Energy Saving Potential from New Industrial Equipment Efficiency Standards in China

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ABSTRACT

Low energy efficiency of Chinese industrial equipment implies that there is significant potential for energy savings. Implementation of energy-efficiency standards is a means to realize these energy savings. Analysis of energy saving potential quantifies the potential costs and benefits of the standards. Where the benefits are large, policy-makers are encouraged to pay more attention to the standards program. Such analyses also provide a scientific reference to help set priorities among candidate products. This paper presents the current status of energy efficiency standards for three major types of energy-consuming industrial equipment and estimates potential national energy savings, assuming the new energy efficiency standards are implemented in 2004 or 2005. Based on this analysis, we estimate the energy saving potential from new energy standards for these three types of equipment in the Chinese industrial sector. Results show that the primary energy savings achieved from small and medium 3-phase asynchronous electric motors, distribution transforms, and industrial boilers are 5.51Mtce, 7.39 Mtce and 35.65Mtce respectively in 2020. The environmental and economic benefits achieved by new standards for these products are substantial and induce considerable net economic benefits over the 2004-2020 period. It is urgent to develop mandatory energy efficiency standards for these three types of equipment in the very near future to recognize the substantial energy savings, and the associated environmental and economic benefits.

Introduction

China's rapid economic growth in recent years has been accompanied by large increases in energy use. China occupies second place in the world, behind only the United States, in energy consumption and greenhouse gases emissions. In 1998, Total primary energy consumption reached 1322.1 Million tons of Coal Equivalents (Mtce), among which the industry sector accounted for 944.1 Mtce (71%). In 2000, Chinese energy consumption per ten-thousand-RMB GDP was 2.77 Mtce. Although this energy intensity is down about two-thirds from the 7.89 Mtce used in 1980, it was still about 2.3 times the world average level. Per unit energy use of major industrial energy-using products is higher than the world's advanced level by an average of about 40% (EIC 2001). The large differences in energy efficiency between China's industrial sector and those of developed countries, and the wide variation in efficiency level among regions in China, indicate that available potential energy savings are considerable.

The Government of China has determined to curb energy consumption by improving energy efficiency. In the 10th Five-Year Plan for Energy Conservation and Resource Comprehensive Utilization developed by the former State Economic and Trade Commission, the government clearly indicates that the priority of governmental management and supervision of energy conservation shall shift from industrial process to end-use energy-consuming products and that future energy conservation work shall focus on improving energy efficiency.

Energy-efficiency standards for appliances and equipment have proven to be one of the most successful policy instruments to improve energy efficiency in many countries. But in China, existing energy efficiency standards are well below international levels and the product coverage is still very limited. Especially in the industrial sector, there are not yet energy-efficiency standards for many common types of industrial equipment. For instance, the energy efficiency of industrial boilers in China is about 80% of that in western developed countries. For electric motors, the electricity consumption to produce a unit of power is higher than the international level by 5-10%. These differences in efficiency indicate the opportunity for achieving substantial savings by developing new energy efficiency standards for industrial equipment.

In the view of limited financial and managerial resources, it is only possible and practical to develop standards for a limited number of products at a time. Therefore, it is necessary to conduct an energy saving potential analysis of major energy-consuming industrial products to help policy makers set priorities for developing energy efficiency standards. With support from the China Sustainable Energy Program of the Energy Foundation (EF), the China National Institute of Standardization (CNIS) with help from the American Council for an Energy-Efficient Economy (ACEEE) conducted a national scale analysis to estimate the overall savings potential from establishing energy efficiency standards for more than a dozen types of products and equipment. This paper presents the analysis results for efficient electric motors, distribution transformers, and industrial boilers. The findings have persuaded the government to accelerate the development of energy standards for industrial equipment in order to increase the sustainability of China's industrial sector by saving energy and reducing pollutant emissions through the implementation of these standards.

Methodology

Setting a Baseline

Baseline means the energy efficiency level of products in the absence of new standards. For medium/small, 3-phase, asynchronous motors, the baseline is the current energy standard. For distribution transformers and industrial boilers, the baseline is estimated according to current energy efficiency levels as determined from discussions with manufacturers, guilds, institutes, testing laboratories, government agencies and information organizations.

Proposing New Standards

After consulting with some known experts, the new standards and the effective dates for the three equipments were proposed according to terms of the present international advanced energy efficiency levels, the development trend of new energy conservation technologies and the capability of domestic manufacturers to produce high efficient products.

Calculating National Energy Savings

These products in operation will save energy during their lifetime due to the increase in efficiency. Because the proposed standards are mandatory, all related products sold will, in theory, meet the new standard(s). In the case where the new standards are not implemented, we assume that efficiency levels remain at present levels. Once the new standards are set, efficiency levels are expected to rise to the level required by new standards and remain at this level. In actuality, product energy efficiency is gradually increasing, even in the absence of new standards. At the same time, some products will be sold with higher energy efficiency than required by the new standards. We implicitly assume these factors counterbalance each other.

The equations for end-use electricity savings and primary energy savings are as follows:

End-use electricity savings = per-unit electricity or coal savings ×inventory[1]
Primary energy savings = end-use electricity savings ÷ T&D loss factor × heat rate

For heat rates (primary energy input required to generate a unit of electricity, in gram of coal equivalent per kWh (gce/kWh), we used 359.6 gce/kWh for 2010 and 334.8 gce/kWh for 2020. We use a 0.85 T&D loss factor (a 15% T&D loss).

Calculating Emission Reductions and Economic Benefits

The equation for calculating carbon, nitrogen oxide, sulfur dioxide, and particulate emissions reductions is as follows:

Emission reductions = end-use electricity savings ÷ T&D loss factor × emission factors

The emission factor for carbon, NOx, SOx, and PM10 is 0.267 kg/kWh, 4.07 g/kWh, 53.1 g/kWh, 24.8 g/kWh, respectively.

We determined the financial savings by multiplying electricity and coal industrial rates by the energy savings, while we calculated financial costs by multiplying the per-unit incremental purchase cost for each product by the number of units sold. Present value (PV) calculations are discounted to 2000 using a 7.6% discount rate. Net present value (NPV) of investment aggregates the present value of annual investments from the effective date of each standard through 2020. The NPV of savings aggregates the present value of annual utility bill savings from the effective date of the standard through the year in which products installed

[1] Inventory means quantity of all equipment meeting new standards and not yet retired by the year in the forecast (e.g. 2010, 2020).

through 2020 die out. That means the NPV of savings also includes savings after 2020 for equipment sold prior to 2020. NPV is calculated as:

$$NPV\ of\ investment = \Sigma\{PV(annual\ sales\ volume \times Per\text{-}unit\ incremental\ cost)\}$$
$$NPV\ of\ savings = \Sigma\{PV(end\text{-}use\ energy\ savings \times industrial\ energy\ price)\}$$

We used an industrial electricity rate of 0.53 Yuan/kWh, a residential coal rate of 242.8 Yuan/ton, and an industrial coal rate of 251.7 Yuan/ton.

Energy Saving Potential from Small and Medium Three-Phase Asynchronous Electric Motors

Overview

In China, energy consumption by electric motors accounts for more than 60% of total electricity consumption. According to data from the China Electric Equipment Industry Association, the total capacity of alternating current motors produced was about 44,100 MW in the year 2001, out of which 71.5% (31,500MW) is medium/small (0.55-315 kW), three-phase, asynchronous motors (Zhou Sheng, Zhao Kai & Xu Jingkui 2002). Promotion of energy efficient medium/small electric motors is important for energy conservation.

There are mainly Y and Y2 low-voltage asynchronous electric motors series produced and applied in China. The power of Y series ranges from 0.55 kW to 250 kW. Its annual average production is about 20,000 MW. The power of Y2 series ranges from 0.12 kW to 315 kW. The production yearly of Y2 series is more than 4000 MW. Some research indicates the production of Y and Y2 series are increasing rapidly (Qin He 2002). Most motors used in China are lower in terms of efficiency compared with international average level. Although some manufacturers are capable of producing energy efficient motors, for example YX, YX2, and Y2E series, the production and stock of high efficiency motors are still very small. In 1998, production of energy efficient motors was less than 2% of total motor production. And most of these energy efficient motors conformed to the National Electrical Manufacturers Association (NEMA) standard for motors and were exported to the U.S. In 2001, the production of energy efficient motors accounted for 6.5% of total motor production. Among these high efficient motors, more than 70% were exported (Zhou Sheng, Zhao Kai & Xu Jingkui 2002). Some investigations show that many domestic consumers hope to select and use high efficiency motors.

Current Situation in Terms of Standards

Worldwide, many countries pay attention to saving energy from motors and have developed energy efficiency standards for motors, such as U.S., Canada, Mexico, Brazil, Australia and New Zealand. European Committee of Manufacturers of Electrical Machines and Power Electronics (EU/CEMEP) standard (a voluntary standard) regulates high and low efficiency indices of electric motor of each size. The efficiency of high performance motors is 1-5% higher than that of common electric motors. (Qin He 2002). In U.S., the Energy Policy Act of 1992 set minimum efficiency standards for motors sold in the U.S. For the moment, electric motor manufacturers in America have followed this Act in motor production, and have completed the transition from production of common motors to high-efficiency motors. To further promote energy conservation of motors, the Consortium for Energy Efficiency (CEE) and the NEMA are encouraging the production and application of Premium-Efficiency Motors, whose efficiency is an average of 2% higher than that of general high-efficiency motors. (Zhao Yuejin 2002).

In China, CNIS developed The Limited Value of Energy Efficiency and Evaluating Value of Energy Conservation for Small and Medium Three-phase Asynchronous Motors in 2002, which took effect on August 1st, 2002. This is the first and the only energy standard for industrial equipment now in effect in China. The limited value of energy efficiency for motors regulated by the standard equals to eff2 efficiency index of EU, and close to the average efficiency of Y2 series. Table 1 shows the average efficiency of motors in different countries. By comparing with international standards, we can see that motors in China are three to five percent lower in terms of efficiency (Qin He 2002; Zhao Yuejin 2002). Therefore, the current motor energy efficiency standard could be improved.

Table 1. Average Efficiency of Motors in Different Countries

Series	China Y2	China Y2E	EU eff2	EU eff1	US EPACT	US NEMA E	US NEMA Premium	US IEEE 841-2000
η (%)	86.3	87.9	86.4	89.1	90.3	92.2	91.7	91.1

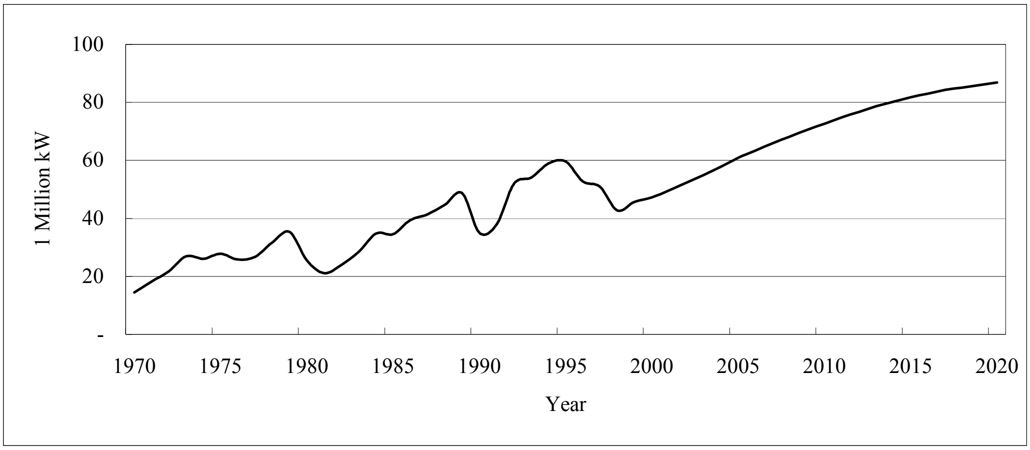
Source: Zhou Sheng, 2002

Energy Saving Potential

Proposed new standard. We assume that in 2004, a national mandatory standard can be established, and new motors will meet the new standard, which means the average efficiency of electric motors produced after 2004 is promoted to 87.9% from 86.3%.

Future development in medium/small tri-phase asynchronous electric motors. Considering the rapid growth of the Chinese economy, medium/small three-phase asynchronous electric motors will enjoy great prospects for market growth. The development of the equipment from the effective year (2004) to 2020 was estimated (see Figure 1). A survival function is constructed around an assumed average product life of 10 years. According to this trend and survival assumption, the inventory of the efficient equipment will reach 89 million kW in 2005, 321 million kW in 2010, and 467 million kW in 2020.

Figure 1. Production of Medium/Small Tri-phase Asynchronous Electric Motors, 1970-2020



Source: Zhao Yuejin, 2002

Energy savings, environmental and economic benefits. Analyses are showed as follows: Annual average energy savings per unit is 289 kWh, and total energy savings in 2010 from electric motors is 11.29 TWh, which amounts to 4.06 Mtce in terms of primary energy; growing to 16.46 TWh in 2020, amounting to primary energy of 5.51 Mtce. Electricity savings will yield present value savings for purchases through 2020 of 46.7 billions Yuan. Incremental cost of high efficiency motors is about 132 Yuan and present value of investment through 2020 is 9.4 billion Yuan. Net benefits will be 37.3 billion Yuan. The emission reductions of air pollutants due to energy conservation are 5.18 million metric tons (MMT) of carbon, 0.08 MMT of nitrogen oxide, 1.03 MMT of sulfur dioxide and 0.48 MMT of PM10 in 2020.

Energy Saving Potential from Distribution Transformers

Overview

Distribution transformers are used in many commercial and industrial buildings to reduce voltages from line voltages to voltages used to power building systems. These systems are typically purchased on the basis of first cost and have long operation time, leaving significant opportunities for cost-effective energy savings, especial for low voltage transformers (mainly 10kV and 35kV).

In China, the total output of transformers was approximately 203.82 million kVA in 2001. The average export of transformers reached about 12.45 million kVA in 2001, accounting for 6.11% of production. Since the average life of transformers is 20 years, there are approximately 1 billion kVA transformers installed in China. Along with fast development of urbanization and commercial buildings, more and more transformers are being applied to change voltages in buildings. The annual growth rate since 1990 has averaged 5% annually (NBS 2000). Among existing transformers, quite a few should be replaced. For instance, '64' and '73' series distribution transformers with high energy consumption have been in operation for over 20 years; these transformers still have a total gross capacity of 22.04 million kVA. In some large enterprises, most distribution transformers are old, and high energy-consuming transformers account for about 29% of the total transformers in use. In China, the total losses of transformers per year reach 41 TWh (ICA, 2000). Higher-efficiency transformers are in great market demand.

Current Situation in Terms of Standards

Distribution transformers are provided with three product standards in EU: international standards (International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC)), European standards (EN) and national standards (for instance Norme Francaise (NF), Deutsche Industrie—Norm (DIN), Una Norma Espaňola (UNE), Nederlandse Norm (NEN), British Standards Institution (BSI)) Among international standards, two primary European agreements regulate energy efficiency level: HD428 tri-phase oil immersed distribution transformers, 50Hz, 50- 2500kVA, and the maximum voltage is no more than 36kV; HD538 tri-phase dry-type distribution transformers, 50Hz, 50- 2500kVA, and the maximum voltage is no more than 36kV. In U.S., National Electrical Manufacturers Association (NEMA) manages ratings methods and standards for distribution transformers. The NEMA TP-1 standard, issued in 1996, covers high-efficiency distribution transformers. The purpose of this standard is to promote the application of high-efficiency transformers and assist buyers in selecting high-efficiency transformers.

In China, most 10kV and 35kV transformers are designed according to product standards in China, which have gone through revisions time after time, and products have developed from former high energy consumption SJ1, SJ2, SJ3, SJ4, SJL and SJL1 series and D1, S2, S5, SL, SL1 and SL3 series to current low energy consumption S9, S10 and S11 series. The efficiency levels of transformers in China are diversified now, as a result of the transformation from a planned economy to a market economy, and demand for energy conservation and environmental protection by the society. Currently, about 10% of existing transformers have a high energy efficiency. New market trend shows higher-efficiency transformers are in great demand. In addition, many manufacturers have the capacity for producing high-efficiency transformers, therefore, energy efficiency standards should be adopted to standardize transformer market under current market economy system, and to boost the development of high-efficiency transformers. Table 2 shows the losses of four series of transformers.

Energy Saving Potential

Proposed new standards. Assuming a new standard will take effect in 2004 and it stipulates S7 series should be replaced by the more efficient S9 series, the annual weighted average savings per unit is expected to reach 2086 kWh.

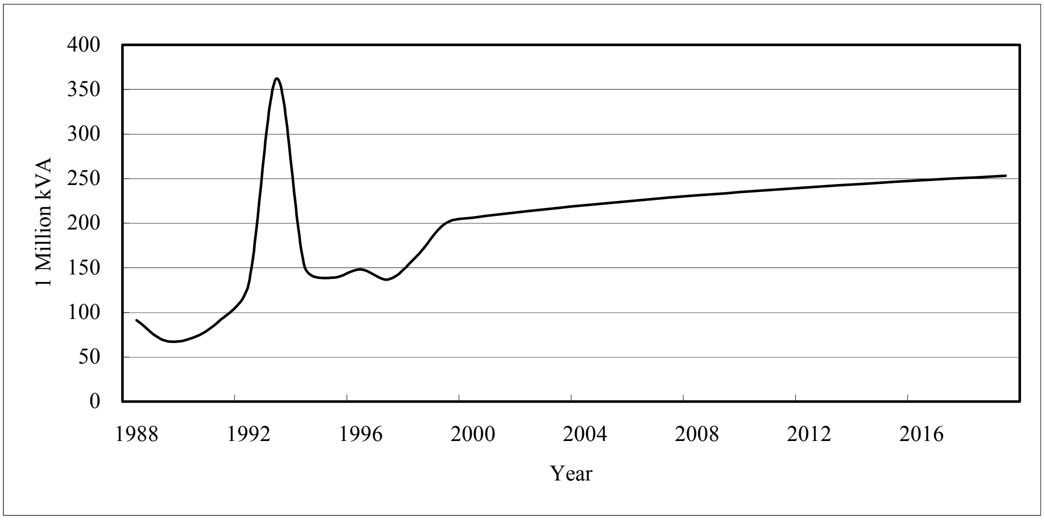
Table 2. Load Losses of Three Series of Oil-Filled Transformers of Different Sizes

KVA	Europe C Series (W)		China S11 (W)		China S9 (W)		China S7 (W)	
	Load losses	No-load losses	Load losses	No-load losses	Load losses	No-load losses	Load losses	No-load losses
50	875	125	870	130	870	170	1150	190
100	1475	210	1500	205	1500	290	2000	320
160	2000	300	2150	284	2200	400	2850	460
250	2750	425	3050	409	3050	560	4000	640
400	3850	610	4300	570	4300	800	5800	920
630	5400	860	6200	851	6200	1200	8100	1300
1000	9500	1100	10300	1200	10300	1700	11600	1800
1600	14000	1700	14500	1706	14500	2400	16500	2650

Source: Zhao Yuejin, 2002

Future development in distribution transformers. Figure 2 shows the production of distribution transformers and their estimated future development. Assuming an average lifetime of 20 years, high efficiency transformers will not be retired by 2020. The inventory of efficient equipment was calculated as follows: 437 million kVA for 2005, 1568 million kVA for 2010, 3994 million kVA for 2020.

Figure 2. Production of Distribution Transformer, 1989-2020



Energy saving, environmental and economic benefits. The findings from our analysis show that the electricity savings due to high-efficiency transformer standards in 2010 will be 8.29 TWh, amounting to 2.98 Mtce in terms of primary energy; the electricity savings in 2020 will be 22.08 TWh, amounting to primary energy of 7.39 Mtce. Electricity savings from the installation of high-efficiency transformers will yield present value savings for purchases through 2020 of 37.93 billion Yuan. Incremental cost of high efficiency motors is about 1500 Yuan and present value of investment through 2020 is 7.75 billion Yuan. Net benefits will be 30.18 billion Yuan, with a benefit-to-cost ratio of 4.9. The emission reductions of air pollutants due to energy savings are 6.94 MMT of carbon, 0.11 MMT of nitrogen oxide, 1.38 MMT of sulfur dioxide and 0.64 MMT of PM10 in 2020.

Energy Saving Potential from Industrial Boilers

Overview

By the end of 1998, gross installation of industrial boilers for the country as a whole was 501 thousand units (or 1.257 million steam tons per hour (t/h)), amounting to 879,814 MW. Among the existing industrial boilers, 238 thousand boilers are used in production, amounting to 0.687 million t/h; 263 thousand boilers are used in residential buildings, amounting to 0.57 million t/h (Hu Yuchang 2002). With the increasing development of real estate, the proportion of boilers with bigger output (>10 t/h) is growing. Table 3 shows this trend. The average life of industrial boilers is 10-15 years. During nineteen years from 1972 to 1991, the number of new stock is 330 thousand in the whole country, but the production of boilers in this period is about 500 thousand. So many boilers must have been replaced after being in operation less than 15 years.

Table 3. Production Proportion of Different Sizes Boilers (%)

Year	≤1t/h	2t/h	4t/h	6t/h	10t/h	20t/h	≥35t/h
1991	8.1	19.9	31.8	15.0	11.8	5.0	8.1
1992	7.7	18.8	29.8	13.8	12.3	10.0	8.5
1993	5.3	17.0	27.6	14.1	14.0	7.7	13.9
1994	7.9	15.3	28.7	15.1	15.8	8.3	9.0
1995	4.1	14.1	26.4	15.6	18.1	8.6	12.8
1996	5.2	16.3	27.7	17.1	18.2	8.2	8.3
1997	1.42	10.5	20.9	14.2	14.6	1.14	23.4
1998	5.08	12.88	25.18	15.7	22.08	11.96	7.10

Source: Hu Yuchang, 2002

Currently, coal-fired industrial boilers account for 90% of the gross capacity, amounting to 1.13 million t/h. The coal used by existing industrial boilers is mainly raw coal with unstable quality and granularity, the content of small coal whose diameter is less than 3mm takes 45-65% in the raw coal, while lump coal whose diameter is bigger than 10mm is only 15-30%. According to investigations, soft coal accounts for 75.5% of coal for industrial boilers, anthracite accounts for 9.7%, lignite accounts for 5.6%, and 9.1% is poor quality coal (Hu Yuchang 2002). Efficiency promotion of industrial boilers, especially coal-fired boilers, is of great importance for improving environmental conditions in China and the world, and for energy consumption reduction.

Current Situation in Terms of Standards

Currently, there is no mandatory energy standard for industrial boilers in China. The First Machinery Industry Ministry developed General Technical Specification of Industrial Boilers in October, 1980. This standard regulated thermal efficiency of industrial boilers sold by state-owned boiler manufacturers. In 1988, the standard was revised and issued as industry standard in 1999. Table 4 shows the thermal efficiency values of industrial boilers in JB/T10094-1999. These standards, apply to many but not all manufacturers, and while nominally required, do not have the force of law. The average efficiency of coal-fired boilers in China is about 15-20% lower than that in foreign countries (Hu Yuchang 2002).

In order to promote the thermal efficiency of coal-fired boilers to the world advanced level, new combustion technologies and product designs should be developed and adopted. The Global Environmental Facility (GEF) has granted funding of 22.8 million SDR (about 32 million U.S. dollars) to the Chinese Government to improve Chinese boiler designs. The objective of the fund is to help Chinese industrial boiler manufacturers to introduce foreign advanced technology, and to produce high efficiency clean boiler products. This project will push China's industrial boiler manufacturing industry to a higher level. Considering the improvement of ability to produce high efficiency industrial boilers in the next two years, it is possible to save energy and reduce emissions through developing a new standard for industrial boilers.

Table 4. Thermal Efficiency of Industrial Boiler in Current Industry Standard

Coal	**Output (t/h or MW)**					
	<0.5 or <0.35	**<0.5~1 or <0.35~0.7**	**<2 or <1.4**	**4~8 or 2.8~5.6**	**10~20 or 7~14**	**>29 or >14**
	Thermal efficiency value (%)					
Soft coal	63	70	73	74	76	77
Poor coal	62	68	70	73	76	77
Anthracite	55	59	62	65	69	72
Lignite	62	67	69	74	76	79

Source: Hu Yuchang, 2002

Energy Saving Potential

We estimate that the thermal efficiency of coal-fired industrial boilers is increased from the present 60- 65% to 80% in the new standard that is effective in 2005 and the average boiler lifetime is 15 years. Based on these assumptions, the energy savings of high efficiency industrial boilers in 2010 will be 11.50 Mtce, and 35.65 Mtce in 2020. The energy savings from the installation of high efficiency industrial boilers will yield present value savings for purchases through 2020 of 32.41 billion Yuan. The present value of investment associated with the incremental cost of increasing the efficiency of industrial boilers through 2020 is 1.07 billion Yuan. Net benefits are forecast to be 31.34 billion Yuan. The emission reductions of pollutants due to energy conservation are 22.82 MMT of carbon, 0.37 MMT of nitrogen oxide, 0.97 MMT of sulfur dioxide and 2.24 MMT of PM10 in 2020.

Conclusions

From the analysis above, we can see clearly that the energy saving potential from energy standards on three major types of energy-consuming industrial equipment is approximately 18.54 Mtce in 2010 and 48.55 Mtce in 2020, which accounts for 2.04% and 5.35% respectively of 1999 energy consumption in the Chinese industrial sector (907.97 Mtce) (Table 5 shows details). According to the initial forecast of power departments, the growth rate of electricity demand in China in the next 10-15 years will be 6% annually, and the proposed standards will slow the predicted increase in power demand if they are implemented soon. These standards will also save Chinese industrial enterprises a substantial amount of money. Over the 2004-2020 period these standards will save industrial enterprises 117 billion Yuan, which is 6.5 times greater than the estimated 18 billion Yuan in increased equipment costs due to standards over this period. The net present value benefits of these three standards will total 99 billion Yuan over this period (see Table 6). The reduction of energy consumption shall result in reduction of discharges of carbon, sulfur dioxide, nitrogen oxide, particles, toxic gases and other suspended particles from power plants and coal combustion (see Table 7). The emission reductions of air pollutants shall greatly relieve greenhouse effect, photochemical smog and acid rain, and shall be important for improving environmental quality and promoting the quality of people's life. The energy standards will not only produce important energy and economic savings but will also significantly reduce pollutant emissions, which will greatly push China's industry onto a more sustainable path in the 21st century.

Table 5. Estimated Energy Savings from Proposed New Energy Standards for Major Industrial Equipment

	2010		2020	
	Electricity TWh	**Primary energy Mtce**	**Electricity TWh**	**Primary energy Mtce**
Electric motor	11.29	4.06	16.46	5.51
Distribution transformer	8.29	2.98	22.08	7.39
Industrial boiler		11.50		35.65
Total		18.54		48.55

Table 6. Estimated Economics of Proposed New Energy Standards for Major Industrial Equipment

	NPV Savings	NPV Costs	Net Benefits
Electric motor	46.7	9.4	37.3
Distribution transformer	37.93	7.75	30.18
Industrial boiler	32.41	1.07	31.34
Total	117.04	18.22	98.82

Table 7. Estimated Emissions Reductions from Proposed New Energy Standards for Major Industrial Equipment (in 2020)

	Carbon Reduction MMT	NOx Reduction MMT	SOx Reduction MMT	PM10 Reduction MMT
Electric motor	5.18	0.08	1.03	0.48
Distribution transformer	6.94	0.11	1.38	0.64
Industrial boiler	22.82	0.37	0.97	2.24
Total	34.94	0.56	3.38	3.36

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