ORNL/Sub/97-SX339V/3

The Pollutant Emissions Reduction Potential of Superconductive Technologies

L. R. Lawrence, Jr., Ph.D.
Bob Lawrence & Associates, Inc.

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Prepared by:

L. R. Lawrence, Jr., Ph.D.
Bob Lawrence & Associates, Inc.
345 S. Patrick Street
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: June 1999
Date published: April 2000

Prepared for:
Superconductivity Program for Electric Systems
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6195
managed by
UT-Battelle, LLC
for the
U.S. Department of Energy
under Contract DE-AC05-00OR22725

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INTRODUCTION

This report was prepared at the request of the Oak Ridge National Laboratory in support of the Superconductivity Technology Program of the U.S. Department of Energy. The information that was gathered to prepare this report came from the following references:

The U.S. Department of Energy; Energy Information Administration (EIA):

- The Electric Power Annual 1997 - Volume I
- A Review of U.S. Electric Utility Statistics, 1997
- The Electric Power Annual 1997 - Volume II
- The Renewable Energy Annual 1998 With Data for 1997, December 1998
- Annual Energy Outlook 1999: With Projections to 2020, December 1998

High Temperature Superconductivity: The Products and Their Benefits, by L. R. Lawrence, Jr., C. Cox, and D. Broman, Bob Lawrence & Associates, Inc. (ORNL/Sub/97-SX339V/2).

ANALYSIS

The analysis for this report began with the analytical effort contained in the earlier cited reference concerning "The Products and Their Benefits." Within this reference, calculations were made of the electric generation savings which would result from the commercialization of a number of superconductive products, under a listed number of assumptions and a delineated methodology. Under this methodology, savings were calculated as the percent reduction in total generation that would result from the commercialization of the superconductive technologies and products. The percentage reductions in total generation, then, are directly proportional to the expected reductions in projected emissions on an equal percentage basis. The tables in this report repeat this basic information as a reference.

The expected emissions of carbon dioxide, sulfur dioxide, and oxides of nitrogen, without the benefit of superconductivity, were taken from the Annual Energy Outlook (AEO) 1999. It should be noted that the SO_2 and NO_x calculations presented on page 86 of this report, when compared to actual data in 1997, show that the calculated projections are falling about 20% below the actual data measured. The carbon calculations are somewhat closer to measured results. For the purposes of this report, for the years where actual data measurements had occurred, those measured numbers were used in the tables and calculations, and for the out years, the EIA calculated projections were utilized.

In examining the results of this analytical effort, it is important to notice that "short tons (tons) of CO_2", "short tons of carbon", and "metric tons (or tonnes) of carbon" are all very different entities. To convert from short tons (tons) of CO_2 to tons of carbon, for instance, one must remember that the molecular weight of CO_2 is 12+16+16 or 44 while the atomic weight of carbon is 12. Therefore, the weight of carbon, within CO_2, is 12/44 times the weight of the CO_2, or .2727 times the weight of CO_2. Similarly, to get to metric tons of carbon from tons of carbon, the quantity of short tons (tons) of carbon must be multiplied by 0.907 to give the correct amount of metric tons. There is deep concern on the part of the author that tons of CO_2, tons of carbon, and metric tons of carbon are being used interchangeably by the uninitiated.

The projections in the AEO have changed slightly between the 1999 volume and the 1998 volume. Fortunately, the projections of electricity demand growth have not changed enough to affect the kilowatt-hour savings originally calculated for "The Products and Their Benefits" report, but the parameters have changed with respect to future electric prices and generation mix. These changes do not affect the values taken from the referenced report from which the present analysis began.

The results of the analysis are presented in Tables 1 and 2.

Table 1: Savings of dollars and carbon emissions due to the market introduction of superconductive products as a function of time.

Year	Dollars saved ($M)	Kw-Hrs saved (millions)	Total generation Kw-Hrs (millions)	Short tons CO_2 to be generated (thousands)	Percent to be saved	Short tons CO_2 to be saved (thousands)	Short tons carbon to be saved (thousands)
1997	0	0	3,494,441	2,508,574	0	0	0
1998	0	0	3,543,363	2,549,000	0	0	0
1999	0	0	3,592,000	2,589,000	0	0	0
2000	0	0	3,643,000	2,631,000	0	0	0
2001	0	0	3,694,000	2,673,000	0	0	0
2002	0	0	3,746,000	2,716,000	0	0	0
2003	0	0	3,798,000	2,759,000	0	0	0
2004	0	0	3,851,620	2,803,000	0	0	0
2005	.96	15.6	3,906,000	2,848,000	negligible	negligible	negligible
2006	23.85	394	3,960,000	2,894,000	0.01	289	79
2007	69.00	1146	4,016,000	2,940,000	0.03	882	241
2008	137.82	2305	4,072,000	2,987,000	0.06	1792	489
2009	251.53	4235	4,129,000	3,035,000	0.10	3035	828
2010	412.28	6988	4,187,000	3,084,000	0.17	5243	1430
2011	644.09	11,029	4,245,000	3,124,000	0.3	9372	2556
2012	992.63	17,174	4,305,000	3,164,000	0.4	12,656	3452
2013	1,505	26,311	4,365,000	3,205,000	0.6	19,230	5245
2014	2,225	39,311	4,426,000	3,247,000	0.9	29,223	7970
2015	3,157	56,375	4,488,000	3,289,000	1.3	42,757	11,661
2016	4,331	77,616	4,551,000	3,332,000	1.7	56,644	15,448
2017	5,754	103,489	4,615,000	3,375,000	2.2	74,250	20,250
2018	7,382	133,249	4,679,000	3,419,000	2.8	95,732	26,109
2019	9,196	166,594	4,745,000	3,464,000	3.5	121,240	33,065
2020	11,134	202,069	4,811,000	3,509,000	4.2	147,378	40,194
					Accumulated Totals	619,723	169,017

Emissions of Nitrogen Oxides and Sulfur Dioxide

The EIA has predicted future emissions from electric generators based on a future generation mix and in-place legislation. Both nitrogen oxide emissions and sulfur dioxide emissions predictions for the future are predicated on in-place legislation, particularly the Clean Air Act Amendments of 1990 (CAAA90). This legislation, plus the Ozone Transport Rule are expected to reduce sulfur dioxide emissions continuously up through 2020, and reduce nitrogen oxide releases through 2005, with slight increases thereafter. Actual measurements, as shown in the Electric Utility Annual are showing 15-20% higher than the EIA predictions. Nonetheless, the following analysis is based on the more conservative EIA predictions.

According to the EIA (AEO 1999, pg 86), nitrogen oxide emissions (NO_x) in the U.S. are expected to fall significantly until the year 2005, due to the effect of new legislation. In fact, 1.5 million tons are expected to be reduced between 1999 and 2000. After 2003, the Ozone Transport Rule will take effect, leading to further reductions. The result will be a reduction of 0.7 million tons between 2002 and 2003. Continuing reductions are expected to occur with boiler retrofits in accordance with legislative limits. These factors are taken into account in Table 2 in which interpolations are used to calculate the expected NO_x release levels without the introduction of superconductive technologies through 2020. The expected release levels, then, conform to the present EIA model results. The calculated results, with the introduction of superconductive technologies, can be found in Table 2.

In-place legislation (CAAA90) calls for sulfur dioxide emissions to be reduced to approximately 12 million short tons in 1996, 9.48 million tons between 2000 and 2009, and 8.95 million tons by 2010. With present and predicted activity due to in-place legislation, emissions are expected to decline from 11.9 million tons in 1995 to 11.4 million in 2000. After 2000, it is expected that 26.4 gigawatts of capacity will be retrofitted with scrubbers to meet the Phase 2 goal. In fact, as may be seen in Appendix II, measured emission levels are 15-20% over these EIA model predictions. For the purpose of these calculations, however, the EIA model results were employed for the out-years between 2000 and 2020. The SO_2 savings resulting from expected superconductivity technology commercialization may be found in Table 2.

Table 2: Savings of NO_x and SO_2 emissions due to the market introduction of superconductive electrical products as a function of time.

Year	Total generation Kw-Hrs (millions)	Kw-Hrs saved (millions)	Short tons SO_2 to be generated (thousands)	Short tons NO_x to be generated (thousands)	Percent to be saved	Short tons SO_2 to be saved (thousands)	Short tons NO_x to be saved (thousands)
1997	3,494,441	0	13,316	8294	0	0	0
1998	3,543,363	0	-	-	0	0	0
1999	3,592,000	0	-	-	0	0	0
2000	3,643,000	0	11,400	4600	0	0	0
2001	3,694,000	0	-	-	0	0	0
2002	3,746,000	0	-	-	0	0	0
2003	3,798,000	0	-	-	0	0	0
2004	3,851,620	0	-	-	0	0	0
2005	3,906,000	15.6	10,200	3900	negligible	negligible	negligible
2006	3,960,000	394	9980	3940	0.01	.998	.394
2007	4,016,000	1146	9760	3980	0.03	2.93	1.19
2008	4,072,000	2305	9540	4020	0.06	5.72	2.41
2009	4,129,000	4235	9320	4060	0.10	9.32	4.06
2010	4,187,000	6988	9100	4100	0.17	15.47	6.97
2011	4,245,000	11,029	9080	4120	0.3	27.24	12.36
2012	4,305,000	17,174	9060	4140	0.4	36.24	16.56
2013	4,365,000	26,311	9040	4160	0.6	54.24	24.96
2014	4,426,000	39,311	9020	4180	0.9	81.18	37.62
2015	4,488,000	56,375	9000	4200	1.3	117	54.6
2016	4,551,000	77,616	9000	4220	1.7	153	71.74
2017	4,615,000	103,489	9000	4240	2.2	198	93.28
2018	4,679,000	133,249	9000	4260	2.8	252	119
2019	4,745,000	166,594	9000	4280	3.5	315	150
2020	4,811,000	202,069	9000	4300	4.2	378	181
					Accumulated Totals	1646	776

RESULTS AND CONCLUSIONS

Based on the reference materials chosen for this analysis, superconductive products have the potential of saving an accumulated 619 million tons of CO_2 through 2020, which equates to 169 million tons of carbon. The savings of NO_x and SO_2 emissions are smaller in quantity, 776 and 1646 thousand tons, respectively, but the pollution potential of these smaller quantities and the destructive influence of them exceed the CO_2 and carbon insults. Therefore, all three of these emission constituents are important to address in any benefits analysis of superconductive technologies.

The projections of total installed generation, and associated emissions, are taken from the AEO99. From the emissions projections within that report, it is assumed that CO_2 emissions will grow at the rate of 1.6% per year through 2010, and 1.3% per year thereafter. This does not correspond to the growth rate in electricity demand, due to the changes in generation mix which occur. In the near term, the EIA estimates that most generation increases will come from fossil fuels; predominantly coal. After 2010, the efforts and incentives included in the climate change action plan begin to have an effect. Clearly, the EIA does not yet feel that the Kyoto protocol will be implemented or that presently known and projected emissions activities will have the effect of causing emissions reductions; just slowed growth.

The EIA information which was used as the starting point for the analysis contained in this report is presented in the following appendices.

APPENDIX A

Table A-1. Electric Power Industry Summary Statistics for the United States, 1996 and 1997.
(Table 1 of EIA/Electric Power Annual 1977, Volume II.)

Item	1996	1997	Percent change
Electric Power Industry[1]			
Generating Capability (megawatts)[2]	775,872	778,513	0.3
Net Generation (million kilowatt-hours)	3,446,994	3,494,441	1.4
Emissions (thousand short tons)			
Sulfur Dioxide (SO_2)	13,070	13,316	1.9
Nitrogen Oxides (NO_x)	8,224	8,294	.9
Carbon Dioxide (CO_2)	2,480,615	2,508,574	1.1
Electric Utilities			
Generating Capability (megawatts)[2,3]	709,942	711,889	.3
Coal	302,420	302,866	.1
Petroleum	70,421	69,539	-1.3
Gas	134,590	136,957	1.8
Nuclear	100,784	99,716	-1.1
Waste Heat	5,408	4,979	-7.9
Renewable			
Hydroelectric (conventional)	73,129	76,177	4.2
Geothermal	1,622	1,622	.0
Biomass[4]	445	482	8.3
Wind	8	14	75.0
Photovoltaic	4	5	25.0
Hydroelectric Pumped Storage	21,110	19,310	-8.5
Net Generation (million kilowatt-hours)	3,077,442	3,122,523	1.5
Coal	1,737,453	1,787,806	2.9
Petroleum[5]	67,346	77,753	15.5
Gas	262,730	283,625	8.0
Nuclear	674,729	628,644	-6.8
Renewable			
Hydroelectric (conventional)	331,058	341,273	3.1
Geothermal	5,234	5,469	4.5
Biomass[4]	1,967	1,983	.8
Wind	10	6	-40.0
Photovoltaic	3	3	.0
Hydroelectric Pumped Storage[6]	-3,088	-4,040	-30.8
Consumption			
Coal (million short tons)	875	900	2.9
Petroleum (million barrels)[8]	113	125	10.6
Gas (billion cubic feet)	2,732	2,968	8.6
Stocks (year End)			
Coal (million short tons)	115	99	-13.9
Petroleum (million barrels)[9]	48	49	2.1
Receipts			
Coal (million short tons)	863	881	2.1
Petroleum (million barrels)[10]	107	118	10.3
Gas (billion cubic feet)[11]	2,607	2,766	6.1

Item	1996	1997	Percent change
Cost (cents per million Btu)[12]			
Coal	128.9	127.3	-1.2
Petroleum[13]	315.7	288.0	-8.8
Gas	264.1	276.0	4.5
Sales to Ultimate Consumers (million kilowatt-hours)	3,097,810	3,139,826	1.4
Residential	1,082,491	1,075,749	-.6
Commercial	887,425	928,491	4.6
Industrial	1,030,356	1,032,672	.2
Other[14]	97,539	102,913	5.5
Revenue from Ultimate Consumers (million dollars)	212,455	215,063	1.2
Residential	90,501	90,694	.2
Commercial	67,827	70,486	3.9
Industrial	47,385	46,772	-1.3
Other[14]	6,741	7,111	5.5
Average Revenue per Kilowatt-hour (cents)	6.86	6.85	-.1
Residential	8.36	8.43	.8
Commercial	7.64	7.59	-.7
Industrial	4.60	4.53	-1.5
Other[14]	6.91	6.91	.0
Net Electric Plant Inc Fuel (million dollars)			
Major Investor Owned	369,298	357,238	-3.3
Major Publicly Owned Generator/Nongenerator	70,416	69,949	-0.1
Emissions (thousand short tons)[15]			
Sulfur Dioxide (SO_2)	12,179	12,452	2.2
Nitrogen Oxides (NO_x)	6,967	7,174	3.0
Carbon Dioxide (CO_2)	2,044,559	2,113,654	3.4
Noncoincidental Summer Peak Load (megawatts)	616,790	637,677	3.4
DSM Actual Peak Load Reductions (megawatts)	29,893	25,284	-15.4
DSM Energy Savings (million kilowatt-hours)	61,842	56,406	-8.8
DSM Cost (million dollars)	1,902	1,636	-14.0
Nonutility Power Products			
Installed Capacity (megawatts)	73,189	74,021	1.1
Coal[16]	11,370	11,236	-1.2
Petroleum Only[17]	2,251	2,994	33.0
Gas Only[18]	30,493	30,748	.8
Petroleum/Natural Gas (combined)	10,912	9,767	-10.5
Nuclear[19]	–	–	–
Renewable			
Hydroelectric (conventional)	3,419	3,776	10.4
Geothermal	1,346	1,303	-3.2
Biomass[4]	10,726	10,897	1.6
Wind	1,670	1,607	-3.8
Solar Thermal	354	354	.0
Photovoltaic	–	–	–
Other[20]	648	1,340	106.8

Item	1996	1997	Percent change
Gross Generation (million kilowatt-hours)	382,423	384,707	.6
Coal[16]	61,375	58,923	-4.0
Petroleum[17]	14,959	15,620	4.4
Gas[18]	213,304	219,753	3.0
Nuclear[19]	–	–	–
Renewable			
Hydroelectric (conventional)	16,555	17,905	8.2
Geothermal	10,198	9,110	-10.7
Biomass[4]	57,937	55,887	-3.5
Wind	3,400	3,385	-.4
Solar Thermal	903	893	-1.1
Photovoltaic	–	–	–
Other[20]	3,793	3,232	-14.8
Consumption[21]			
Coal (thousand short tons)	53,199	51,781	-2.7
Petroleum (thousand barrels)[6]	42,928	38,979	-9.2
Natural Gas (million cubic feet)	2,447,720	2,247,613	-8.2
Other Gas (million cuvic feet)[23]	1,737,271	1,372,001	-21.0
Supply and Disposition (million kilowatt-hours)			
Gross Generation	382,423	384,707	.6
Receipts[24]	103,219	89,045	-13.7
Deliveries[25]	238,929	241,401	1.0
Facility Use	246,713	232,327	-5.8
Emissions (thousand short tons)[26]			
Sulfur Dioxide (SO_2)	1,521	1,503	-1.2
Nitrogen Oxides (NO_x)	1,438	1,379	-10.3
Carbon Dioxide (CO_2)	593,221	542,615	-8.5

[1]Electric utility and nonutility values (capability versus capacity, net versus gross generation, total emissions versus emission for the production of electricity) may not be summed directly--see Technical Notes for summation methodology.

[2]Data are based on the initial commercial operation year for the generator.

[3]Net summer capability based on primary energy source; waste gases, and waste steam are included in the original primary energy source (i.e., coal, petroleum, or gas)--historical data have been revised to reflect this change.

[4]Includes wood, wood waste, peat, wood liquors, railroad ties, pitch, wood sludge, municipal solid waste, agricultural byproduct, straw, tires, landfill gases, fish oils.

[5]Includes petroleum coke.

[6] Represents total pumped storage facility production minus energy used for pumping. Negative generation denotes that electric power consumed for plant use exceeds gross generation.

[7]Includes 209 megawatts of multi-fueled capacity and 13 megawatts fueled by hot nitrogen.

[8]Does not include petroleum coke consumption of 681 thousand short tons in 1996 and 1400 thousand short tons in 1997.

[9]Does not include petroleum coke stocks of 91 thousand short tons at year end 1996 and 469 thousand short tons at year end 1997.

[10]Does not include petroleum coke receipts of 1,410 thousand short tons in 1996 and 2,192 thousand short tons in 1997.

[11]Includes small amounts of coke-oven, refinery, blast furnace gas, and landfill gas.

[12]Average cost of fuel delivered to electric generating plants with a total steam-electric nameplate capacity of 50 or more megawatts; average cost values are weighted by Btu.

[13]Does not include petroleum coke cost of 78.2 cents per million Btu in 1996 and 91.2 cents per million Btu in 1997.

[14]Includes public street and highway lighting, other sales to public authorities, sales to railroads and railways, and interdepartmental sales.

[15]Includes only those power plants with a fossil-fueled steam-electric nameplate capacity (existing or planned) of 10 or more megawatts. As of 1993, emission factors for the calculation of carbon dioxide emissions and reductions from nitrogen oxide control technologies have been changed--historical data were revised to reflect that change--see the Technical Notes for more information.

[16]Includes coal, anthracite culm, coke breeze, fine coal waste coal, bituminous gob and lignite waste.

[17]Includes petroleum, petroleum coke, diesel, kerosene, liquid butane, liquid propane, oil waste and tar oil.

[18]Includes natural gas, waste heat, waste gas, butane, methane, propane and other gas.

[19]Nuclear reactor and generator at Argonne National Laboratory used primarily for research and development in testing reactor fuels as well as for training. The generation from the unit is used for internal consumption.

[20]Includes hydrogen, sulfur, batteries, chemicals, purchased steam.

[21]Includes all combustible fuels burned at generating facilities (not just for the production of electricity).

[22]Does not include petroleum coke consumption of 4,484 thousand short tons for 1996 and 4,315 thousand short tons for 1997.

[23]Includes butane, methane, propane, digester gas, and other gas.

[24]Includes purchases, interchanges, and exchanges of electric energy with utilities and other nonutilities.

[25]Includes sales, interchanges, and exchanges of electric energy with utilities and other nonutilities. The disparity in these data and data reported on other EIA surveys occurs due to differences in the respondent universe. The Form EIA-867 is filed by nonutilities reporting the energy delivered, while other data sources are filed by electric utilities reporting energy received. Differences in terminology and accounting procedures contribute to the disparity. In addition, since the frame for the Form EIA-867 is derived from utility surveys, the Form EIA-867 universe lags 1 year.

[26]As of 1993, emission factors for the calculation of carbon dioxide emissions and reductions from nitrogen oxide control technologies have been changed--historical data were revised to reflect that change--see Technical Notes for more information.

NM = Calculation not meaningful.

Notes: Estimation methodology. Form EIA-412, "Annual Report of Public Electric Utilities"; Form EIA-759, "Monthly Power Plant Report"; Form EIA-860, "Annual Electric Generator Report"; Form EIA-861, "Annual Electric Utility Report"; Form EIA-767, "Steam-Electric Plant Operation and Design Report"; Form EIA-867, "Annual Nonutility Power Producer Report." , "Coordinated Bulk Power Supply Programs"; Department of Energy, Office of Emergency Policy, Form OE-411, "Coordinated Bulk Power Supply Program."

Appendix B

Table B-1. Subset of interest taken from Electric Power Industry Summary Statistics for the United States, 1996 and 1997.

(See Table 1 of EIA/Electric Power Annual 1997, Volume II, shown in Table A-1.)

Item	1996	1997	Percent change
Electric Power Industry[1]			
Electric Utilities	709,942	711,889	.3
Generating Capability (megawatts)[2, 3]	302,420	302,866	.1
Coal	70,421	69,539	-1.3
Nonutility Power Producers			
Installed Capacity (megawatts)	73,189	74,021	1.1
Coal[16]	11,370	11,236	-1.2
Electric Utilities			
Net Generation (million kilowatt-hours)	3,077,442	3,122,523	1.5
Coal	1,737,453	1,787,806	2.9
Petroleum[5]	67,346	77,753	15.5
Gas	262,730	283,625	8.0
Nonutility Power Producers			
Gross Generation (million kilowatt-hours)	382,423	384,707	.6
Coal[16]	61,375	58,923	-4.0
Petroleum [17]	14,959	15,620	4.4
Gas [18]	213,304	219,753	3.0
Total Net Generation (million kilowatt-hours)	3,446,994	3,494,441	1.4
Emissions (thousand short tons)			
Sulfur Dioxide (SO_2)	13,070	13,316	1.9
Nitrogen Oxides ($_{Nox}$)	8,224	8,294	.9
Carbon Dioxide (CO_2)	2,480,615	2,508,574	1.1

(Note: References same as in Appendix A.)

Observations Regarding this Table

From 1996 to 1997:

Overall Generation increased 1.4%

- Coal increased 2.7% or 47,901 MkwHrs
- Oil increased 13.4% or 11,068 MkwHrs
- Gas increased 5.7% or 27,344 MkwHrs

1997:

- Petroleum was 5.06% of coal use
- Gas was 27.3% of coal use

Emission increases:

Carbon Dioxide: 1.1% or 27,959 thousand short tons
Sulfur Dioxide: 1.9% or 246 thousand short tons
Nitrogen Oxides: .9% or 70 thousand short tons

To convert from short tons of CO_2 to metric tons of carbon: Multiply the number of short tons of CO_2 by 27.27% (carbon of CO_2) and by .907 metric tons per ton. Factor is .2473 times short tons of CO_2 gives metric tons of carbon.

From AEO, carbon emissions from electricity generation increase 1.6% per year through 2010, and then by 1.3% per year through 2020.

From AEO, electric generation increases an average 1.4% per year through 2020.