LBNL-61800

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Achieving China's Target for Energy Intensity Reduction in 2010:

An exploration of recent trends and possible future scenarios

Jiang LIN, Nan ZHOU, Mark D. Levine, and David Fridley

Environmental Energy Technologies Division

December 2006

Prepared for and with the support of the China Sustainable Energy Program of the Energy Foundation through the Department of Energy under contract No. DE-AC02-05CH11231

LBNL-61800

Published in the United States by
China Energy Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
One Cyclotron Road, MS 90R4000
Berkeley, CA 94720 USA
http://china.lbl.gov

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Acknowledgement

This work is supported by the Energy Foundation through the Department of Energy under contract No. DE-AC02-05CH11231. We would like to thank Nate Aden for research assistance, and Lynn Price, Joe Huang, and Christina Galitsky for their insights and comments.

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Achieving China's Target for Energy Intensity Reduction in 2010
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1. Background

China's 11th Five-Year Plan (FYP) sets an ambitious target for energy-efficiency improvement: energy intensity of the country's gross domestic product (GDP) should be reduced by 20% from 2005 to 2010 (NDRC, 2006). This goal signals a major shift in China's strategic thinking about its long-term economic and energy development. It also provides further evidence that the Chinese government is serious in its call for a new "scientific development perspective" (*科学发展观*) to assure sustainability in accordance with long-run carrying capacity of the natural environment.

This target for energy efficiency is likely to be difficult to achieve, considering that energy consumption has grown more rapidly than GDP in the last five years and, as a result, energy use per unit of GDP (energy intensity)[1] has increased. This recent trend in energy intensity stands in sharp contrast to the trend observed from 1980 to 2000, when energy demand grew less than half as fast as GDP and energy intensity declined steadily. China's long-term development plan, which calls for a quadrupling of GDP and doubling of energy use from 2000 to 2020, was based on this earlier experience, as are projections of China's energy consumption by major Chinese and international institutions (IEA, 2004; Zhou et al., 2003). However, if the recent trend continues, not only will it jeopardize China's development goals, it will also create significantly greater adverse environmental impacts and major threats to long-run sustainability. Further, it could introduce a huge "unexpected" disturbance to the global energy and climate system. It is in recognition of the likely costs of "run-away" energy growth that China's leaders have decided to highlight the need to reduce energy intensity.

With support from the China Sustainable Energy Program of the Energy Foundation, a team of scientists from Lawrence Berkeley National Laboratory is working with leading Chinese research institutions to analyze how China could achieve its energy-efficiency target within the next five years. This report summarizes the initial findings of this research.

The results are presented in four sections in this report. The first section provides a detailed analysis of energy intensity trends in China during the last ten years, highlighting the shift in industrial structure toward energy intensive sub-sectors such as steel and cement as the leading cause of the recent rebound in energy intensity in China. The second section provides an explorative analysis of possible scenarios through which efficiency gains could be achieved to reach the 20% target. The third section summarizes key energy use indices by sectors. Finally, a set of policy recommendations is presented. Two appendices are included: one describes the modeling approach used in the analysis and the second describes model drivers and outputs.

[1] We note that this term is used to describe *economic* energy intensity in this report. *Physical* energy intensity (energy use per physical unit) can also be used at the sectoral level to understand trends in specific sub-sectors (e.g. energy use/ton steel; energy use per cubic meter of built space).

2. Recent Trends in Energy Consumption in China

Between 1980 and 2000, China achieved a quadrupling of its GDP with only a doubling of energy consumption (Figure 1), effectively decoupling the relationship between economic growth and energy consumption (Sinton et al., 1998; Lin, 2005). This was a remarkable achievement, since it is widely accepted that growth in energy use is likely to be faster than economic growth in the early stage of economic development (Galli, 1998). In fact, no other major developing country has witnessed declining energy intensity (or an energy elasticity less than one) until much later in their development process. In the early stage of economic development, industrialization and urbanization tend to lead to extensive infrastructure and housing development: both are energy- and material-intensive activities. As a result, energy intensity tends to increase. In the later stage of economic development, demand for services often grows faster than demand for goods, leading to a shift in economic structure towards the service sector which has much lower energy and material intensity. In addition, efficiency of energy and material use also tends to increase as better technology and materials become available. Thus, energy intensity tends to decline. This is a pattern observed across economies (Quah, 1997; Janicke et al., 1989; and Ausubel et al., 1993).

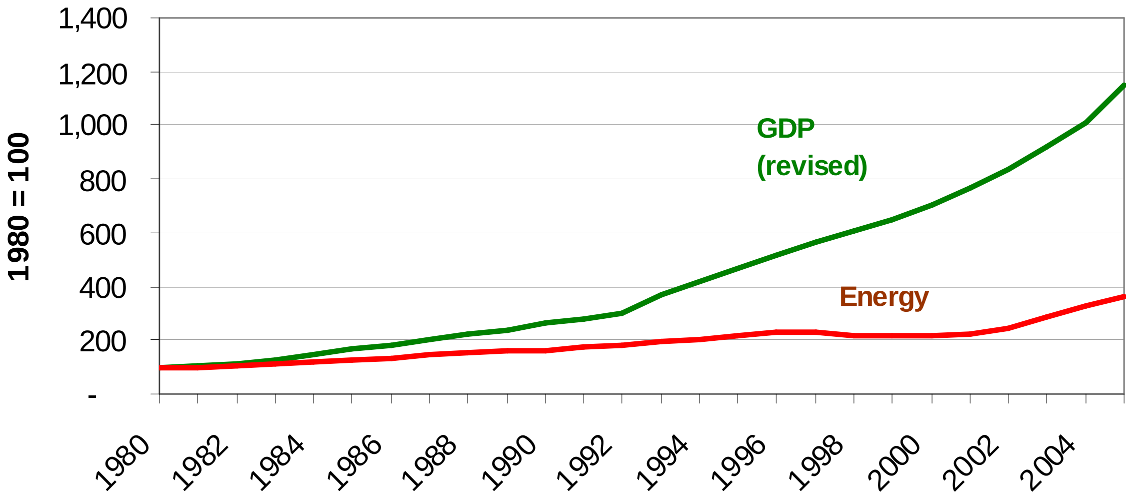


Figure 1 Energy consumption and GDP growth in China, 1980-2000

China's experience from 1980 to 2000 was an exception, in large measure because of far-reaching policy reforms established by the Chinese government. Two of the most significant of these reforms involved the allocation of capital investment to energy efficiency and the creation of a network of energy conservation service centers throughout China (Wang, 1995). All of this was brought about very quickly once the policy was established (1980); the institutions implementing energy efficiency continued to exert substantial influence through the middle 1990s. However, energy and economic development in China over the last few years suggests that China may have lost its ability or will to sustain a drive to reduce energy intensity, a policy that has been central to achievement of other of its development goals. Since 2001, China has experienced much faster growth in energy use than economic growth, with an elasticity reaching 1.6 in 2004. While the growth in energy has moderated to some extent in 2005, the growth rate of energy consumption from 2000 to 2005 maintained a high 9.5% annual average, slightly lower than that of GDP, resulting in an elasticity of just under one, as compared with an elasticity between 0.4 and 0.5 in the period 1980-2000 (NBS 2006).

This development has alarming implications. At the current rate, China's energy growth could lead to energy shortages and mounting environmental problems. Such problems could in turn undermine China's own development goals for 2020. The consequences for the global energy market could be equally dramatic, since China's energy demand in 2020 would be easily twice as large as expected – a further increase of 3 billion tons of coal (Zhou et al 2003). Given China's reliance on coal, China's emissions of greenhouse gases (GHG) are likely to be much larger than anticipated as well, further exacerbating the problem of global warming.

In this context, it is timely that China has set a target of reducing energy intensity by 20% within the next five years. Historical evidence suggests that such a target is extremely ambitious and may be very challenging to meet. A thorough analysis of factors affecting energy intensity over the last ten years may help shed some light on what would be the best ways to achieve such a goal.

2.1. Energy Intensity Trends

Figure 2 presents energy intensity trends in China by three main sectors as defined by China's statistical administration: primary (agriculture), secondary (industry and construction), and tertiary (transportation, telecommunications, post, and retail)[2]. The GDP values are the revised figures (NBS, 2005), adjusted to 2000. It can be seen that energy intensity for the secondary sector is much higher than that for the primary and tertiary sectors. The trend in aggregate energy intensity mirrors closely that for the industrial sector with both showing a rebound in energy use per unit of GDP after 2001, after steady declines since the mid-1990s.

[2] Commercial sector energy use is included in the tertiary sector, while that for the residential sector is not.

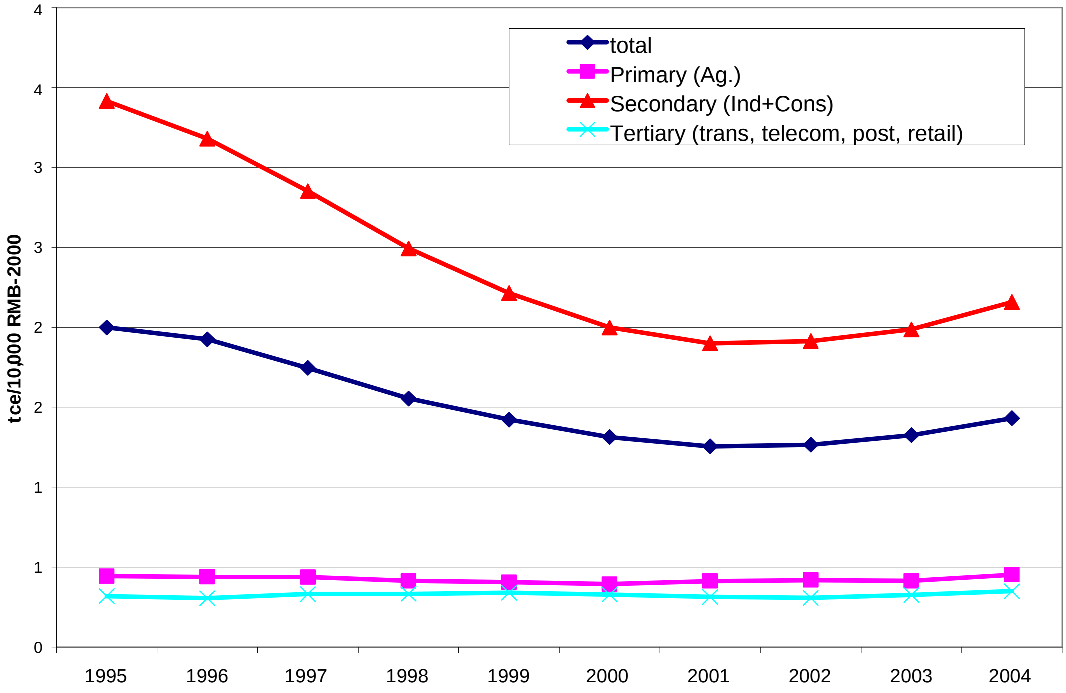


Figure 2 Energy intensity trends in China by three main sectors, 1995 to 2004

2.2. Structural Trends

The dominance of the industrial sector in China is not surprising, since industrial energy intensity is not only much higher than that of the other two sectors, but also because industry remains the largest sector in the Chinese economy. After 25 years of rapid industrialization, the industrial share of GDP continues to increase, while the share of the tertiary (service) sector remains flat at 40% (Figure 3). The service sector share in China is not only much lower than developed countries but also lower than developing countries. For example, India's service sector comprised about 54% of the economy in 2005, while in the US, the share reached 76.5% in 2003 (World Bank, 2006). If the share of the service industry in China reached the Indian or US levels, China's energy intensity would drop 22% and 31%, respectively. While it may be difficult to boost the share of service industries in China to the levels in India or the U.S., structural shifts in the Chinese economy could nonetheless eventually contribute significantly towards the 20% reduction target for energy intensity.

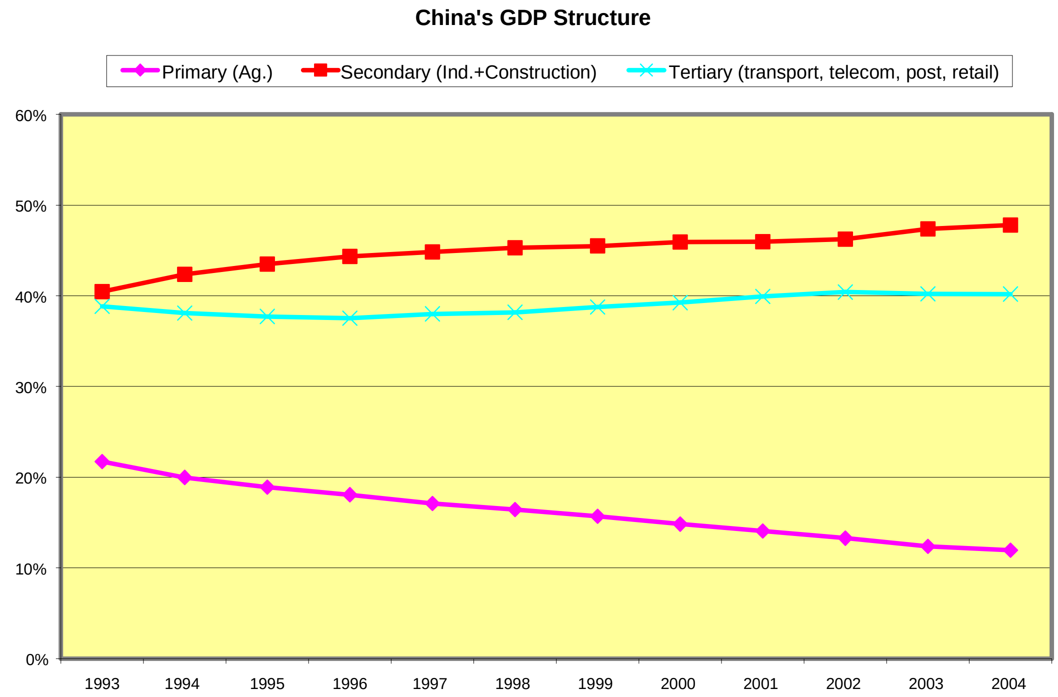


Figure 3 Sectoral shares of GDP in China, 1993-2004

2.3. Understanding Energy Intensity and Structural Shift Trends

In this section, the results of a decomposition analysis of energy intensity trends are discussed to identify the relative contributions of shifts in economic structure and changing efficiency of energy use. We used a variation of Laspeyres decomposition method presented in Sinton and Levine (1994), with a minor modification. Instead of using a constant base year, we use the preceding year as the base year to minimize the error introduced in the analysis. The modified equation is expressed as follows,

$$E^t = Q^t I^{t-1} + Q^t \sum_{i=1}^{N} S_i^{t-1} \Delta I_i + Q^t \sum_{i=1}^{N} \Delta S_i I_i^{t-1} + Q^t \sum_{i=1}^{N} S_i \Delta I_i$$

Where

E^t = energy consumed (in Mtce) in year t
Q^t = GDP or Value-Added (in 2000 yuan)
I_i = intensity of energy use in the ith sector in year t
S_i = the ith sector's share of GDP
i = reference number for sector
t = the time period
N = number of sectors
$\Delta x_i = x^t_i - x_i^{t-1}$

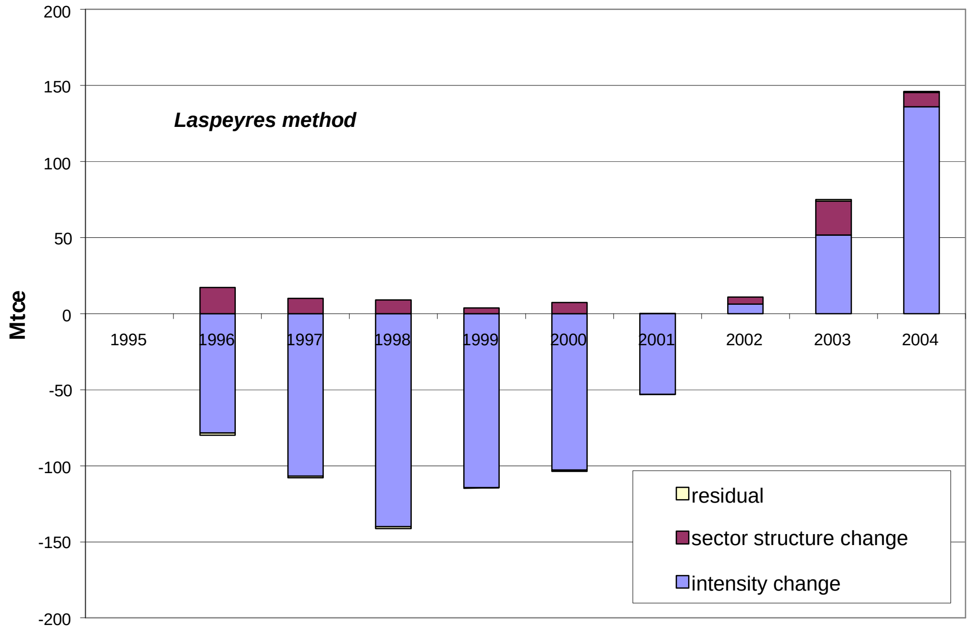


Figure 4 Inter-sector structural change versus energy intensity change

We first apply this methodology to aggregate data using only three sectors: the primary, the secondary, and the tertiary. Figure 4 illustrates the results of this analysis, showing the change in energy use due to inter-sector structural change and energy intensity change for each year. Note that for this figure structural change refers only to change in relative shares of GDP among primary (agricultural), secondary (industry), and tertiary (service) sectors.

It can be seen that energy intensity reduction within each sector was the dominant factor driving the decline in energy use in the late 1990s, leading to a drop in total energy intensity. However, since 2002, total energy intensity increased mostly due to the increase in industry energy intensity (as shown previously in Figure 2), particularly strong for 2003 and 2004.

Structural shift among the three sectors has always had a small positive effect on total energy intensity; that is, a growing share of the industrial sector tends to cause total energy intensity to increase, other things being equal.

At first glance, these results are counter-intuitive. In a rapidly expanding economy, new and more efficient technologies are typically deployed throughout the economy, which should lead to a reduction in energy intensity in industries. However, industrial energy intensity is determined by two factors: 1) energy efficiency in industrial sub-sectors, 2) the relative outputs of the sub-sectors. Thus, it is possible that overall industrial energy intensity could increase, even when energy intensities at the sub-sectors are declining because the relative outputs of energy intensive sub-sectors such as cement and iron and steel are rising. This is in fact what has happened in China since 2001.

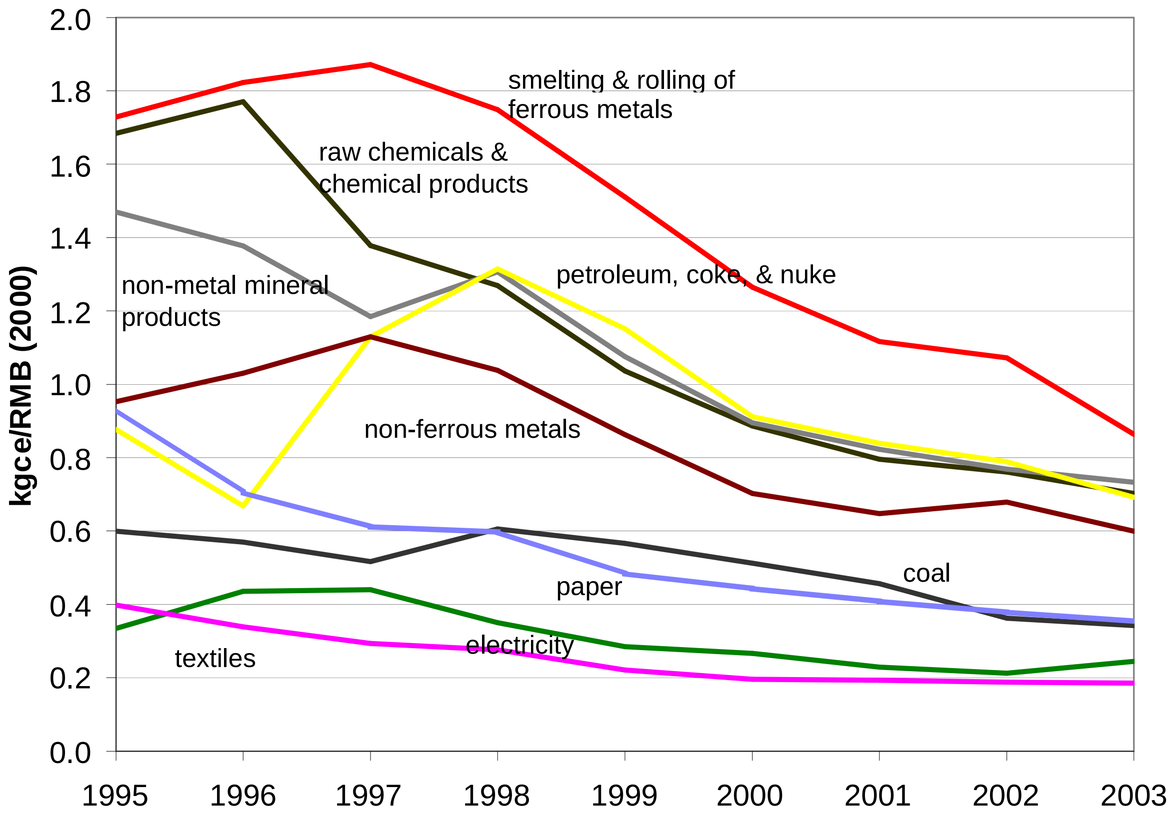


Figure 5 Energy intensities for major industry sub-sectors in China.

Figure 5 shows that for nine major energy-intensive industries, energy intensities have declined steadily since the mid-1990s, with the exception of the electricity generation industry. This exception is likely to be caused by the heavy use of small and thus less efficient generators since 2002 when there were widespread electricity shortages, and the fact the profit margins could be eroding in the electric generation industry since the tariff has been held artificially low while fuel prices have gone up tremendously.

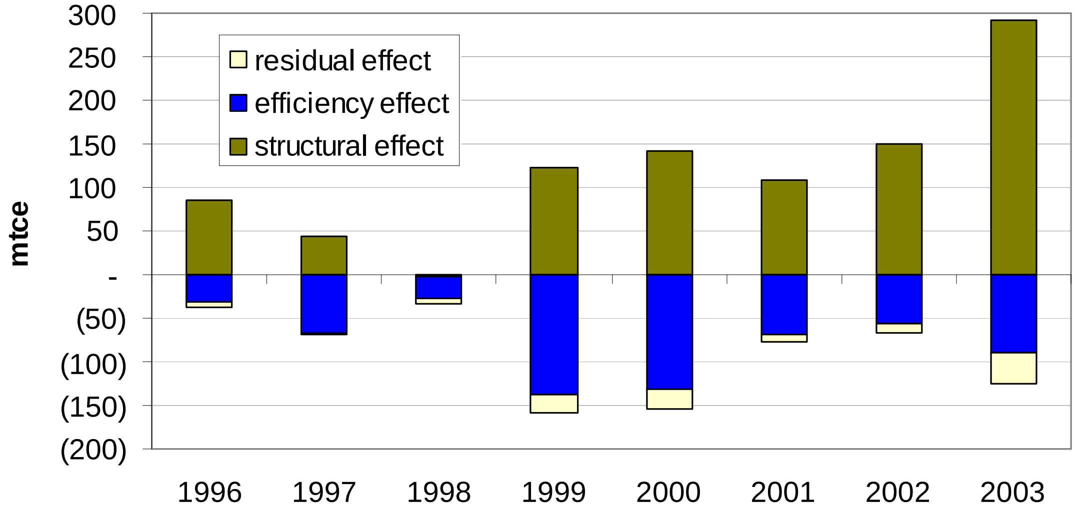


Figure 6 Effect of efficiency changes and structural shift among industry sub-sectors

Further analysis of the effect of efficiency changes and structural shift among the nine industrial sub-sectors shows that from 1996 to 2003 there was steady efficiency improvement; however, the pace of efficiency gains slowed down somewhat since 2000 (see Figure 6).

In the meantime, the effect of structural shift within industrial sub-sectors towards rapid growth in cement and steel production increased in recent years, and since 2001 has overwhelmed the effect of efficiency gains. Since 2001 efficiency gains alone have not been nearly sufficient to compensate for the effect of heavy industrialization. For example, in 2003, the effect of efficiency gains in industries on energy use is about 30% of that due to structural shift among industrial sub-sectors. As a result, the overall energy intensity of industries is higher today than its recent low point in 2001.

2.4. Summary

In summary, the recent increase in energy intensity in China can be largely attributed to three main factors:

1. Rapid growth in production of commodities in heavy industries (iron and steel, chemicals, cement, etc.).
2. Overall growth of the industrial sector, relative to services and agriculture.
3. Slow down in energy efficiency improvement relative to structural changes.

Since 2001 efficiency gains alone have not been nearly sufficient to compensate for the effect of heavy industrialization. For example, in 2003, the effect of efficiency gains in industries on energy use is about 30% of that due to structural shift among industrial sub-sectors.

The results of this analysis are consistent with the traditional understanding of economic development where energy intensity tends to rise in the early stage of industrialization due to rising demand for energy-intensive products, extensive infrastructure development, and urbanization. China simply has returned to normalcy in this regard, after two decades of exceptional experience.

This return to a more traditional development pattern represents a tipping point in the relationship between energy and economic development in China, and suggests that without major policy interventions both to boost efficiency gains and to accelerate the development of service industries, energy intensity of the Chinese economy could continue to rise or stay at the current level for some time to come. The rapid decline in energy intensity observed in the 1980s and 1990s is unlikely to return any time soon without such intervention. This calls for a major revision of current understanding of energy demand growth in China in the immediate future, since most projections of China's energy demand were based on a continuation of the trend experienced from 1980 to 2000. In other words, China's energy demand in the future could be much higher than projected.

3. An Analysis of Possible Scenarios Toward 20% Energy Intensity Target

In this section, we develop a series of scenarios to assess the feasibility of achieving the 20% target for energy intensity reduction from 2005 to 2010. The analysis is based on the China End-use Energy Model developed by the China Energy Group of the Lawrence Berkeley National Laboratory (LBNL). China's current development plan forms the basis of the "baseline" scenario evaluation in the study. In addition to the baseline scenario, we develop several policy scenarios targeting efficiency opportunities in industries, appliances, and the power sector.

3.1. 11th Five Year Plan Energy Intensity Target

China's 11th Five-Year Plan (FYP) has set a binding target for energy efficiency: energy intensity of GDP should be reduced by 20% from 2005 to 2010. China's GDP grew at an average annual rate of 9.9% from 2000 to 2005. The 11th FYP aims for an average GDP growth rate of 7.5% from 2005 to 2010. Thus, a 20% reduction in energy intensity implies an annual growth rate (AGR) of 2.8% in energy use. However, both GDP and energy use have been growing much faster recently. In 2005, total energy consumption reached 2,225 Mtce (NBS 2006), a 9.5% increase from 2004, while the GPD growth rate was 9.9%. If China's energy/GDP elasticity remains at 1 and economic growth unfolds as forecast, total energy consumption in 2010 would reach 3,192 Mtce. To reach the 20% energy intensity target, it has to be reduced to 2,552 Mtce, or a reduction of 640 Mtce. Figure 7 presents two possible levels of energy consumption in 2010: 1) if GDP grows an average of 7.5% with an energy/GDP elasticity of 1 based on recent trends, and 2) if GDP grows an average of 7.5% and the 20% energy intensity reduction target is met.

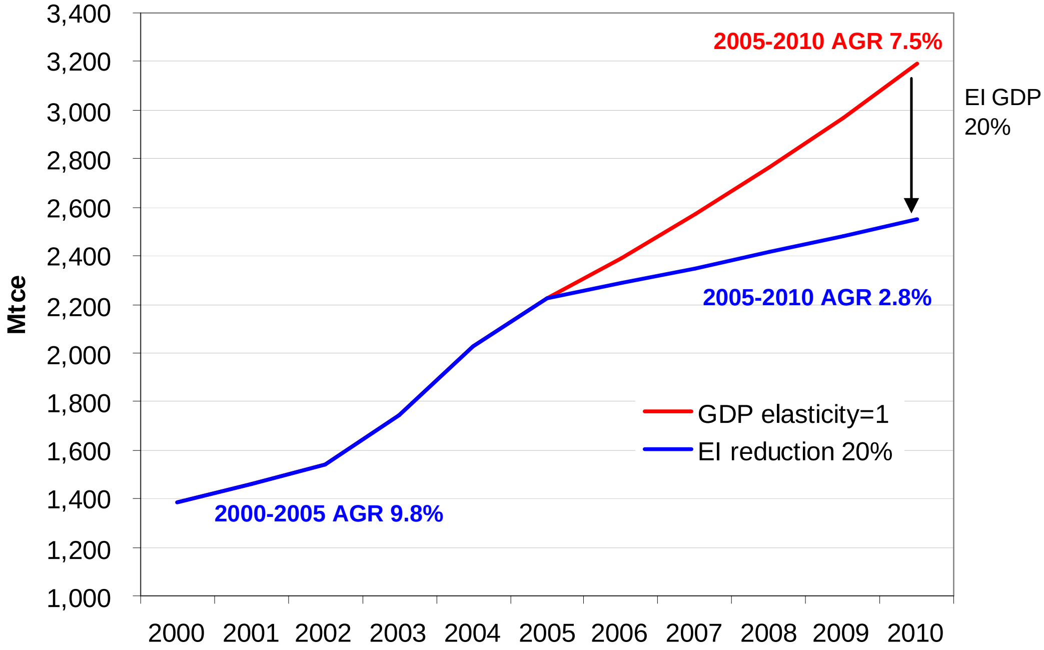


Figure 7 Energy Consumption Implied by the 11th Five Year Plan Energy Intensity Target

3.2. Baseline Policy Scenario (BPS)

LBNL's Baseline Policy Scenario (BPS) incorporates the collective scope of technology choices, efficiency improvements, policy targets, fuel switching, production trends, equipment ownership and other elements of the development plan that China has proposed to shape its energy growth path to 2010.[3]. Underlying this scenario is the assumption that the GDP target of 7.5% annual average growth from 2005 to 2010 will be met. Within this scenario, intensity improvement goals are similar to those used in China Energy Development Strategy 2004 by the Development Research Center (RNECSPC, 2005). The long-term development plan, though rich in detail in the industrial sector, omits a range of details in some areas, such as residential appliance ownership. In these cases, we have applied reasoned judgment based on experience working on Chinese appliance efficiency standards and efficiency programs, with additional reference to similar developments in Japan, Korea, and the United States.

[3] The primarily analytical tool used in this study was an accounting framework of China's energy and economic structure, built using the Long-Range Energy Alternatives Planning (LEAP) modeling software (http://forums.seib.org/leap/). This approach allowed a detailed consideration of technological development—industrial production, equipment efficiency, residential appliance usage, vehicle ownership, lighting and heating usage etc—as a way to evaluate China's energy development path below the level of its macro-relationship to China's economic development path. The modeling approach is described in Appendix A.

Key macro economic drivers are total population growth, urbanization rate, total GDP, and floor area per capita. Base year data are available from China's statistical yearbooks (NBS, 1985-2005), and projections are made based on existing assumptions from the United Nations and China's official plans which are described below.

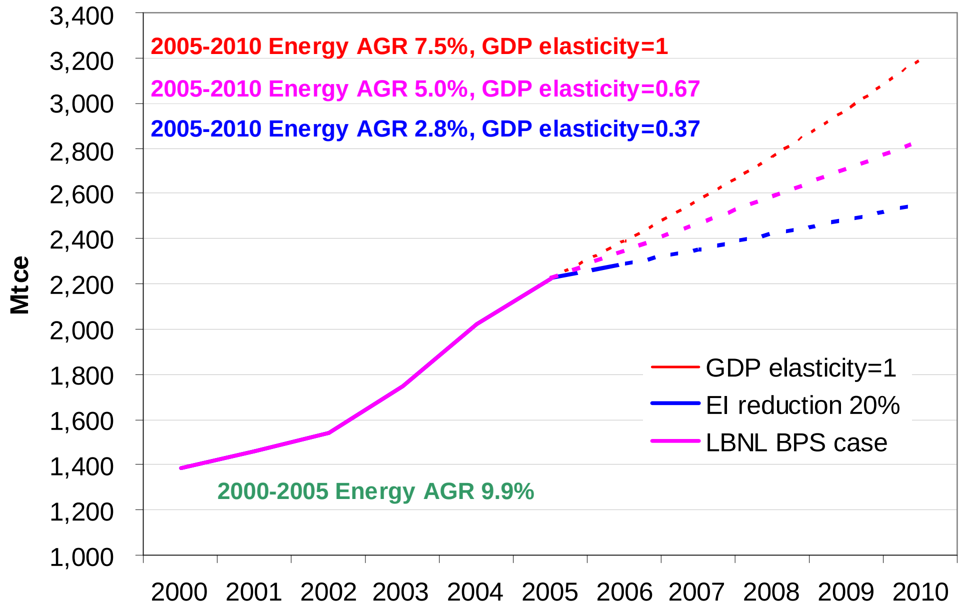
Table 1 shows the macro drivers and provides a comparison to Japan. China's population is projected to be 1.365 billion in 2010 (WB, 2006), with an AGR of only 0.8%. Population will continue to migrate from the north to the south. GDP is estimated to grow at 7.5% from 2005 to 2010, according to China's official 11th Five Year Plan. Despite this high rate of growth, China's per capita GDP will reach only $1,714 in 2010, far behind that of Japan's $35,757 in 2005 (IMF, 2006). Household size will continue to decline from 3.19 in 2000 and 3.0 in 2005 to 2.9 members per household in 2010 in urban areas and from 4.35 in 2000 and 4.05 in 2005 to 3.9 members per household in 2010 in rural areas, based on extrapolation of the recent growth rate from 1989 to 1999, which is 1.5% reduction each year. The living area per capita and commercial floor area derived from China's official plan shows a significant improvement in 2010 (Zhou, 2003). Residential living area per capita will exceed that of Japan in 1997, and commercial floor space will be nearly double that in 2000 owing to continued rapid growth.

Table 1 Macro drivers and assumptions in the model

		Unit	China in 2000	China in 2005	China in 2010	Growth Rate	Japan recent	Note
Population		billion	1.269	1.311	1.365	0.8%	0.127	2003 data
	north	%	34.30%	33.90%	33.50%			
	transition	%	36.20%	36.20%	36.20%			
	south	%	29.50%	29.90%	30.40%			
GDP		Billion US$	1,080	1,676	2406	7.5%	5,684	2004 data
GDP per capita		US$ /person	851	1,278	1,714	6.0%	33,819	2005 data
Urbanization rate		%	35.6	42	45.1	1.3%	66	2006 data
Household size								
	urban	person	3.19	3	2.9	-0.7%		
	rural	person	4.35	4.05	3.9	-0.8%	2.88	2000 data
Living area								
	urban	m^2/capita	19.8	25.7	29	2.4%		
	rural	m^2/capita	24.8	28.4	31	1.8%	32.43	1997 data
Commercial floor area		million m^2	8,000	11,860	15,700	5.8%	1,655	2000 data

Note: Japan data are from IEA (2004) and IEEJ (2003)

The BPS analysis shows that moderate technology improvement and restructuring of China's economy could lead China's energy demand to grow considerably slower than the economy over the next 5 years. Figure 8 illustrates the differences in 2010 primary energy consumption among three scenarios: 1) GDP growth of 7.5% with an energy/GDP elasticity of 1%, which approximates the business-as-usual scenario, 2) GDP growth of 7.5% and attainment of the 20% energy intensity reduction goal (EI reduction 20%), and 3) the BPS with energy demand at 5.0% and an elasticity of 0.67, reducing energy consumption to 2,833 Mtce in 2010. The BPS energy demand growth rate exceeds the implied 11th Five Year Plan target of a 2.8% AGR for energy, so additional measures will need to be taken and more aggressive energy efficiency improvements will need to be implemented to bring the growth down further.



Source: 2000-2005 data from NBS

Figure 8 Energy Consumption Implied by the 11th Five Year Plan Energy Intensity Target and the BPS Case.

3.3. Policy Scenarios

The BPS case offers a systematic and complete interpretation of the social and economic goals proposed in China's national plan, and incorporates moderate energy efficiency improvement in all sectors. Building upon the BPS case, three additional policy scenarios were prepared to assist the Chinese government to explore the potential approaches that might lead to achievement of the 20% energy intensity reduction goal. A rapid physical intensity decline in heavy industrial sub-sectors (moving 2020 targets to 2010) was addressed in the Aggressive Industrial Efficiency scenario. The Aggressive Industrial and Appliance Efficiency Aggressive scenario explores the possibility of further incorporating accelerated efficiency improvements in the building sector, particularly in appliances. The additional impact of a reduction in transmission and distribution losses and further thermal efficiency improvement is covered in the Aggressive Industrial, Appliance and T&D Efficiency scenario.

Aggressive Industrial Efficiency Scenario

Reduction of energy intensity across a host of industrial sectors holds great promise for achieving China's overall goal of reducing the energy intensity of GDP by 20%. The Aggressive Industrial Efficiency scenario demonstrates how an aggressive industrial energy efficiency improvement target in the 7 major heavy industry sectors (including glass, ethylene, ammonia, paper, cement, aluminum, and iron & steel) and other industries could provide a significant contribution towards achieving the 2010 target. In this scenario, the 2020 energy intensity targets for these sectors, as laid out in China's Energy Conservation Medium- and Long-Term Plan (NDRC, 2005) were brought forward to 2010. Figure 9 shows that such an acceleration of efficiency improvements in the 7 major energy consuming industrial sectors would reduce the energy growth rate from 5% in the BPS to 3.8%, thereby reducing total energy consumption from 2,833 Mtce to 2,677 Mtce in 2010.

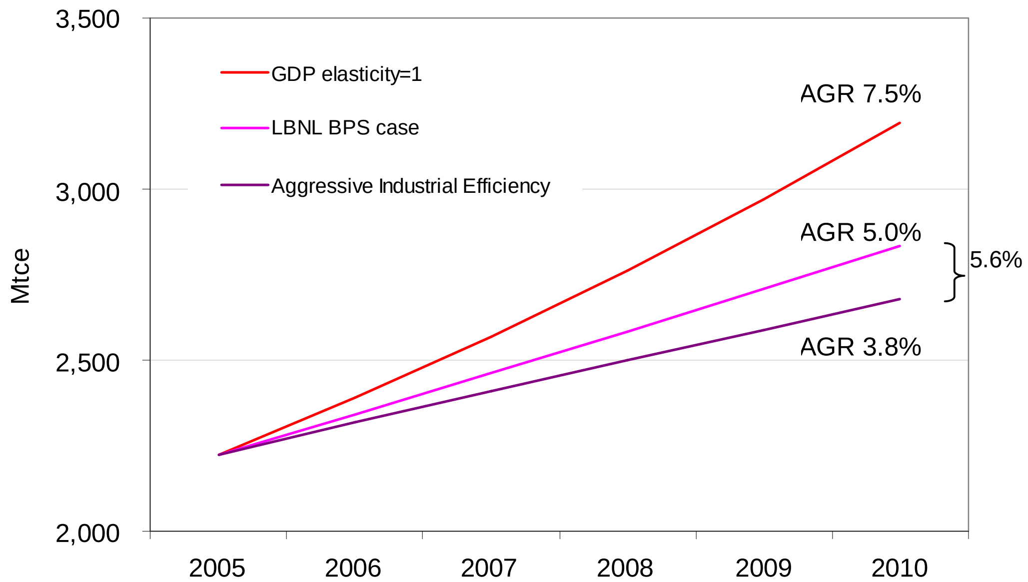


Figure 9 Achieving the 2020 targets for industrial energy intensities in 2010 would reduce energy growth rate from 5% to 3.8%

Aggressive Industrial and Appliance Efficiency Scenario

Codes and standards for building and appliances have been found to be highly effective in promoting energy efficiency in many countries. Mixed approaches have been adopted in various countries, including combinations of standards for materials and equipment, to ensure retrofitted buildings also receive the most efficient technologies. Codes and standards are updated periodically to reflect changes in building practices and technologies. China has designed and promulgated new building codes and appliance standards. However, there is still a large gap with the standards in advanced counties.

The analysis encompasses both the standards levels being proposed, higher standards levels, and different levels of implementation (applying the 2020 target to 2010). It includes such measures as increasing the share of energy-efficient residential air conditioners sales from 50% to 60% of the market, and of highly efficient air conditioners from 10% to 20%. Such measures would further reduce the average growth rate of energy consumption by 0.1 percentage points, from 3.8% to 3.7%., bringing total energy consumption in 2010 to 2,668 Mtce. The small impact reflects the fact that these standards only apply to new appliances thus would not change the efficiency of existing appliance stock. Their impact increases over a longer period of time.

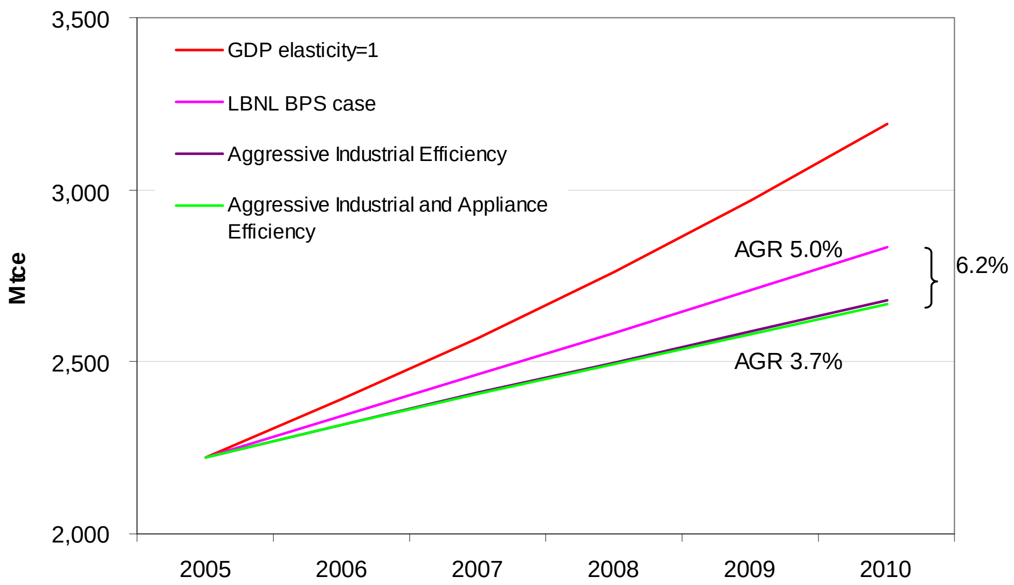


Figure 10 Additional appliance efficiency improvement brings the growth rate down to 3.7%

Aggressive Industrial, Appliance and T&D Efficiency

The effect of further efficiency improvement in power generation plants is covered in this scenario. It includes increasing coal-fired power plant efficiency by 1 percentage point from other scenarios (Figure 11). Transmission & Distribution (T&D) losses are still significantly higher in China than those observed in developed economies. Energy efficiency improvements in transmission and distribution systems would not only reduce energy losses but also improve the reliability of the electricity distribution network. In this scenario, reduction of T&D losses by a further 1% has been assumed (Figure 12). Figure 13 shows that these efforts would further reduce the annual average growth rate of energy consumption to 3.5% to 2010, resulting in total energy consumption of 2,641 Mtce in that year.

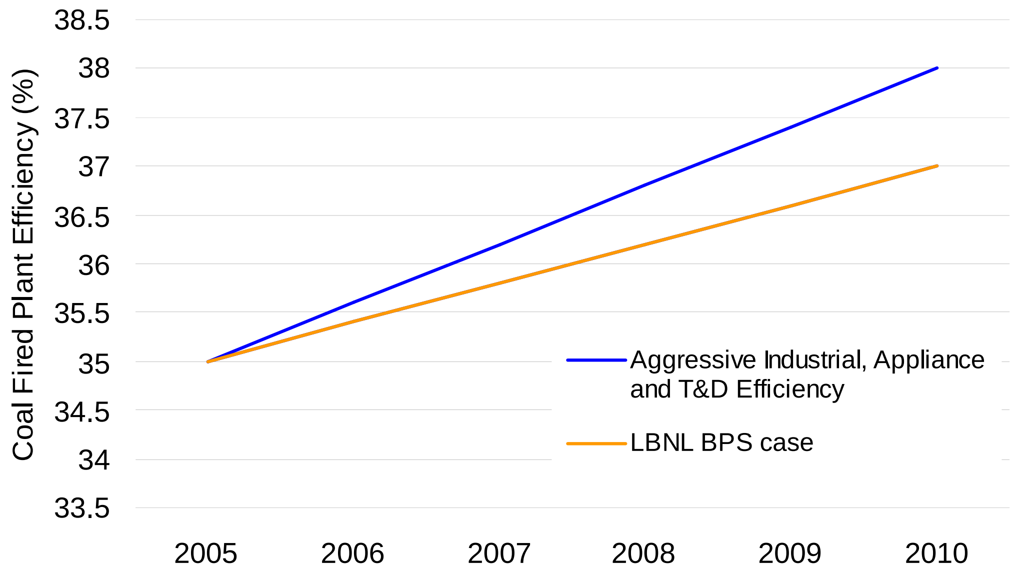


Figure 11 Aggressive energy efficiency improvement in coal power plant

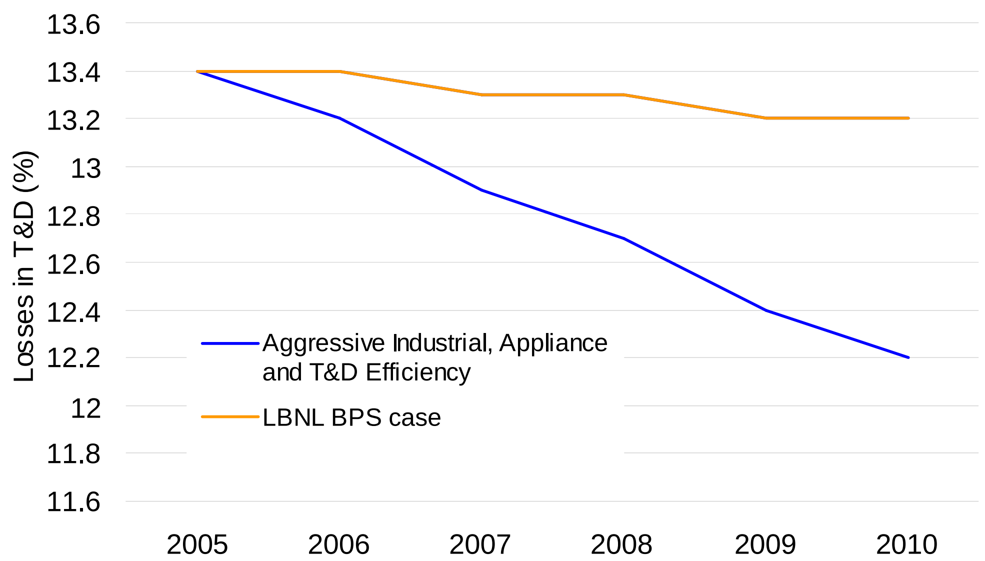


Figure 12 Aggressive loss reduction in Transmission & Distribution

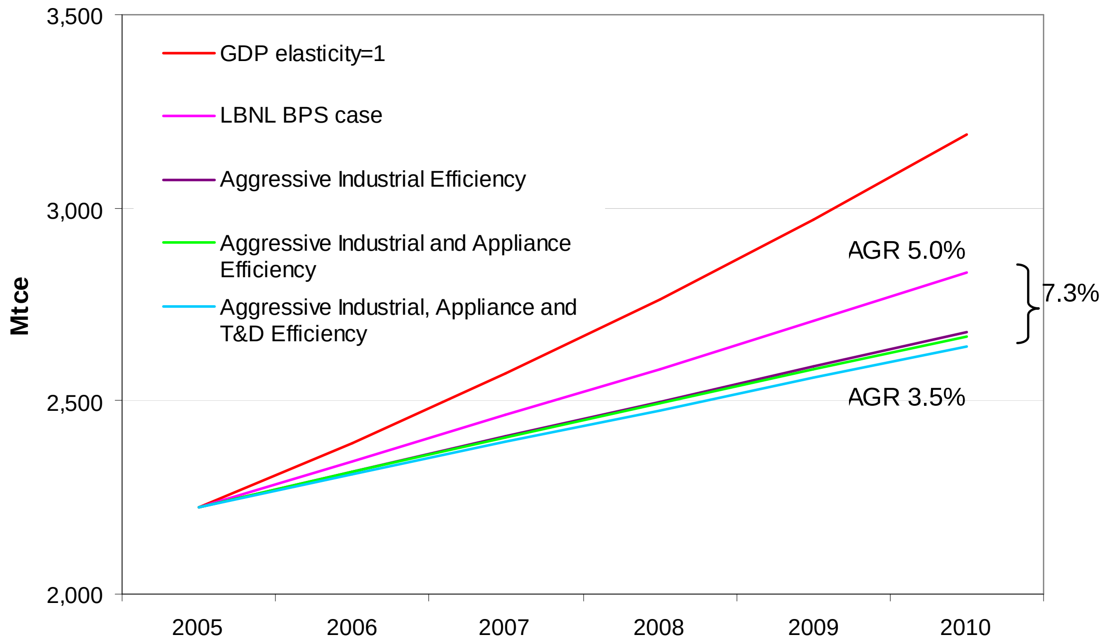


Figure 13 Additional improvement in T&D losses and thermal efficiency of power generation would reduce energy growth to a 3.5% annual average rate

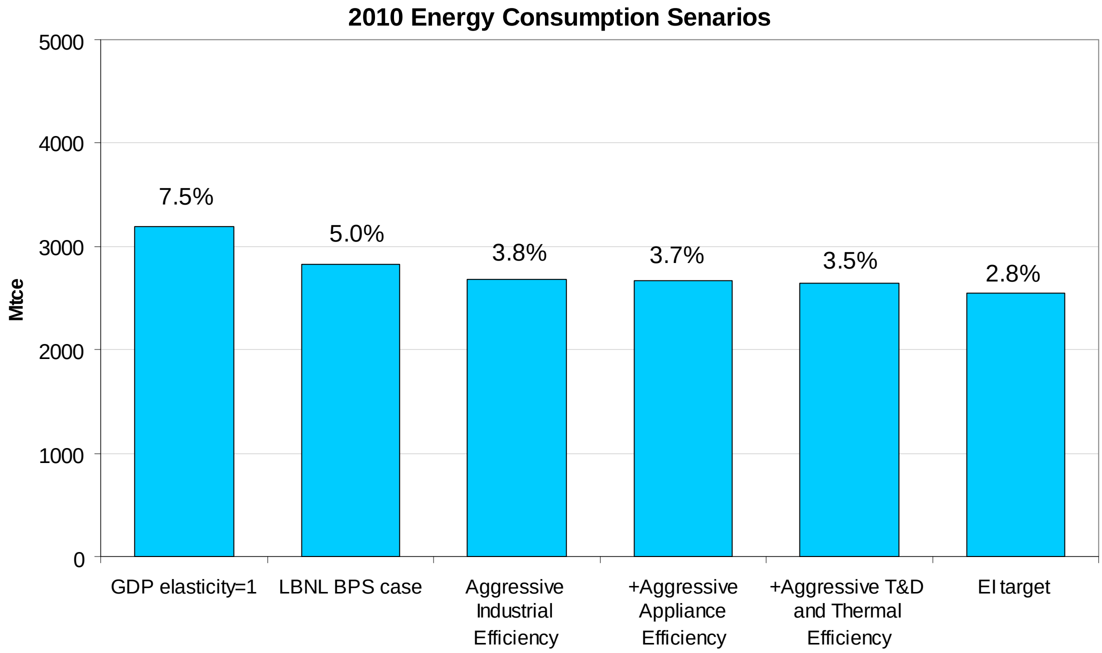


Figure 14 Comparison of Policy Scenarios to Current Trends, Baseline Policy Scenario, and 2010 Energy Intensity Target

The cumulative impact of the three policy scenarios reduces the growth rate of China's energy use from 5% per year in the BPS case scenario to 3.5%, which in aggregate provides 85% of the reduction that is necessary to reach the goal of reducing the energy intensity of GDP by 20% in 2010 (Figure 14). The results suggest that energy efficiency improvement can play a critical role in reaching the energy intensity target; however, other macro-economic approaches are also necessary to shift the Chinese economy to more productive activities and sectors.

Total energy consumption, energy savings and the major assumptions of each scenario can be summarized in Table 2.

Table 2 Energy Consumption and Major Assumptions of the Scenarios

Scenario	Average Energy Demand Growth Rate	2010 Energy Consumption (Mtce)	Incremental Energy Savings (Mtce)	Cumulative Energy Savings (Mtce)	Major Assumptions
Business As Usual	7.5%	3200	(none)		
BPS Case	5.0%	2833	367	367	• GDP target • "moderate" improvement in energy efficiency
Aggressive Industrial Efficiency	3.8%	2677	156	523	• move 2020 target to 2010 in industry sector
Aggressive Industrial and Appliance Efficiency	3.7%	2668	9	532	• move 2020 appliances efficiency target to 2010
Aggressive Industrial, Appliance and T&D Efficiency	3.5%	2641	27	559	• +1% in coal fired plant efficiency • -1% in T&D loss
20% target achieved	2.8%	2552	89	648	

Note: all scenarios assume a 7.5% average GDP growth rate.

4. Sectoral Energy Consumption

Figure 15 illustrates the primary energy consumption for the BPS, Aggressive Industrial Efficiency, Aggressive Industrial and Appliance Efficiency, and Aggressive Industrial, Appliance and T&D Efficiency scenarios by sector between 2000 and 2010. The four scenarios show that energy demand in China in 2010 may range from 2,641 Mtce to 2,833 Mtce, with energy demand growth rates ranging from 3.5% per year (in aggressive energy efficiency improvement scenario) to 5% per year (in the BPS). The energy demand elasticity of GDP over this period to 2010 ranges from 0.47 to 0.67, much smaller than the value from 2000 to 2005 (Figure 16).

Historically, energy consumption in China has been dominated by industry, while the buildings and transportation sectors only represented smaller percentages of energy consumption. In developed countries, building energy consumption comprises a much larger share which is also expected to be the trend in China in the future. In 2005, industrial energy consumption accounted for 64% of the total, and it is expected to be 63% in the BPS case. With the aggressive energy efficiency improvement, the share of industry energy consumption could be reduced to 60%.

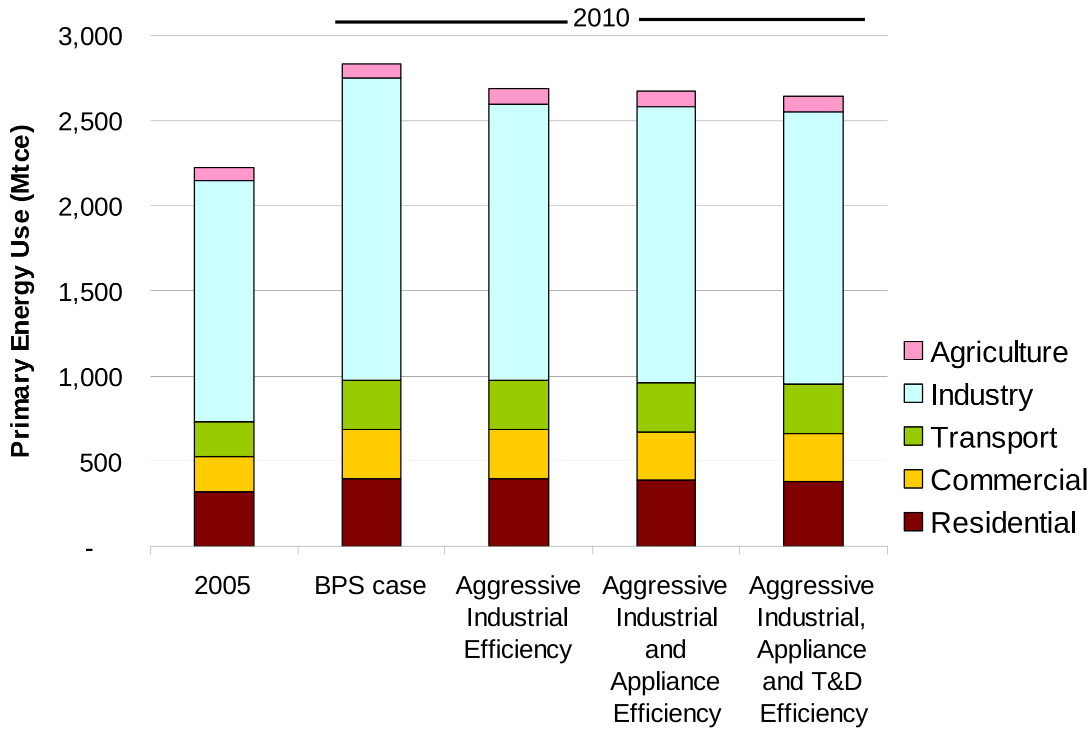


Figure 15 Primary energy consumption by sector in three scenarios

Figure 17 shows that China's economic energy intensity in 2000 stood at 0.139 kgce per RMB of GDP, in 2000 real RMB, based on newly revised GDP data (NBS 2005). Economic energy intensity rose to 0.142 kgce/ real RMB of GDP in 2005. In 2010, the BPS case results in a reduction of energy intensity to 0.127 kgce/RMB, while the Aggressive Industrial and Appliance Efficiency Scenario reduces it further to 0.119 kgce/RMB, and the Aggressive Industrial, Appliance and T&D Efficiency scenario to 0.118 kgce/RMB; this last figure represents a 17% reduction compared to 2005.

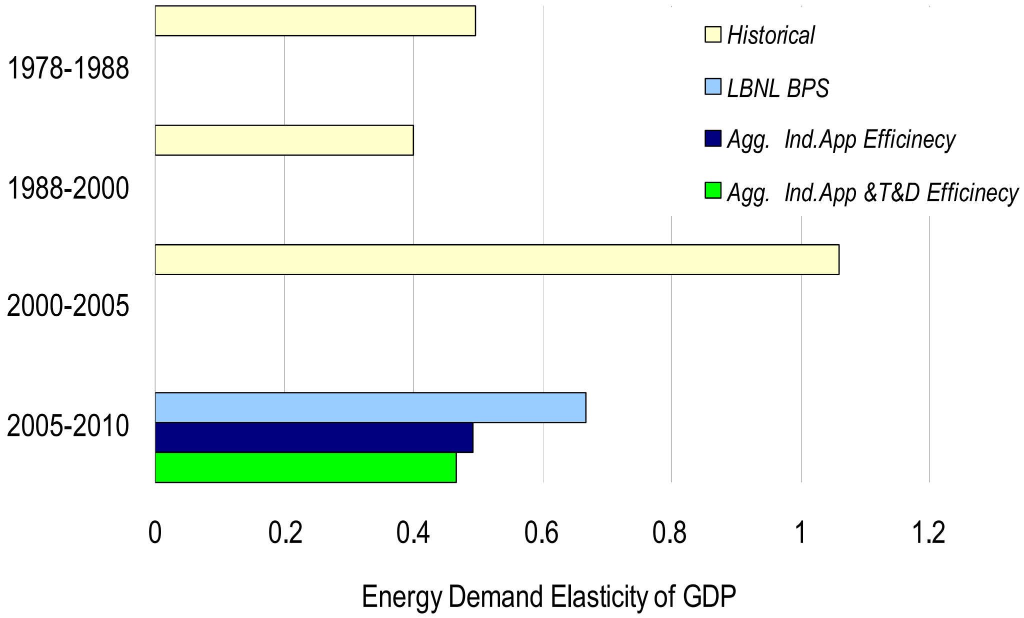


Figure 16 Energy Consumption Elasticity of GDP

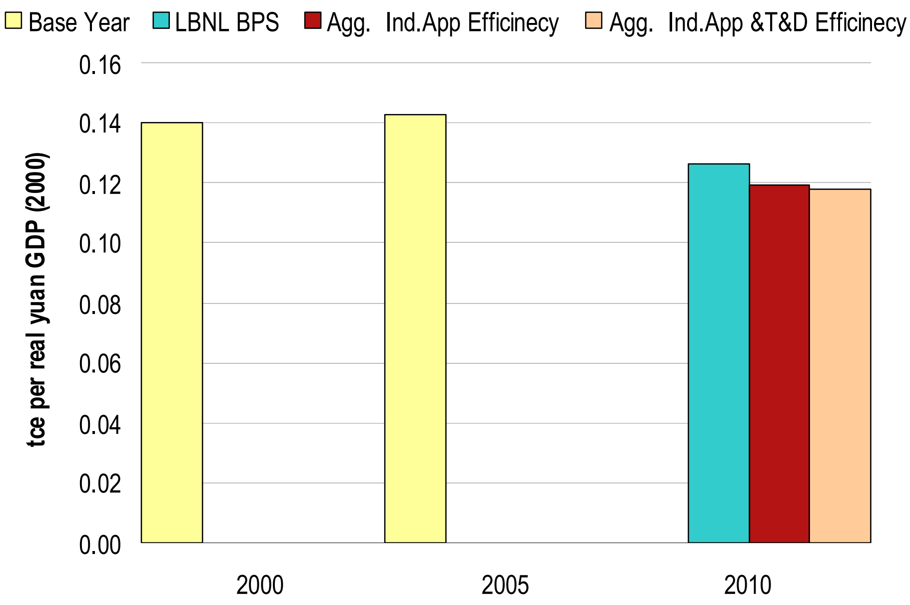


Figure 17 Energy Intensity

Industry

The modeling results illustrated in Figure 18 suggest that the energy demand of the industrial sector in 2010 in the Aggressive Industrial Efficiency scenario could be 9.4% lower compared to the BPS case, with the annual growth rate of energy demand in industry declining from 4.6% to 2.6%. While the amount of energy consumed rises in both scenarios, the overall proportion of energy-intensive industries in the total industry decreases. In some industries, energy efficiency improvement could lead to significant energy reduction. For example, the cement industry could achieve an additional 17% reduction in the Aggressive Industrial Efficiency scenario and the iron and steel industry could achieve an additional 10% reduction. The reduced energy demand in these two sectors alone totals 64.4 Mtce. At the same time, energy consumption in industries other than the major six cannot be ignored. These other sectors account for 43% of total industry energy consumption, so a 2% per year intensity reduction across these other sectors could lead to a reduction of 75.5 Mtce of energy consumption.

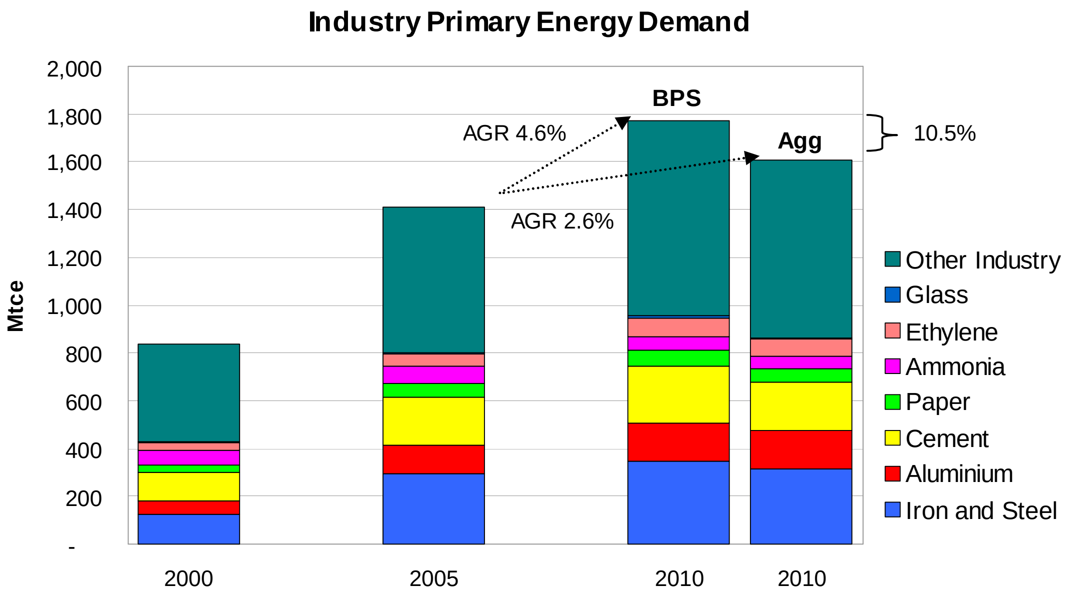


Figure 18 Aggressive energy efficiency improvement in Industry could lead to significant energy savings

Buildings

As living standards rise, energy efficiency improvements in the building sector are likely to be offset by the growing demand for higher levels of energy services: more space heating and cooling, improved lighting, more hot water, and larger appliances. These responses to higher living standards make it difficult to reduce energy intensity in building sector. However, higher equipment efficiency and stronger implementation can together act to reduce primary energy consumption in the short term. The aggressive appliance efficiency scenarios incorporate these measures, the results of which are shown in Figure 19. In 2010, residential building energy consumption is 1.4% lower in the Aggressive Industrial and Appliance Efficiency scenario and 2.8% lower in the Aggressive Industrial, Appliance, and T&D Efficiency case compared with the BPS case.[4] The annual average growth rate of energy demand is correspondingly reduced from 4.2% to 3.9% and 3.6%, respectively.

Energy consumption in the commercial sector shows similar results (Figure 20) declining by 3.5% in the Aggressive Industrial, Appliance scenario and 5.1% in Aggressive Industrial, Appliance and T&D Efficiency scenario compared with the BPS case, with the annual average growth rate declining from 7.3% to 6.6% and 6.2%, respectively.

The results also suggest that the energy consumption reduction in the buildings sector can be limited only if associated with efficiency improvements; there is less control over other factors driving the

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[4] The numbers are primary energy consumption. Is this different than the other values? If not, then this footnote isn't needed, but perhaps this point should be made earlier in the text.

increase in energy consumption such as population growth, urbanization, increases in average per capita floor area, and higher living standards.

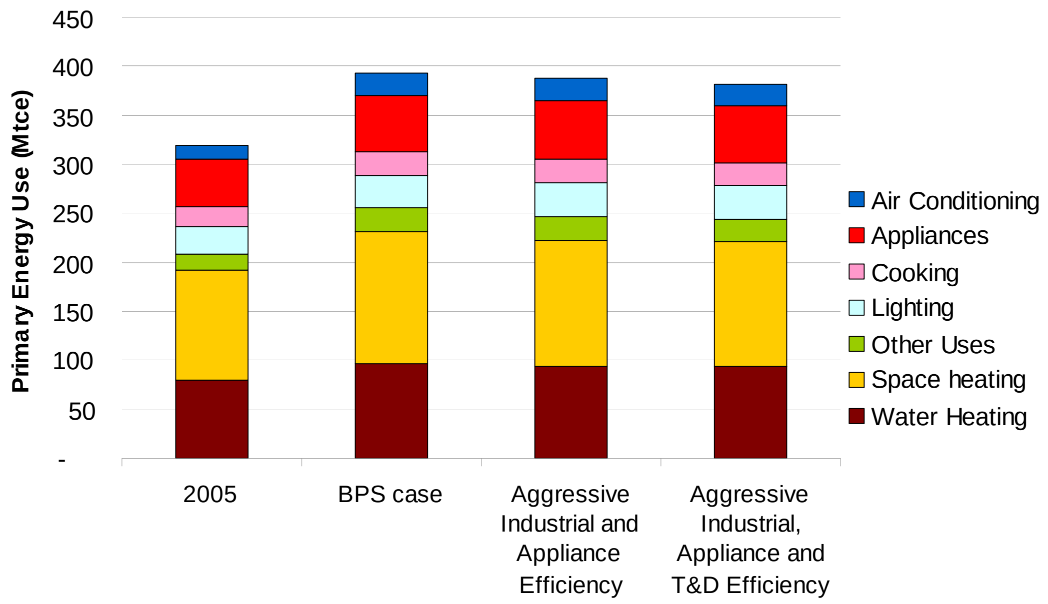

Figure 19 Residential building energy consumption by end use

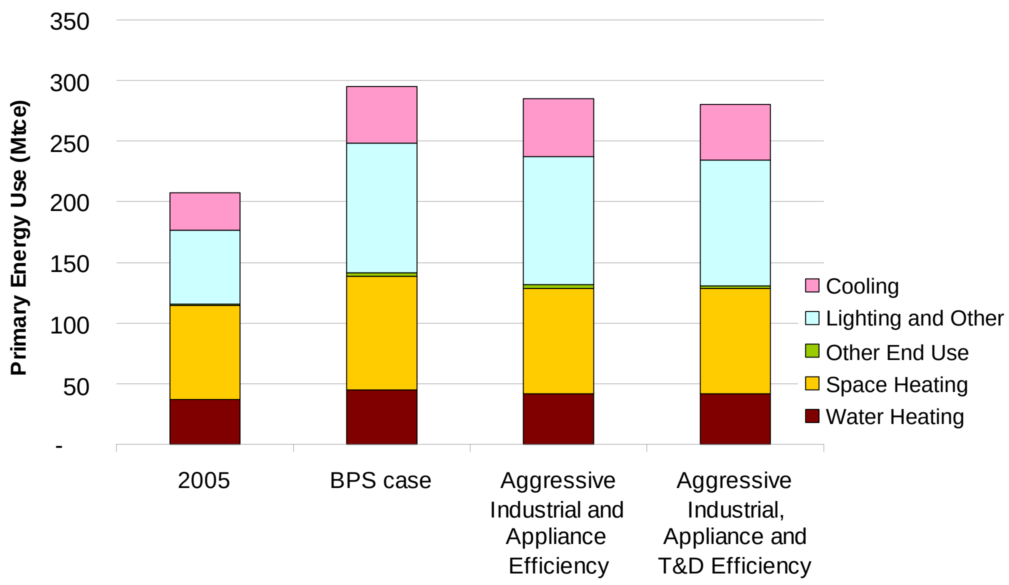

Figure 20 Commercial energy consumption by end use

5 Conclusions

China's 11th FYP set an extremely ambitious target of reducing the energy intensity of GDP by 20% by 2010. This is a particularly challenging goal in light of the recent increase in energy intensity in China. The results of this analysis show that this increase is caused mostly by rampant growth in industries, especially energy-intensive industries such as cement, steel, and chemicals; with some exceptions, energy efficiency improvements have continued in industry even during this period of rapid energy demand growth.

Thus, achieving the 20% target requires major policy changes that would both revitalize investment in energy efficiency throughout the Chinese economy and encourage the shift to less energy intensive and more economically productive sectors. Without major incentives to support energy-efficient technologies and discourage wasteful practices, it is almost certain that the target won't be met, as illustrated by energy and GDP statistics from China in the first half of 2006.[5]
.
However, meeting the 20% target is still feasible. The efficiency potential explored in this report indicates that efficiency improvements in the industrial and buildings sectors could contribute substantially toward the 20% energy intensity reduction target, while significant structural changes in the economy are also necessary. However, realizing such a potential requires adoption or vigorous implementation of a host of policies to promote energy efficiency improvement.

For the industrial sector, energy performance targets for energy-intensive industries should be used as a tool to spur innovation (Price et al., 2003) and to increase enterprise competitiveness. Promoting industry best practices and benchmarking are needed to provide valuable information to enterprises to identify areas of improvement within their facilities. Financial and non-financial incentives should be provided to induce industrial firms to pursue such retrofit potentials. It is important to ensure that all new and expanded facilities conform to industry best practices. In particular, the 1,000 Enterprise Energy Savings Program, which commits about 1000 large state-owned enterprises to specific energy saving targets, provides an excellent opportunity to showcase the potential to improve industry energy efficiency. Given sub-national developmental disparities in China, the central government could further improve aggregate energy efficiency by forbidding the transfer of old, inefficient equipment from coastal to inland areas.

For the building sector, China has developed an extensive set of building energy codes and minimum efficiency standards for appliances. However, local government agencies need to significantly increase the resources for enforcement actions in order to realize the full impact of the building energy codes. For appliances, national testing programs need to be instituted, and penalties for violations need to be raised significantly to ensure compliance to the existing appliance efficiency standards. In addition, these standards should also be tightened over time as more efficient technologies are developed, in order to deliver greater amount of societal and consumer savings.

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[5] Reuters, "China unlikely to meet energy efficiency goal," 12/19/2006.

Government agencies at all levels should take the lead in purchasing energy-efficient products and ensuring that all government-funded buildings meet the best energy performance code.

For the transportation sector, priority should be given to the development of efficient mass transit systems including bus rapid transit (BRT). An efficient and comfortable mass transit system is critical in stemming the switch to private cars, which could lock in high energy usage for years to come. At the same time, fuel economy and emissions standards for vehicles should be raised to mitigate the impact of rapidly rising vehicle sales on energy use and air quality.

To implement these programs, China needs to attract huge investment for the adoption of energy efficiency technologies and practices. China was successful in stimulating investment in energy efficiency in the past through a combination of low-interest loans, interest subsidies, and tax credits. It is time for China to re-vitalize these incentive programs.

Another source of funding for energy efficiency could be utility-based DSM programs, which has been extremely successful in the North America in slowing down demand growth. In the on-going utility sector reform, China should incorporate the principles of integrated resource planning (IRP) to put demand-side solutions on the equal footing with supply-side resources, and reward utilities for energy saved.

Setting energy prices to reflect costs of extracting, delivery, and use of energy would also help both China's effort to reduce energy intensity in the near future and to move toward a sustainable energy future. Maintaining artificially low prices not only encourages wasteful consumption of energy, but also deters the development of more efficient technologies and renewable energy.

The policy options outlined here have all been successfully implemented individually elsewhere in the world. They all aim to align the interests of energy consumers (such as steel mills) and providers (such as utilities) with societal interests of energy conservation, environment protection, and economic development. Once combined, they could unleash tremendous societal and market forces toward meeting China's goals of energy intensity reduction in the short term and sustainable development in the long term. China has demonstrated to the world in the 1980s and 1990s that it is capable of initiating path-breaking policy reforms with great success. Once again, with the new call for the development of "a harmonious society", China has the opportunity to lead a new path for the world.

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Appendix A. Sectoral Modeling Approaches

Two general approaches have been used for the integrated assessment of energy demand and supply – the so-called "bottom-up" and "top-down" approaches. The *bottom-up approach* focuses on individual technologies for delivering energy services, such as household durable goods and industrial process technologies. The *top-down* method assumes a general balance or macroeconomic perspective, wherein costs are defined in terms of changes in economic output, income, or GDP. Each approach captures details on technologies, consumer behavior, or impacts that the other does not. Consequently, a comprehensive assessment should combine elements of each approach to ensure that all relevant impacts are accounted for and that technology trends and policy options for reducing energy consumption or mitigating climate change are adequately understood.

This section describes the methodologies used to develop an end-use model to provide insights regarding the technologies that would be used, including energy intensity and saturation levels, to reach the energy consumption levels envisioned. A baseline scenario that incorporates targets stated in China's official plans and business-as-usual technology improvement was developed first and energy efficiency improvement scenarios was created to examine the influence of oil shortage. To keep the consistency of the storylines, key driver variables were kept the same.

The model consists of both the energy consumption sector and the energy production sector (transformation sector) including:

- residential buildings,
- commercial buildings,
- industry,
- transportation,
- agriculture, and
- transformation.

Sectoral energy consumption data are available in published statistics. We used China's energy statistics to prepare time series (1971-2002) of primary energy use (counting the losses occur in transformation sector). After building the model from the bottom-up, we calibrated the data by comparing the results of energy use with the statistical data for the base year (top-down).

Key drivers of energy use and carbon emissions include activity drivers (total population growth, urbanization, building and vehicle stock, commodity production), economic drivers (total GDP, income), energy intensity trends (energy intensity of energy-using equipment and appliances), and carbon intensity trends. These factors are in turn driven by changes in consumer preferences, energy and technology costs, settlement and infrastructure patterns, technical change, and overall economic conditions.

Residential Buildings

Residential energy provides numerous services associated with household living, including space heating and cooling, water heating, cooking, refrigeration, lighting, and the powering of a wide variety of other appliances. Energy demand is shaped by a variety of factors, including location and climate. In developing countries such as China, it is important to divide households into rural and urban locales due to the different energy consumption patterns found in these locations. Within the locales, end uses were broken out into space heating, air conditioning, appliances, cooking and water heating, lighting, and a residual category.

The end uses were further broken out by technologies; some appliances were broken out into classes by level of service, associated with different levels of efficiency. Space heating varies by climate type, so it is broken out by North and Transition zones. For all end uses, appropriate devices and fuels were assigned, with saturation (rates of penetration) and energy efficiencies based on statistical and survey data pertaining to the base year (2000) and future values based on analysis of government plans, trends, and comparisons to other countries. Changes in energy demand in the model are in part a function of driver variables, e.g., GDP, population, household size and urbanization rate, which were determined exogenously and included in the model. Table A- 1 shows the breakouts.

Table A- 1 End-use structure of the residential sector

End use	Space Heating		Air conditioning	Lighting	Cooking and water heating	Appliances		
Category	North	Transition				Clothes Washer	TV	Refrigerator Three sizes
Technologies	electric heater gas boiler boiler stove district heating heat pump air conditioner		Ordinary efficient Highly efficient	Incandescent Florescent CFL	Electricity Natural gas LPG Coal Coal gas Other	Vertical Horizontal	Black Color	Ordinary efficient Highly efficient

The equation for energy consumption in residential buildings can be summarized as follows (some subscripts have been omitted for brevity of presentation):

Equation 1.
$$E_{RB,i} = \sum_{k}^{OPTION} \sum_{m}^{OPTION} \frac{P_{m,i}}{F_{m,i}} \times \left[\left(H_{m,i} \times \left(SH_i \right) \right) + \left(\sum_j p_{i,j} \times UEC_{i,j} \right) + C_i + W_i + L_i + R_i \right]$$

where, in addition to the variables above:

k	=	energy type
m	=	locale type (urban, rural)
$P_{m,i}$	=	population in locale m in region i
$F_{m,i}$	=	number of persons per household (family) in locale m in region i
$H_{m,i}$	=	average floor area per household in locale type m in region i in m^2

SH_i	=	space heating energy intensity in residential buildings in region *i* in kWh/m^2-year
j	=	type of appliance or end-use device
$p_{i,j}$	=	penetration of appliance or device *j* in region *i* in percent of households owning appliance (values in excess of 100% would indicate more than one device per household on average)
$UEC_{i,j}$	=	energy intensity of appliance *j* in region *i* in MJ or kWh/year
C_i	=	cooking energy use per household in region *i* in MJ /household-year
W_i	=	water heating energy use per household in region *i* in MJ /household-year
L_i	=	average lighting energy use per square meter in region *i* in kWh /square meter-year
R_i	=	residual household energy use in region *i* in MJ /household-year

Air conditioner and refrigerator end uses are detailed with stock turnover modeling, which includes information on initial stocks by vintage, energy efficiencies by vintage (allowing explicit modeling of the impacts of standards), efficiency degradation profiles, and lifetime or survival profiles.

Commercial Buildings

The commercial buildings sector is represented in a fashion similar to residential buildings. A subsectoral breakout includes retail, office, hotel, school, hospital, and other buildings. The key **end uses** by the subsectors listed above include space heating, space conditioning, water heating, lighting, and other uses. The end-uses were further broken out by technologies shown in Table A- 2.

Table A- 2 End-use structure of the commercial sector

End use	Space heating	Space cooling	Lighting and other applications	Water heating
Technologies	Electric heater Gas boiler Boiler Small cogen Stove District heating Heat pump	Centralized AC Room AC Geothermal Heat Pump Centralized AC by NG	Existing Efficient	Electric water heater Gas boiler Boiler Small cogen Oil boiler

Omitting repetitive subscripts for the energy intensity terms, this can be represented as:

Equation 2. $$E_{RB} = \sum_{k}^{OPTION} \sum_{n}^{OPTION} \sum_{q}^{OPTION} \left[A_{CB,n} \times P_{q,n} \times \left(\sum_{k} Intensity_{q,n} \times Share_{k,q} / Efficiency_{k,q} \right) \right]$$

where, in addition to the variables listed above:

k	=	energy type (technology type)
q	=	type of end use
$A_{CB,n}$	=	total commercial floor area in commercial building type *n* in m^2

$P_{q,n}$ = penetration rate of end use q in building type n
$Intensity_{q,n}$ = intensity of end use q in building type n
$Share_{k,q}$ = type of technology k for end use type q
$Efficiency_{k,q}$ = efficiency of technology k for end use type q

Industry

The industry sector is divided into seven specific energy-intensive industries (iron and steel, aluminum, cement, glass, paper, ethylene, ammonia) and the residuals. **Physical energy intensities** in terms of energy use per ton (or other unit) of industrial product produced for each industrial sector is used. Physical production values are multiplied by industry average physical intensities and then summed to derive energy consumption values for the energy-intensive industries. Any other industrial production is treated as a remainder. Energy use in the other industry is simply the product of industry value added GDP, and the residual energy use in industry per unit of GDP (**economic energy intensity**), given the total industry energy consumption from the statistical yearbooks.

The end-uses were further broken out by technologies shown in Table A- 3

Table A- 3 Subdivision of the industry sector

End use	Iron and Steel	Aluminum	Cement	Glass	Paper	Ethylene	Ammonia		
Category or feed stock				Flat		Naphtha Feed Stock	Coal and coke	NG	Fuel Oil
Fuels	Coal Coke Electricity NG Heavy oil	Coal Coke Electricity Diesel Heavy oil	Coal NG Electricity Heat H	Coal Heavy oil NG Electricity heat	Coal Heavy oil NG biomass Electricity heat	Naphtha Electricity heat	Coal Electricity heat	NG Electricity heat	Heavy oil Electricity heat

Equation 3. $E_{I,i} = \sum_{k}^{OPTION} \left[\sum_{c}^{OPTION} Q_c \times EI_{c,k} \right] + G_v RI_k$

where, in addition to the variables listed above:

c = commodity type
Q_c = quantity of energy-intensive commodity c produced,
$EI_{c,k}$ = average intensity of energy type k for producing energy-intensive industrial commodity c in GJ/metric ton (or other physical unit),
G_v = Industrial value added GDP, and
$RI_{,k}$ = average intensity of energy type k for producing residual, i.e. remaining industrial GDP.[6]

[6] This residual can be derived based on historic and projected trends in the share of energy use or industrial sector GDP of

Transportation

In a fashion peculiar to the transport sector, final energy is employed in a large variety of modes and technologies to provide a small range of end-use services, i.e., the transport of passengers and goods, ultimately representing a single service: *mobility*.

While for the other sectors the combination of fuel and technology is nearly always sufficient to determine the end-use service provided, this is not necessarily true for transport. Neither does the combination of the end-use and technology alone provide a level of detail adequate to accurately estimate end-use energy demand. For example trucks and locomotives used to haul freight can share the same engine technology and fuel and provide the same end-use service, but the associated energy intensity will be significantly different.

Transport could be broken out by *mode*:

- water (internal waterways vessels, sea transport vessels, international transport vessels)
- air (national and international air transport),
- rail (intracity and intercity mass transit)
- pipeline (subdivided by good delivered, when detail is available)

For China, urban and rural transport on Road could exhibit very different energy intensities. Thus, it was broken out by urban and rural; the urban module is divided into cars, taxis, motorcycles and buses, while the rural module is divided into cars and motorcycles. The highway module comprises primarily of buses which are subdivided into Heavy Duty, Medium Duty, Light Duty and Mini Buses (see Table A- 4).

Table A- 4 Subdivision and end-use of the transportation sector

					Fuel
passenger	road	urban	Cars		Gasoline, diesel, NG, Hybrid
			Taxis		Gasoline, diesel, NG
			Buses	Heavy duty, medium duty, light duty, minibus	Gasoline, diesel, NG
			Motorcycles		Gasoline, diesel, NG
		rural	cars		Gasoline, diesel, NG
			motorcycles		Gasoline, diesel, NG
		highway	Buses	Heavy duty, medium duty, light duty, minibus	Gasoline, diesel, NG
	rail	Intercity			Diesel, electricity, Fuel oil, Steam
		local			Diesel, electricity, Fuel oil, Steam
	water	Inland			Diesel, Fuel Oil
		coastal			Diesel, Fuel Oil
	air	Domestic			Jet Kero, Avgas
		International			Jet Kero, Avgas

light industries compared to energy-intensive industry in a country or region.

Freight	road	urban	Trucks		Diesel, Gasoline
		rural	Trucks		Diesel, Gasoline
			Tractor	Heavy duty, medium duty, light duty, minibus	Diesel
			Rural Vehicle	Three wheeler, four wheeler	Diesel
		highway	Trucks	Heavy duty, medium duty, light duty, minibus	Gasoline, Diesel
	rail	Intercity	Coal, oil, coke, other		Steam, diesel, electricity
		local			Steam, diesel, electricity
	water	Inland	Coal, oil and oil product, crude oil, other		Diesel
		coastal	Coal, oil and oil product, crude oil, other		diesel
		Ocean			Fuel oil
	air	Domestic			Jet Kerosene, Avgas
		International			
	Pipeline		Crude oil, oil products, NG, other Gas		electricity

The **physical energy intensities** used are in terms of energy use per kilometer (km), per passenger-km, or per tonne-km.

This can be summarized as follows:

Equation 4. $$E_{TR,i} = \sum_{k}^{OPTION} \sum_{t}^{OPTION} \sum_{r}^{OPTION} \sum_{j}^{OPTION} Q_{t,r,m,i} \times s_{t,r,j,i} \times f_{k,t,r,j,i} \times EI_{TR,k,t,r,j,i}$$

where, in addition to the variables above described:

j = transport technology class (e.g., vehicle classes)
$s_{t,m,i}$ = share of transport services t, delivered through the mode m employing the transport end-use technology j
$f_{k,t,m,j}$ = share of fuel k used for technology j in providing transport services of type t
r = mode type (road, rail, water, air, pipeline)

m = locale type (rural, urban)

$Q_{t,r,m}$ = quantity of transport service of type t in mode r and in locale m of region i in passenger-km and tonne-km, and

$EI_{TR,k,t,,m}$ = average energy intensity of energy type k for transport service of type t in mode r and in locale m in MJ/(passenger-km-year) and MJ/(tonne-km-year).

k = energy type

t = transport type (passenger, freight)

Turnover data series for rail, water, air and intercity highway road can be acquired from China Statistical Yearbooks and the Transportation Yearbooks for different years. However, such data does not exist for vehicles intra-city or intra-rural. Data on stocks and the usage pattern (such as average travel distance and the annual amount of the trips) were used to calculate the total turnover.

Agriculture

Energy use was modeled simply as the product of agriculture value added GDP, and the energy use in agriculture per unit of GDP (**economic energy intensity**), given the total agriculture energy consumption from the statistic yearbooks. Historic agriculture energy consumption is available in the China Energy Databook.

Appendix B. Detailed Drivers and Results in BPS Scenario

Buildings

Building sector end use energy consumption in the base year is based on results of existing research carried out by the Energy Research Institute, China, and LBNL led energy consumption survey (Brockett et al 2002). Historical trends and the current situation in developed countries were used as the reference to reflect the specific energy efficiency improvement trend and the change in life style (IEA.2004). Table B-1 and Table B-2 shows the values for the major driver variables that were used in residential buildings to obtain an outcome in line with China's government plan to 2010.

Table B-1 End-use saturation and the projection in residential sector

		Urban enduse			Rural enduse		
		2000	2005	2010	2000	2005	2010
Space Heating							
North	%	100	100	100	100	100	100
Transition	%	30	33	43	8	9	10
Refrigerator	%	80	83	85	12	19	25
Clothes washer		91	96	97	29	38	45
vertical	%	70	67	63	90	86	82
horizontal	%	30	33	37	10	14	19
TV		117	135	142	102	115	123
black		0	0	0	52	33	29
color	%	100	100	100	48	67	71
Air Conditioner	%	31	73	89	1	6	11

Table B-2 The end use intensities the projection in residential sector

			Urban enduse			Rural enduse intensity			Japanese 2004 most efficient technology	note
			2000	2005	2010	2000	2005	2010		
Space Heating										
	North	kWh/m^2-year	79	75	71	5.85	10.2			
	Transition	kWh/m^2-year	30	31	30	0.2	3.2			
Cooking		MJ/household-year	901	1031	1161	997	1085			
water heating			3605	4125	4645	3988	4340			
Other use		kWh/year	100	180	260	50	75	100		
lighting		kWh/m^2-year	3.0	3.3	3.7	1.5	1.7	1.8		
Refrigerator UEC		kWh/year	461			458.9			380	for 250L-300
Clothes washer										
	vertical	kWh/year	25.0	24.0	23.0	16.6	17.3	17.6		
	horizontal	kWh/year	49.0	48.0	46.0	33.3	34.5	35.1	21.9 to 40.2	for 4.2 kg
TV										
	black& white	kWh/year	38.0	45.0	51.0	38.0	44.5	50.9		
	color	kWh/year	125.0	152.0	180.0	125.0	152.4	179.8	79	for 29 inch
Avg. Air Conditioner UEC		kWh/year	387.6	245.6			375	248.9	47 kWh/month for cooling, 116 kWh/month for heating	for capacity of 2.5 kW

Statistical data for appliance ownership in both urban and rural areas and end use intensities for space heating, cooking and water heating are available in Zhou (2003). Future projections were made either based on the quantitative objectives stated in the above mentioned publication (Zhou,2003), or by extrapolating from historic trends. For urban China, the estimation was made by applying the average growth rate in developed countries from 1970 to 1997.. The unit energy consumption (UEC) is also used for appliances to measure the electricity consumption per unit per year. UECs for clothes washers and TVs in 2020 were estimated using current UECs of developed countries.

The overall result from this disaggregation effort — total building energy use growing by 5.4% between 2005 and 2010 — is at odds with China's recent performance and its stated development goals, suggesting that the BPS scenario values have incorporated reasonable energy efficiency improvement. From 2000 to 2005, energy use in China grew at a rate of 10%, and, in the recent past, energy in buildings has been growing as fast as or faster than the national average (NBS, 2004; Sinton *et al*., 2004). Simulating a scenario with lower energy growth requires assuming slower than expected growth in driver variables, e.g., commercial building area, and greater progress in efficiency. A detailed explanation of the differences between the scenario we simulated and expected future changes is beyond the scope of this paper, but the results discussed below show the kinds of policy-relevant features that can be illuminated when top-down scenarios are disaggregated with bottom-up models.

At the sectoral level, the results reflect changes that are generally in line with expectations. The breakout between residential and commercial buildings shows commercial building energy use rising much faster than residential buildings (Figure B- 1**).** Because of rapid urbanization, the simulation shows rural energy use actually shrinking slightly, so virtually all of the growth is in urban buildings **(**Figure B- 2**)** At the same time, the fuel end use structure changes substantially, with direct use of biomass and coal shrinking substantially in favor of gas, oil and hydro power (Figure B- 3). To judge a scenario critically, however, requires going beyond this level of detail.

The case of refrigerators in urban households provides an example of how this disaggregation approach can lead to insights at the end-use level. Under the BPS scenario, the urban residential buildings sector is expected to consume, among other forms of energy, 239.8 TWh in 2010. Refrigerators and air conditioners are a major electricity user in all households in China, and we project that they will account for over 26% and 25% of appliance energy use, respectively, in all years of the simulation (Figure B- 4), and 14.2% and 13.9% of urban household electricity use, respectively, in 2010.

To understand future trends in refrigerator technology, we simulate trends in refrigerator energy intensity and size levels. Refrigerators are broken out into three efficiency classes, termed ordinary, efficient, and highly efficient. Current data for actual refrigerators on the Chinese market and information on possible future efficiency standards (China National Institute of Standardization, 2003) are used to determine efficiency levels for these three efficiency classes in each of three typical refrigerator sizes (170 liters, 220 liters, and 270 liters). Average intensity levels for the three efficiency classes, which are assumed to decline over the 2000 to 2010 period, are shown in Figure B- 5. The figure shows that, over the period of the scenario, the average size of new refrigerators is assumed to rise, as well as the rate of ownership, which increases from 80% of urban households to 85%.

Urbanization and shrinking household size multiply the effects of rising refrigerator size and penetration to overwhelm efficiency improvements, and the result is that refrigerator electricity use rises 3.1% per year from 2005 to 2010. This is slower than the 7.6% growth in total electricity use. Most of the growth in electricity use is due to air conditioner use with the growth rate of 11.7%.

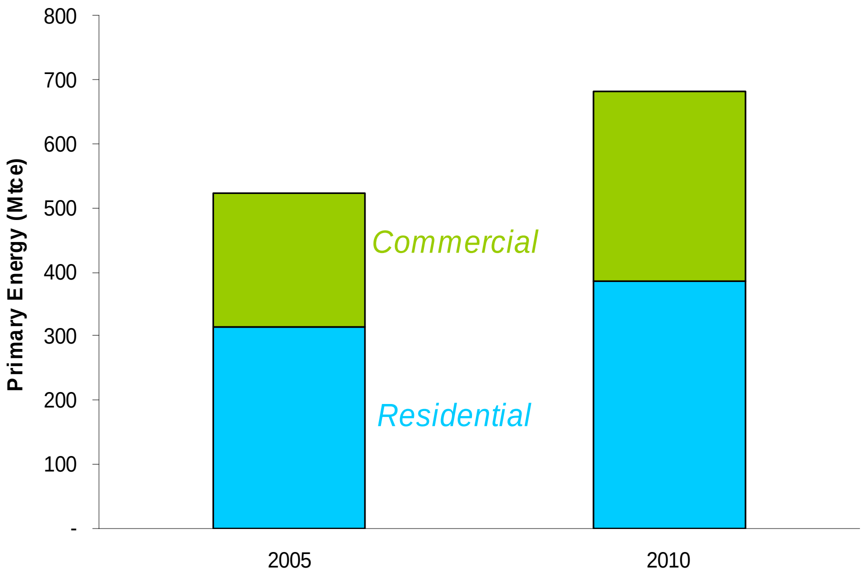

Figure B- 1 In this rendition of the BPS scenario for China, most of the prospective rise in building energy use is in the commercial buildings sector.

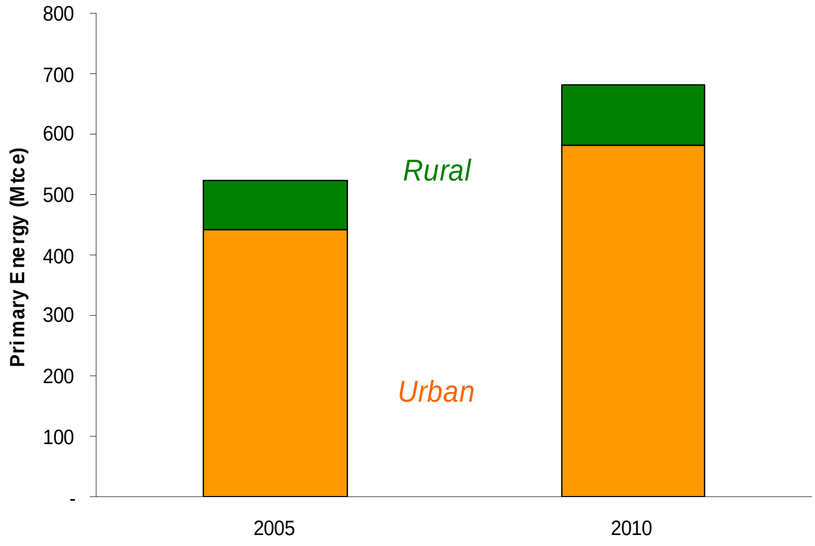

Figure B- 2 The projected shift of rural population to cities means that energy use in the countryside will shrink as energy use rises overall.

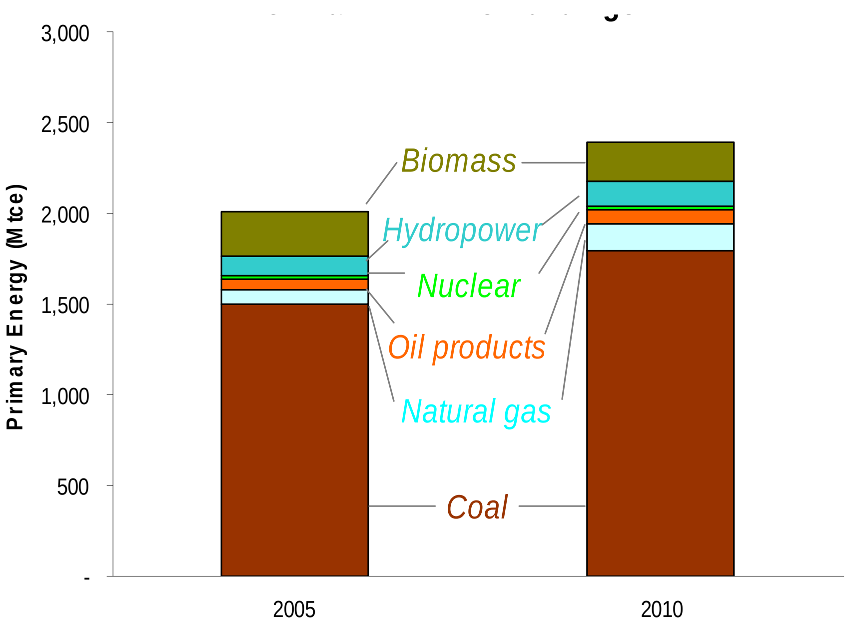

Figure B- 3 Primary energy use by energy type shows growth in oil products, coal and gas, decline in biomass.

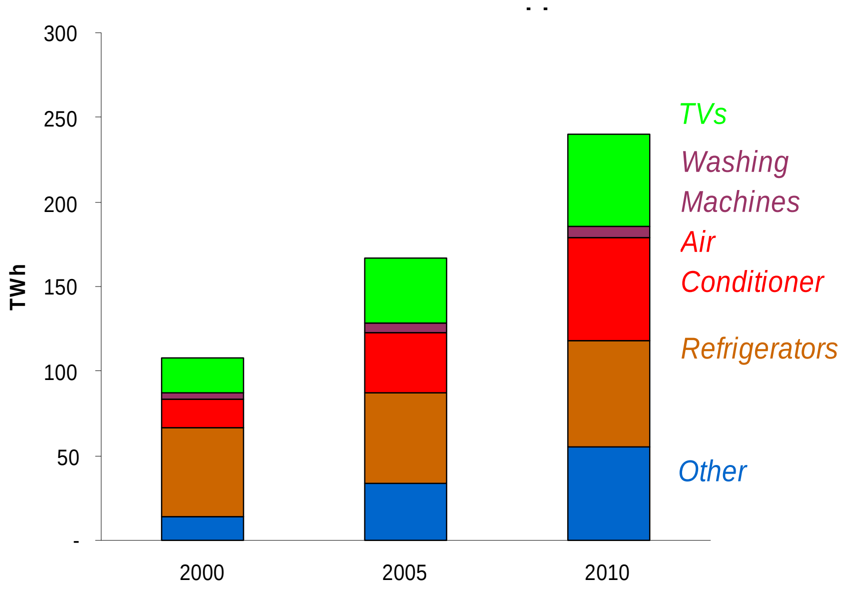

Figure B- 4 While refrigerators remain the dominant appliance, the projected rise in consumption in other appliance categories is significant.

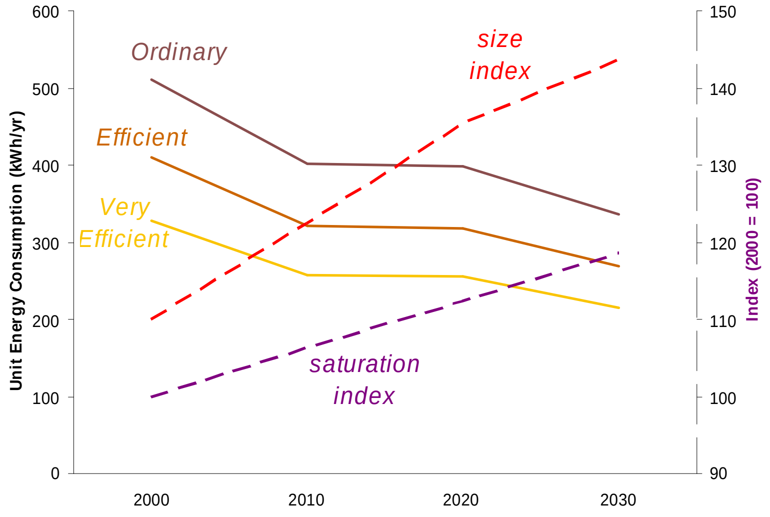

Figure B- 5 In the refrigerators sub-model, efficiencies improve as tighter standards are implemented, while ownership and average size rise.

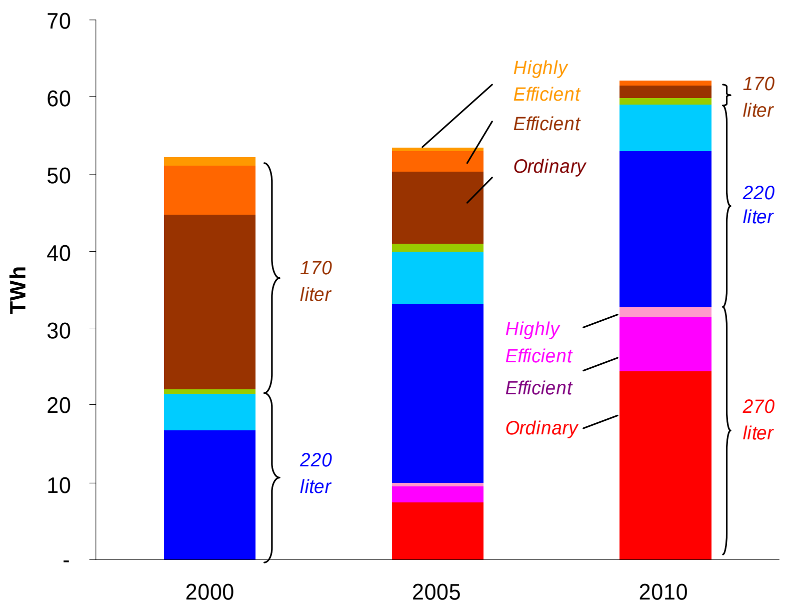

Figure B- 6 As larger refrigerators grow to dominate energy consumption, the share of efficient models also rises.

Commercial energy use varies by different building types. Our projections are based the on assumption that the distribution of building types in China in 2030 will reach the Japanese level of 2000.[7]

Figure B- 7 shows total commercial building floor area and its growth, and the distribution by building type. We project that the floor area will nearly double in 2010 compared with 2000; retail buildings will grow the fastest at AGR of 9.4%, followed by hospitals and schools with AGRs of 8.4% and 7.7%, respectively. The share of office buildings and hotel in the overall figure will decrease. This implies that as the economy develops, more needs for the development of educational and healthcare infrastructure.

Figure B- 8 shows an example of the energy intensities of various end uses in office buildings. Heat loss through exterior walls, which is the greatest single source of heat loss in these buildings, is about 3-5 times higher in Chinese buildings as in similar buildings in Canada and other northern countries, including Japan. Loss through windows in Chinese commercial buildings is over twice as high. Additional major losses are caused by imbalances and inability to control heat use in centralized heating systems, forcing consumers to commonly open windows as the only means to regulate overheating (The World Bank, 2001). With energy efficiency improvement and strengthened implementation of building codes, space heating intensity in China could decline to the developed country level. However, because all buildings currently do not have space heating equipment, energy use for space heating will continuously grow to penetrate the total buildings floor area in areas with cool climates.

[7] These data are based on IEEJ (2003).

In addition, although the share varies in different buildings, the use of conventional coal boilers will be reduced significantly, while more efficient technologies such as gas boilers and heat pumps will grow faster and eventually dominate. Figure B- 9 shows that energy efficiencies for each technology will be improved, and the efficiency improvement potential for heat pump is substantial.

Many older buildings as well as hospitals and schools are not air conditioned. As living standards rise, space s cooling intensity will increase. We project that the share of electric central air conditioning and air conditioning will decline while air conditioning using natural gas and geothermal air conditioning will gradually expand. The efficiency of space cooling technologies will be improved;[8] Demand for lighting and other electric applications will continue to grow as the need for a more comfortable lighting environment that includes other office equipment grows; Water heating requirements will remain the same.

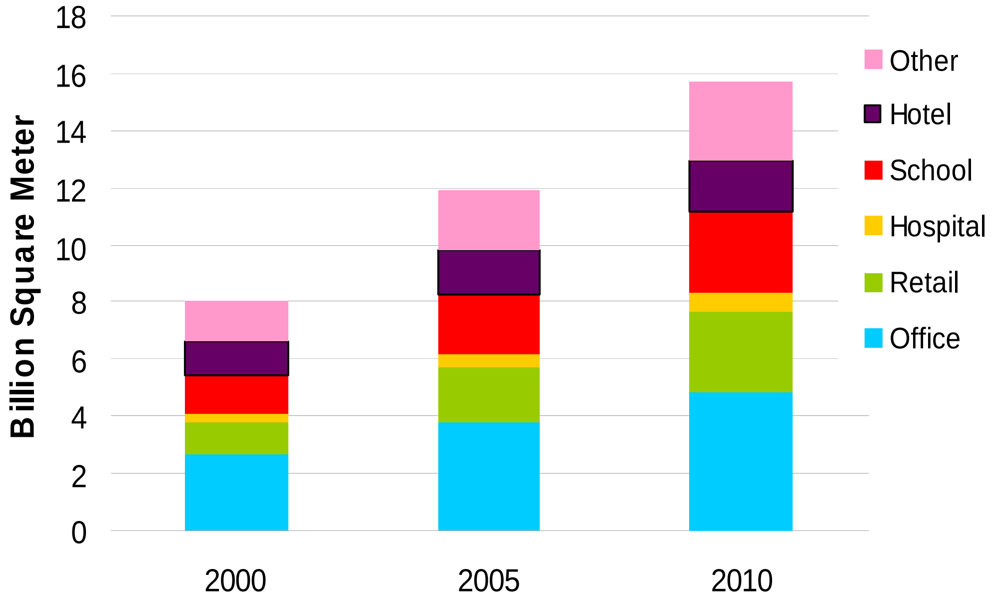

Figure B- 7 Commercial Building Floor Area Distribution by Building Type

[8] Our estimate based on qualitative objectives stated in China's Sustainable Energy Scenarios in 2020 (Zhou, 2004) this is shows as 2003 in the references, and Nishida (1997). We assume that the efficiency of technologies in 2030 will reach the level of Japan today The latest data were based on the HAVC efficiency in Japan.(http://www-atm.jst.go.jp:8080/01050211_1.html)

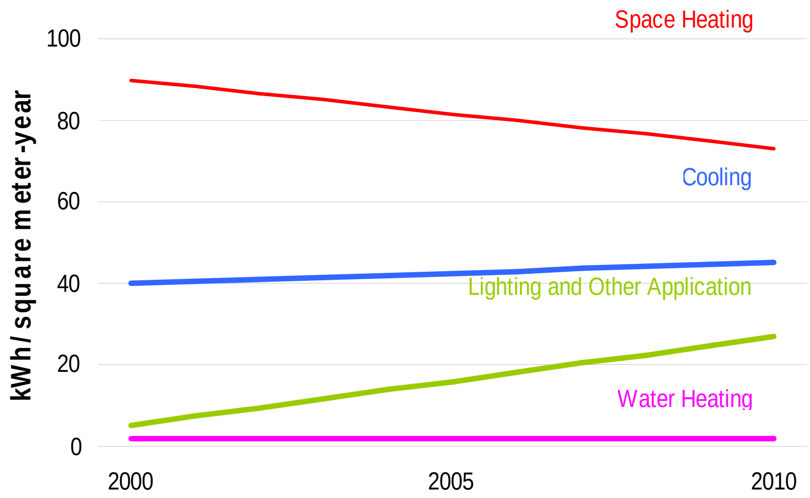

Figure B- 8 End-use Energy Intensities in Office Building

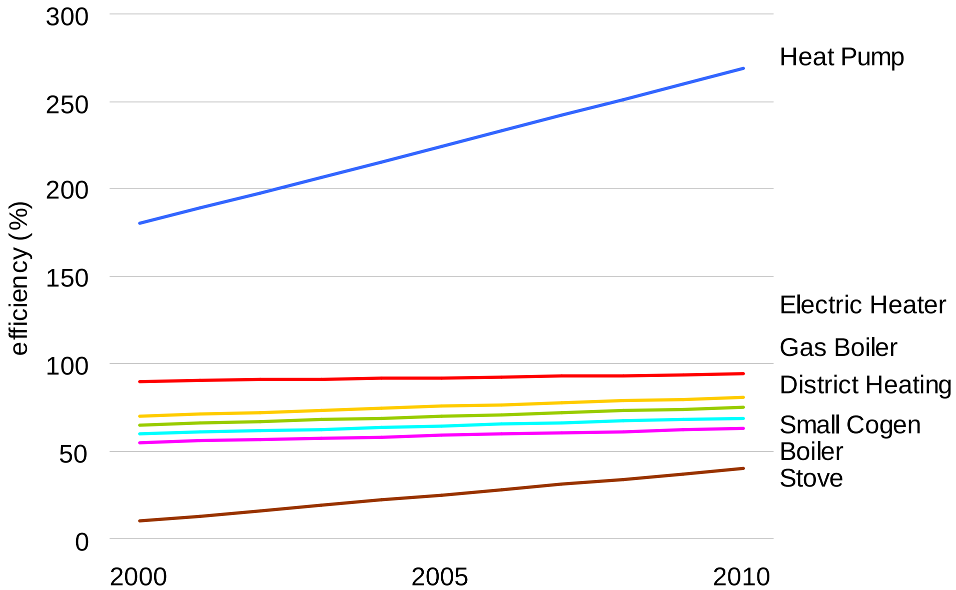

Figure B- 9 Energy Efficiency of Each End-use Technologies

From the model results, Figure B- 10 illustrates that energy consumption in commercial buildings grew from 128 Mtce in 2000 to 208 Mtce in 2005, and will grow to 297 Mtce in 2010 with an AGR of 7.4%. Energy use will grow faster especially in retail, hospital and office buildings, with AGRs of 9.4%, 7.9 % and 7.5%, respectively, mostly corresponding with the faster growth rate of floor area except for school buildings where the energy intensity is low. By looking at the energy consumption by end-use presented in Figure B- 11, commercial energy use grows for all end uses, but particularly for lighting and appliances with an AGR of 11.9%, followed by space cooling at 8.4%.

To look at what factors and to what extent the factor drive energy demand in commercial sector, Figure B- 12 shows the growth rate contributed by each driver in final energy consumption. Commercial energy use is predominantly driven by floor area growth, followed by penetration of end uses such as space heating and cooling. In addition, although the energy efficiency of the technologies improves constantly, the effect will be offset by the overall building load growth due to the demand for higher levels of comfort. Among the factors that reduce demand, the choice of more energy-efficient technologies has considerable impact in reducing building energy consumption, and is followed by the efficiency improvement of each technology.

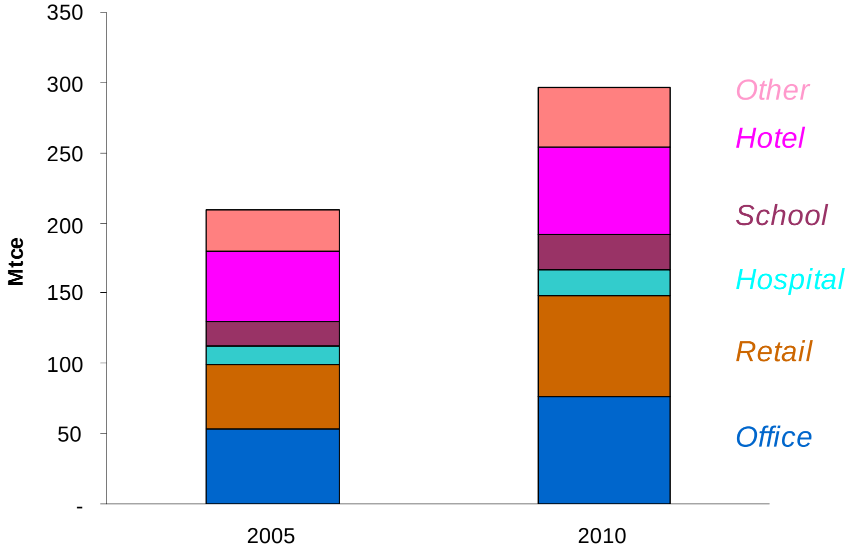

Figure B- 10 Commercial Energy Consumption by Building Type

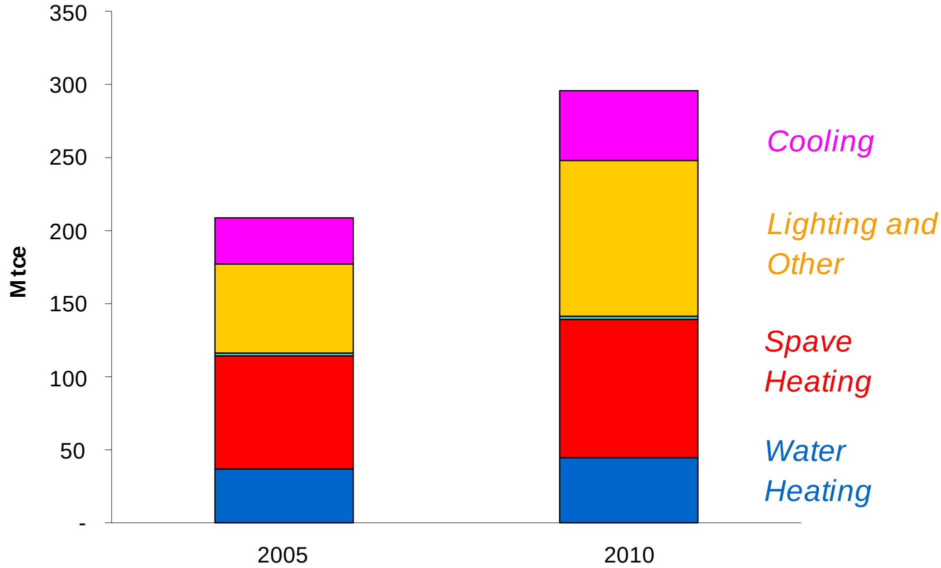

Figure B- 11 Commercial energy use grows for all end uses, but particularly for lighting and other application

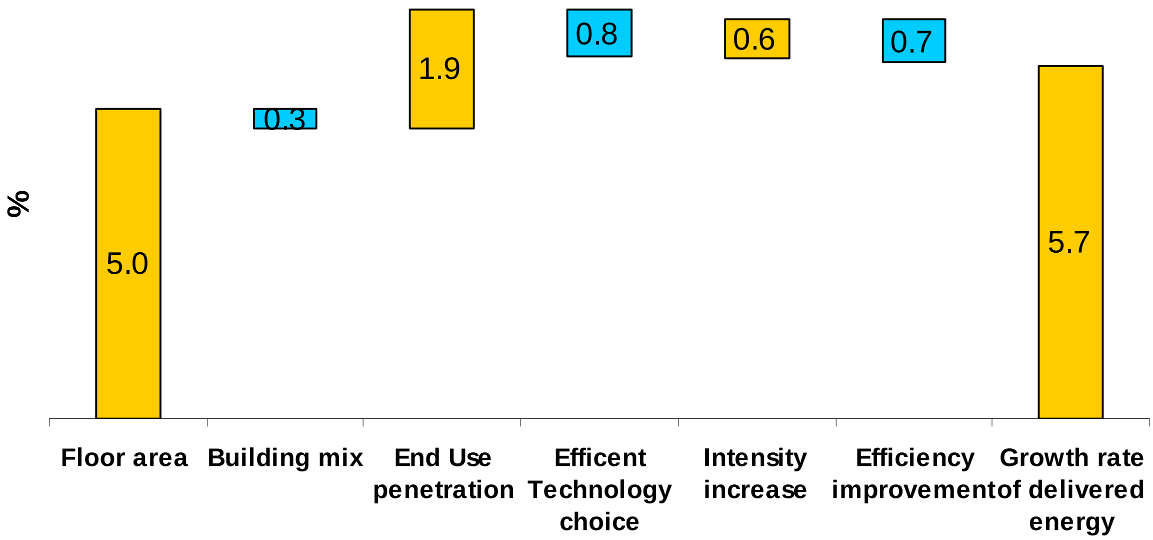

Figure B- 12 Growth Rate Contributed By Each of the Growth Drivers in Commercial Sector (%)

Note: Final energy consumption

Industry

For the major energy intensive sub-sectors, the assumptions are production-driven. Historical production data were obtained from China's statistical yearbooks (NBS, 1985-2005). In the 10th five year plan, the government has projected or set the target for industrial production from 2000 to 2005. However based on actual data, the production in major industrial sectors in 2005 exceeded the original target by 50% on average. The numbers are shown below:

- Cement: exceeds target by 54%,
- Iron and Steel: exceeds target by 40%.
- Glass: production exceeds target by 82.3%
- Ethylene: no change
- Ammonia: production exceeds target by 28%
- Paper: production exceeds target by 31.5%
- Aluminum: production exceeds target by 92.5%

According to these developments, many industrial associations have revised their new production projections to 2010. Figure B- 13 provides examples in the iron and steel industry and in the cement industry. Table B- 3 shows the gap between the previous projected production values and newly revised projections for the 6 major industrial sectors.

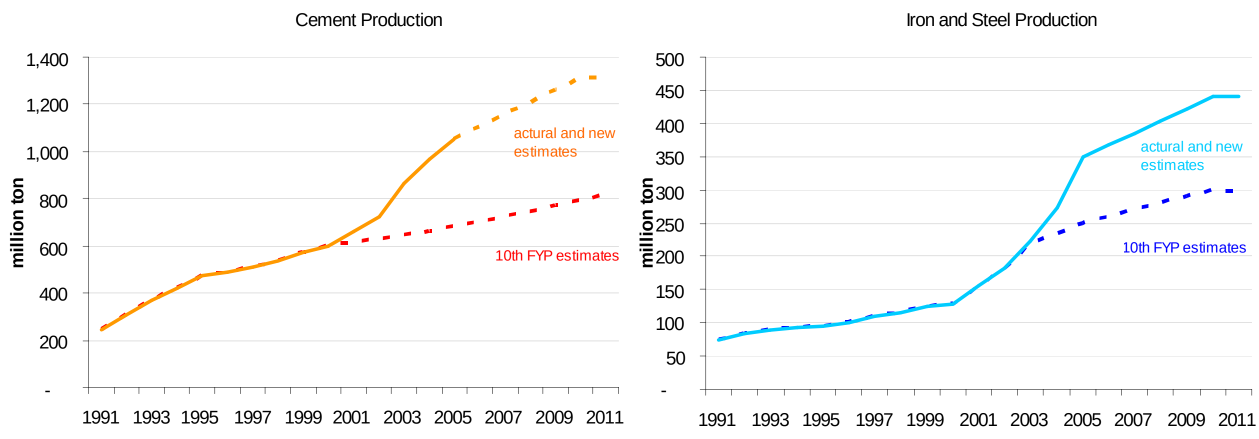

Figure B- 13 The gap between projected and actual production in two major industry sectors

Table B- 3 Production growth in major industries (Million Tons)

	2000	2005	2010	00-05	05-10
Glass previous	9.1	9.6	10.1	1.1%	1.0%
Glass revised	9.1	17.5	27.5	14.0%	9.5%
Ethylene previous	4.7	7.7	12.0	10.4%	9.3%
Ethylene revised	4.7	7.6	13.0	10.1%	11.3%
Ammonia previous	33.6	36.0	38.0	1.4%	1.1%
Ammonia revised	33.6	46.0	38.0	6.5%	-3.7%
Paper previous	30.5	40.0	50.0	5.6%	4.6%
Paper revised	30.5	52.6	68.0	11.5%	5.3%
Cement previous	597.0	680.0	790.7	2.6%	3.1%
Cement revised	597.0	1050.0	1310.0	12.0%	4.5%
Aluminium previous	3.0	4.0	4.6	6.0%	2.8%
Aluminium revised	3.0	7.7	11.2	20.7%	7.8%
Iron and Steel previous	128.5	250.0	300.0	14.2%	3.7%
Iron and Steel revised	128.5	349.4	440.0	22.1%	4.7%

Note: revised projections are from industry associations

The intensity data for historic years was derived from official energy statistics, and the projection is based on China's strategic plans for specific industries (RNECSPC, 2005). The energy intensity indicates a trend of slow intensity reductions. The decline is especially strong in the iron and steel sector (Table B- 4).

China's government plan calls for the industrial sector to become more efficient. Table B- 4 shows key indicators of aggregate energy intensity in seven sub-sectors as stated in China's plan (RNESPEC, 2005) and the comparison with international advanced levels (
Table B- 5).

Table B- 4 Energy intensity change in major industry sectors (tce/ton)

	2000	2005	2010	2020	00-05	05-10	10-20
Glass	0.50	0.46	0.40	0.36	-1.7%	-2.8%	-1.0%
Ethylene	1.21	1.00	0.93	0.86	-3.7%	-1.4%	-0.8%
Ammonia							
coal feed stock	1.17	1.10	1.05	0.95	-1.2%	-1.0%	-1.0%
NG feed stock (kWh)	1300	1229	1168	1055	-1.1%	-1.0%	-1.0%
fuel oil feedstock	0.13	0.12	0.12	0.11	-1.3%	-1.0%	-1.0%
Paper	0.86	0.84	0.79	0.71	-0.5%	-1.1%	-1.1%
Cement							
Rotary	0.19	0.17	0.16	0.13	-1.3%	-1.4%	-2.1%
Shaft	0.16	0.15	0.145	0.14	-0.7%	-0.7%	-0.7%
Aluminum	9.56	8.55	8.40	8.20	-2.2%	-0.4%	-0.2%

Iron and Steel*	0.78	0.71	0.67	0.61	-2.0%	-1.0%	-0.9%

*Comparable energy consumption

Reference: RNECSPC (2005) and Zhou (2003)

Table B- 5 Comparison of Chinese and International Industry Energy Intensity Values

	Unit	China	International
Comparable Energy consumption for Steel	kgce/ton	726 (2003) 640 (2020)	646 (2003 Japan)
Energy Consumption for Ethylene	kgcek/ton	890 (2003) 600 (2020)	629 (2003 Japan)
Energy Consumption for Synthetic Ammonia	kgcek/ton	1200 (2000) 1000 (2020)	970 (2000 US)
Energy Consumption for Cement	kgcek/ton	181 (2003) 129 (2020)	128 (2003 Japan)

Note: compiled by the authors

Industry value added (VA) GDP was used as the driver for energy consumption in “other industry” which represents the residual industrial sectors other than the energy-intensive sectors. VA in other industry has been growing at an AGR of 11% from 1970 to 2000, faster than the AGR for total GDP. However, in developed countries such as Japan, the AGR for GDP was only 2.8% from 1970 to 2000, 2.2% from 1980 to 2000, and 1.2% from 1990 to 2000 (WDI, 2003). According to RNECSPC (2005), industry GDP accounted for 43.6 % of the total GDP in 2000 and 44.9% in 2002, and is estimated to be 49% in 2020. The industrial GDP growth rate is 7% based on Zhou (2003). Based on the above values, LBNL estimated that industry VA GDP will grow 7% from 2005 to 2010.

Energy use per GDP in the industrial sector has been declining since 1980. The AGR from 1980 to 2000 was -5.3% (RNECSPC, 2005). In Japan, industrial sector energy use per GDP was -1.6% from 1980 to 2000. Because there is no clear consensus stated regarding the projection or target for energy intensity in other industry sectors, it was set to be flat from 2005 in the model. However, historic trends in developed countries (IEA, 2004) indicate that shifts in industry structure and processes contributed to the changes in fuel mix, and some change in fuel mix may be attributed to substitution driven by changes in relative fuel price. In IEA countries, oil use has declined 62% in 2000 compared to 1973, and coal and coke use fell 29% while electricity use expanded by 65% and natural gas use also increased (IEA, 2004). In our analysis, we assume that the use of gas and electricity will grow faster to substitute for coal and oil products.

In 2005, China’s industrial sector energy consumption was 1,416 Mtce, accounting for 64% of total energy consumption. In 2006, NDRC initiated a comprehensive national program entitled “Monitoring and Guiding of Energy Efficiency Improvement of Top 1000 Energy-Consuming Enterprises in China” in which 1008 top energy-consuming enterprises have been identified and asked to improve their energy efficiency with the goal of saving 100 Mtce by 2010. The highly energy-intensive industries that are included in China’s “Top 1000 Enterprises” make up about 47.5% of total industrial energy consumption (Figure B- 14).

From the model results, shown in Figure B- 15 industrial energy consumption will grow 4.6% annually from 2005 to 2010, reaching 1773 Mtce. China expects the iron and steel industry and cement industry energy consumption to grow more slowly by 2010, but the two will still retain the largest share of industrial energy usage with 20% and 13% of the total, respectively.

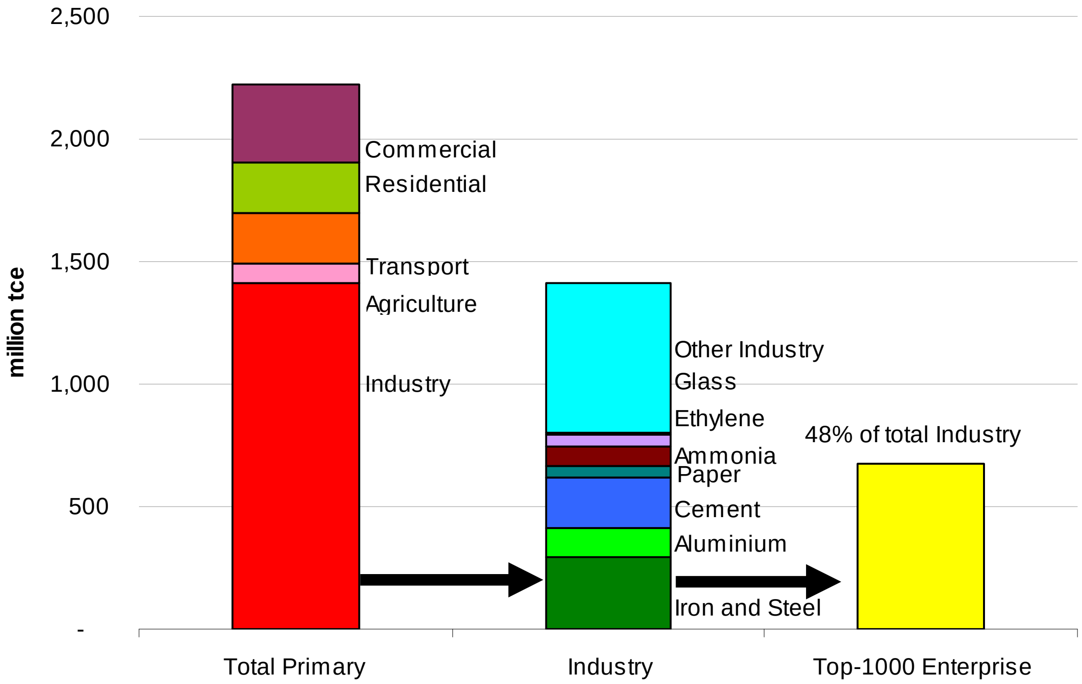

Figure B- 14 Industry is still the dominant energy-consuming sector in China and 7 major industries account for more than half of total industrial energy use

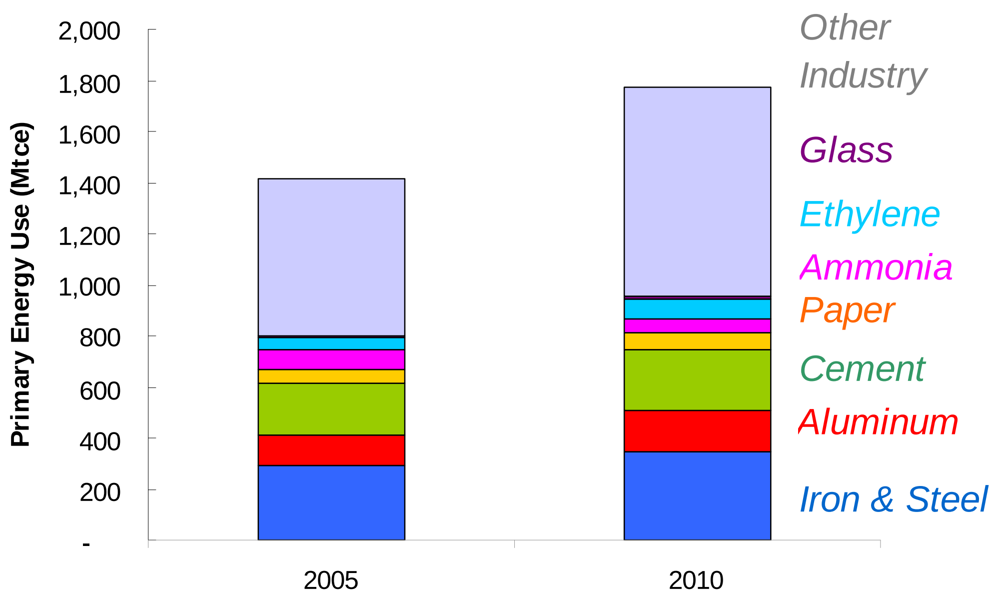

Figure B- 15 Industrial Energy Consumption by Subsectors

Transportation

Personal mobility and the movement of goods have increased significantly around the world, and the energy use for transportation has grown rapidly. Energy use in transportation consists of two activities: passenger travel and freight travel. A common indicator of travel activity is passenger-km for passenger travel and ton-km for freight travel (turn over). They are both shaped by the characteristics of stocks, and average traveled distance.

Turnover data series for rail, water, air and intercity highway road can be acquired from China Statistical Yearbooks and the Transportation Yearbooks for different years. However, such data does not exist for vehicles intra-city or intra-rural. Data on stocks and the usage pattern (such as average travel distance and the annual amount of the trips) were used to calculate the total turnover.

Total vehicle stocks were divided by registration type such as private and business. Private vehicle stock numbers were often miscounted as number of personal cars (family cars). Our analysis of the definition of this category suggests that it not only includes privately-owned cars, but also mini buses and most of the taxis. Existing data on car ownership per 100 household in urban and rural, and urban taxi shares were used to break the stock number down to each vehicle type. Stock of urban cars in our model is the sum up of urban private cars and government vehicles.

Total stock of urban buses and trucks were further subdivided into heavy duty, medium duty, light duty and mini buses. The stock breakout into the abovementioned subclasses of buses was made possible using ratios obtained from the He (2005).

Total number of civil motor vehicles is based on the statement in China's official plan (RNECSPC-Strategy Report) that these are projected to reach 110 million vehicles in 2020. The historical trend in China was used to extrapolate the future demand, and insights regarding infrastructure limitations were also taken into account based on historical trends in developed countries with similar density (such as Japan and Korea). Table B- 6 shows an example of the projected total vehicle stock breakout in passenger road vehicles. Ownership of private cars rises rapidly, with about 15% of AGR, leading to rapid growth in passenger transport energy use.

Table B- 6 Total Passenger Road Vehicle Stock Projection (million)

	2000	2005	2010	Growth Rate 2005-2010
Cars				
urban	4.5	9.2	18.6	15%
rural	0.6	1.3	2.6	15%
Taxis	0.8	1.1	1.5	6%
Buses[9]	1.9	5.2	9.5	13%
Motorcycles				
urban	14.8	24.2	32.2	6%
rural	22.9	42	59.6	7%

Average travel distance, intensities and fuel share for each type were calculated based on existing research (Rits, 2003). Although fuel economy values increase with better technology (see Table B- 7), energy use per passenger-kilometer is estimated to increase slightly after 2010 due to the projected decrease in vehicle occupancy rates from 2.5 in 2000 to 2.3 in 2020, which is attributed to increasing car stocks.

Table B- 7 Energy Intensity assumptions for urban/ rural cars and taxis (MJ/pass-km)?

	2000	**2005**	**2010**	**2015**	**2020**
Urban Cars					
Gasoline	1.2	1.2	1.17	1.22	1.22
Diesel	0.9	0.9	0.94	0.94	0.98
Gasoline Hybrid				0.54	0.57
Rural Cars					
Gasoline	1.2	1.2	1.17	1.22	1.22
Diesel	0.9	0.9	0.94	0.94	0.98
Gasoline Hybrid				0.54	0.57
Taxis					
Gasoline	1.2	1.2	1.17	1.22	1.22
Natural Gas	0.38	0.38	0.39	0.41	0.41
LPG	0.42	0.42	0.44	0.45	0.45

[9] Includes urban public buses and highway buses

Transportation energy consumption is expected to grow rapidly over the next five years, and this is reflected in the model analysis. Transportation comprised about 9.2% of total energy consumption in 2005, and according to the model results will rise to 10.1% in 2010. The annual growth rate is 7%. Figure B- 16 shows that the transport energy end use is currently dominated by freight transport, comprising 57% of the total in 2005, but its share will decrease to 54% in 2010, while the share of passenger transport increases. Road dominates the passenger energy use, accounting for 34% of the total transportation energy use. Cars and taxis, which are considerably more energy-intensive than public transport, together are responsible for 15.4% of energy use in transport sector in 2010 (Figure B- 17).

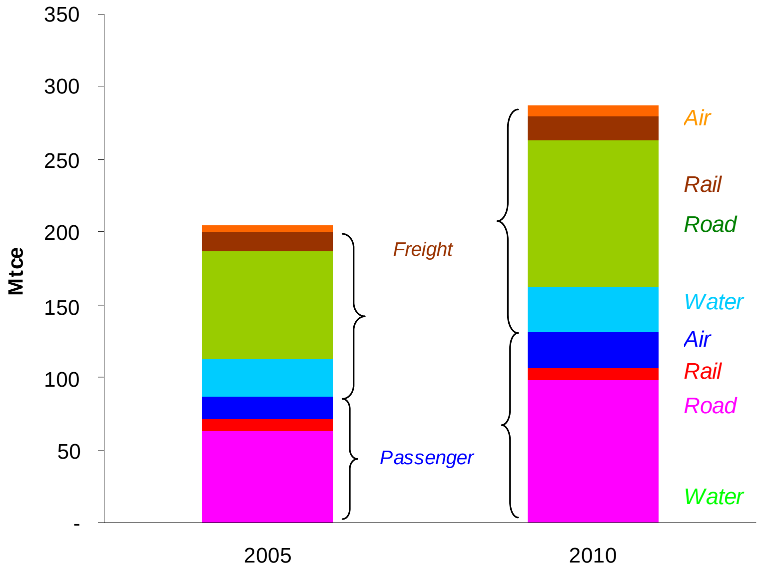

Figure B- 16 Passenger road transport will overtake freight in 2010

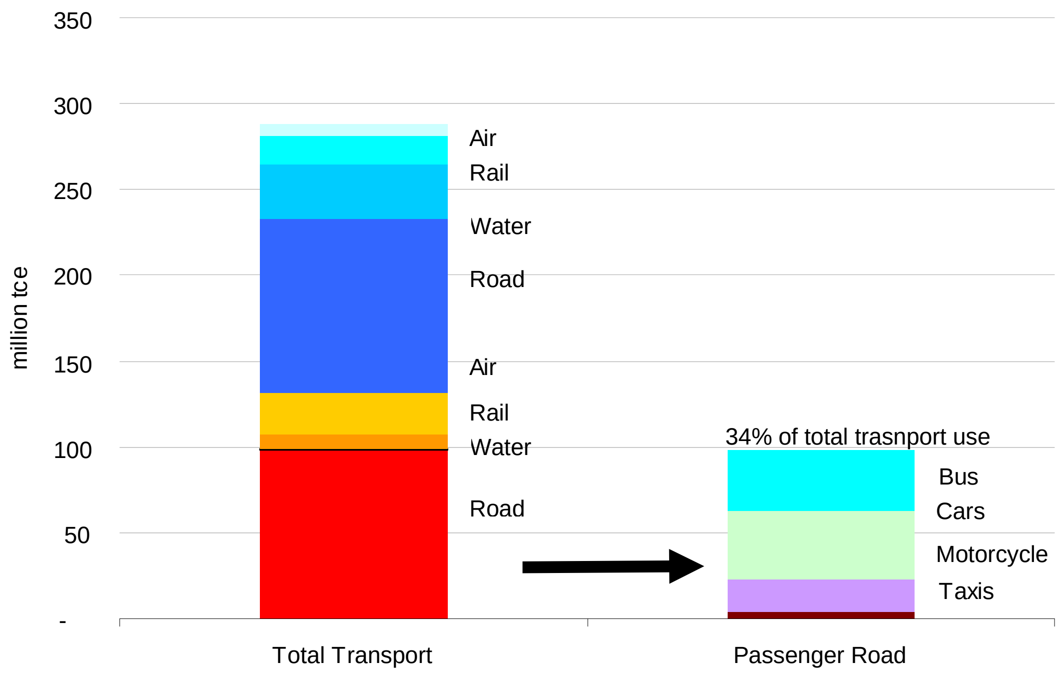

Figure B- 17 Energy Used in Passenger Road Transport

Agriculture

For the agricultural sector, energy use was modeled simply as the product of agriculture value added GDP and the energy use in agriculture per unit of GDP (economic energy intensity), given the total agriculture energy consumption from the statistic yearbooks. Historic agriculture energy consumption is available in the China Energy Databook (reference).

Although a 19961996 report on China's energy forecast to 2015 predicted a 0.94% decrease in energy intensity in agriculture (McCreary, 1996), we predict that the intensity will only decline by 1% annually due to the efficiency improvement based on historic trends (see Figure B- 18).

Figure B- 19 shows the result of the energy consumption projection in agriculture sector, which will rise from 79.2 Mtce to 86.6 Mtce during the period of 2005 to 2010 with the growth rate of 1.8%. Electricity and coal will still be the major energy sources in this sector.

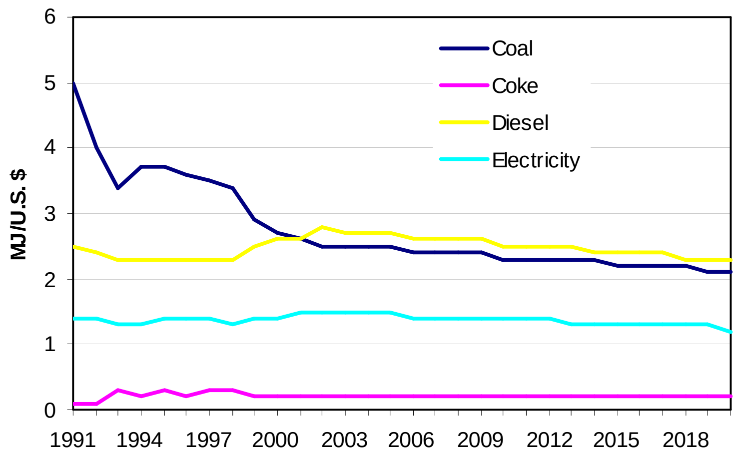

Figure B- 18 The Trend of Agriculture Value Added GDP Energy Intensity

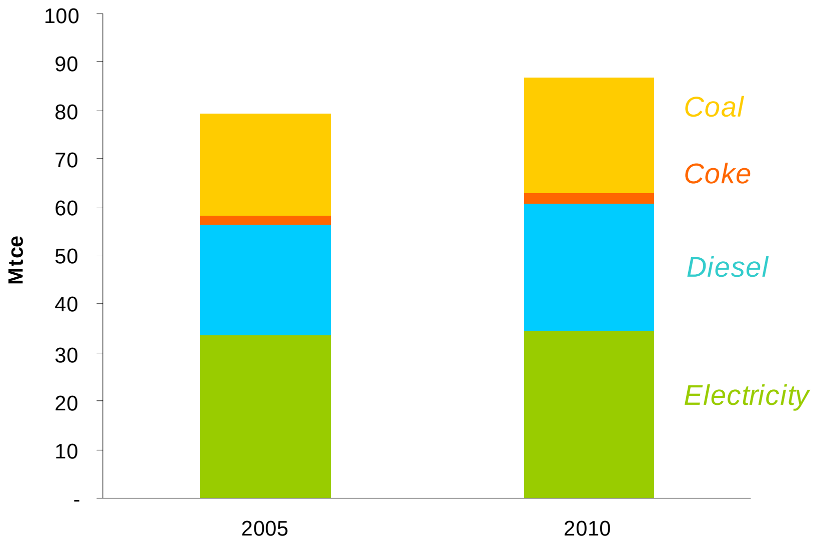

Figure B- 19 Agriculture Energy Use by Fuel

Transformation

The transformation sector includes the conversion and transportation of energy forms from the point of extraction of primary resources and imported fuels all the way to the point of final fuel consumption. As with demand analyses, alternative scenarios can be used represent different future transformation configurations reflecting alternative assumptions about policies and technologies.

The transformation sector model consists of a number of modules representing an energy conversion sector such as district heating supply, cogeneration, electricity generation, transmission and distribution, oil refining, coking, etc. For each module, numbers of processes that represent the individual technologies that convert energy from one form to another or transmit or distribute energy are created, such as groups of power plants. The technology data such as capacities, efficiencies, and capacity factors are specified. Coal mining and other transformation sectors are not incorporated in this exercise, assuming there is enough resource and capacities to produce the secondary fuels.

Power generation capacity and efficiency are all derived form the quantitative object stated in China's Strategic plan (Committee of RNECSPC, 2005)

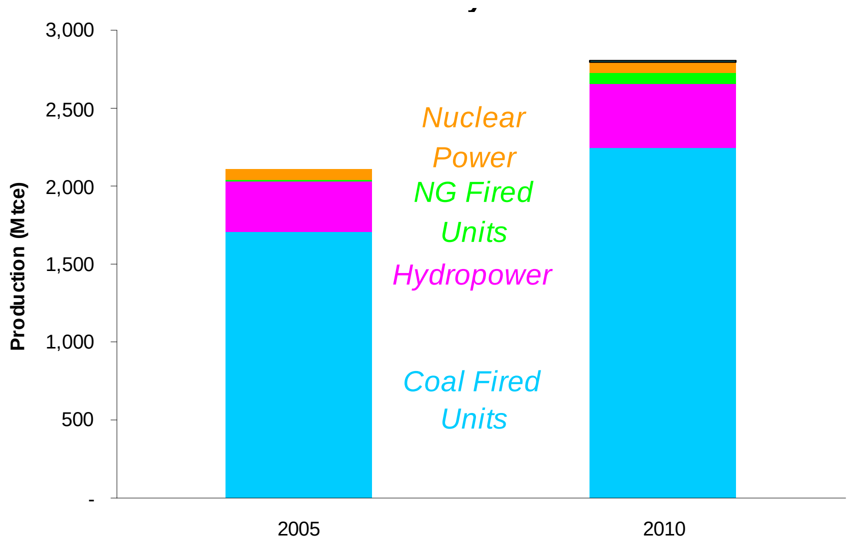

Figure B- 20 Electricity Generation Breakdown

Figure B- 20 shows the power generation production by type. Current plans call for installed hydropower capacity to be 240 GW, natural gas capacity to be 70 GW, nuclear capacity to be 30 GW and wind power to be 10 GW in 2020. Although the total installed capacity for more efficient power plants such as natural gas and nuclear power will grow faster than others, coal will still play a major role, accounting for 65% of the total capacity in 2020