNAL DISTRIBUTION

43. N. Aversa, Consultant, Waukesha Electric Systems, 400 S. Prairie Ave., Waukesha, WI 53186-5937
44. U. Balachandran, Argonne National Laboratory, ET/212, 9700 South Cass Avenue, Argonne, IL 60439-4838
45. R. D. Blaugher, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401
46. S. Bray, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303
47. S. Brody, Superconductor Week, P. O. Box 411433, San Francisco, CA 94141-1433
48. J. Cave, Hydro-Quebec, 1800 Boul. Lionel-Boulet, Varennes, Quebec, Canada J3X 1S1
49. C. W. Chu, University of Houston, Texas Center for Superconductivity, 4800 Calhoun, Houston, TX 77204-5506
50. S. J. Dale, ABB-TTI, 1021 Main Campus Dr., Raleigh, NC 27606
51. J. G. Daley, EE-12, U.S. Department of Energy, Office of Utility Technologies, 5H-078/FORS, 1000 Independence Avenue SW, Washington, DC 20585-0121
52. D. Driscoll, Rockwell Automation, 24800 Tungsten Road, Cleveland, OH 44117
53. K. Efferson, American Magnetics, Inc., P.O. Box 2509, Oak Ridge, TN 37831-2509
54. J. Ekin, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303
55. G. H. Epstein, Intermagnetics General Corporation, P.O. Box 461, Latham, NY 12110-0461
56. A. Funkenbusch, 3M Corporate Research Tech. Development Laboratory, 3M Center Bldg. 218-1-05, St. Paul, MN 55144-1000

57. M. A. Gazda, Georgia Transmission Corp., P. O. Box 2088, Tucker, GA 30085-2088
58. J. R. Gaines, Superconductive Components, Inc., 1145 Chesapeake Ave., Columbus, OH 43212
59. P. M. Grant, Electric Power Research Insititute, P.O. Box 10412, Palo Alto, CA 94303
60. L. Grossman, CSAC, 700 13th Street NW, Suite 400, Washington, DC 20005
61. J. E. Hack, Midwest Superconductivity, Inc., 1315 Wakarusa Dr., Lawrence, KS 66049
62. E. Hahn, New York Power Authority, 123 Main St., White Plains, NY 10601
63. P. Haldar, Intermagnetics General Corporation, P.O. Box 461, Latham, NY 12110-0461
64. R. L. Hughey, Jr., Southwire Company, One Southwire Drive, Carrollton, GA 30119
65. A. T. Hunt, MicroCoating Technologies, 3901 Green Industrial Way, Chamblee, GA 30341
66. H. S. Hsu, Imtech, 12417 Butternut Circle, Knoxville, TN 37922
67. A. J. Jelacic, EE-12, U.S. Department of Energy, Office of Utility Technologies, 5H-078/FORS, 1000 Independence Avenue SW, Washington, DC 20585-0121
68. R. C. Johnson, Rochester Gas and Electric, 89 East Avenue, Rochester, NY 14649-0001
69. D. C. Larbalestier, University of Wisconsin–Madison, Applied Superconductivity Center, 1500 Engineering Drive, Madison, WI 53706-1687
70. A. Lauder, DuPont Central R&D Superconductivity Group, Exp. Station 304/C119, Wilmington DE 19880-0304
71. E. Leung, Lockheed Martin Missiles & Space, Adv. Tech. Ctr., P. O. Box 232225, San Diego, CA 92193-2225
72. W. C. Lin, U.S. Department of Energy, P.O. Box 2008, Oak Ridge, TN 37831-6269
73. K. R. Marken, Jr., Oxford Superconducting Technology, P.O. Box 429, Carteret, NJ 07008-0429
74. S. P. Mehta, Waukesha Electric Systems, 400 S. Prairie Ave., Waukesha, WI 53186-5937
75. J. W. Muehlhauser, University of Tennessee Space Institute, B. H. Goethert Parkway, MS 8, Tullahoma, TN 37388-8897
76. D. E. Peterson, Los Alamos National Laboratory, Superconductivity Technology Center, P.O. Box 1663, MS K763, Los Alamos, NM 87545
77. D. Piatt, Southern Company Services, P. O. Box 2625, Birmingham, AL 35202
78. W. C. Pittman, Hqtrs, U.S. Army Aviation and Missile Command, Attn: AMSAM-RD-MG, Redstone Arsenal, AL 35898-5000
79. C. Platt, EE-12, U.S. Department of Energy, Office of Utility Technologies, 5H-078/FORS, 1000 Independence Avenue, S.W., Washington, DC 20585-0121
80. M. Rahman, Pirelli Cable Corp. R&D Center, 710 Industrial Drive, Lexington, SC 29072
81. J. Reilly, Edison Technology Solutions, 6040 N. Irwindale Avenue, Irwindale, CA 91702
82. G. B. Riley, American Superconductor Corporation, Two Technology Drive, Westborough, MA 01581
83. F. Rodriguez, U.S. Air Force, WL/POOX, Building 450, 2645 Fifth St., Ste. 13, WPAFB, OH 45433-7919
84. M. W. Rupich, American Superconductor Corporation, Two Technology Dr., Westborough, MA 01581
85. H. Schneider-Muntau, Florida State University, National High Magnetic Field Laboratory, 1800 E. Paul Dirac Drive, Tallahassee, FL 32310
86. S. Shanmugham, MicroCoating Technologies, 3901 Green Industrial Way, Chamblee, GA 30341

87. S. S. Shoup, MicroCoating Technologies, 3901 Green Industrial Way, Chamblee, GA 30341
88. U. K. Sinha, Southwire Company, One Southwire Drive, Carrollton, GA 30119
89. J. Storer, 3M Industrial and Consumer Sector, 3M Center, Bldg. 60-1N-01, St. Paul, MN 55144-1000
90. M. Strasik, Boeing Defense & Space Group, P. O. Box 3999, MS 73-09, Seattle WA 98124-2499
91. M. Suenaga, Brookhaven National Laboratory, Bldg. 480, P. O. Box 5000, Upton, Long Island, NY 11973-5000
92. M. J. Tomsic, Plastronic, Inc., 11641 N. Dixie Dr., Tipp City, OH 45371
93. T. Vanderah, National Institute of Standards and Technology, Ceramics Division, Building 223, A-256, Gaithersburg, MD 20899
94. J. Voigt, Sandia National Laboratories, MS 1405, P.O. Box 5800, Albuquerque, NM 87185-1405
95. J. E. Wagner, Waukesha Electric Systems, 400 S. Prairie Ave., Waukesha, WI 53186-5937
96. M. S. Walker, Intermagnetics General Corp., P.O. Box 461, Latham, NY 12110-0461
97. H. Weinstock, AFOSR/NE, 110 Duncan Ave., Ste. B115, Bolling AFB, DC 20332-0001
98. D. O. Welch, Brookhaven National Laboratory, Materials Science Division, Upton, Long Island, NY 11973
99. J. W. Wilson, Midwest Superconductivity, Inc., 1315 Wakarusa Dr., Lawrence, KS 66049
100. P. W. Winkler, Air Products and Chemicals, 7201 Hamilton Blvd., Allentown, PA 18195-1501
101. J. V. Worth, President, Oxford Superconducting Technology, P.O. Box 429, Carteret, NJ 07008-0429
102. G. J. Yurek, American Superconductor Corporation, Two Technology Drive, Westborough, MA 01581