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How Can China Lighten Up?
Urbanization, Industrialization and Energy Demand Scenarios

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Executive Summary

Urbanization has re-shaped China's economy, society, and energy system. Between 1990 and 2007 China added 290 million new urban residents, bringing the total urbanization rate to 45%. This population adjustment spurred energy demand for construction of new buildings and infrastructure, as well as additional residential use as rural biomass was replaced with urban commercial energy services. Primary energy demand grew at an average annual rate of 10% between 2000 and 2007. Urbanization's effect on energy demand was compounded by the boom in domestic infrastructure investment, and in the export trade following World Trade Organization (WTO) accession in 2001.

Industry energy consumption was most directly affected by this acceleration. Whereas industry comprised 32% of 2007 U.S. energy use, it accounted for 75% of China's 2007 energy consumption. Five sub-sectors accounted for 78% of China's industry energy use in 2007: iron and steel, energy extraction and processing, chemicals, cement, and non-ferrous metals. Ferrous metals alone accounted for 25% of industry and 18% of total primary energy use. The rapid growth of heavy industry has led China to become by far the world's largest producer of steel, cement, aluminum, and other energy-intensive commodities. However, the energy efficiency of heavy industrial production continues to lag world best practice levels.

This study uses scenario analysis to quantify the impact of urbanization and trade on industrial and residential energy consumption from 2000 to 2025. The BAU scenario assumed 67% urbanization, frozen export amounts of heavy industrial products, and achievement of world best practices by 2025. The China Lightens Up (CLU) scenario assumed 55% urbanization, zero net exports of heavy industrial products, and more aggressive efficiency improvements by 2025. The five dominant industry sub-sectors were modeled in both scenarios using a LEAP energy end-use accounting model.

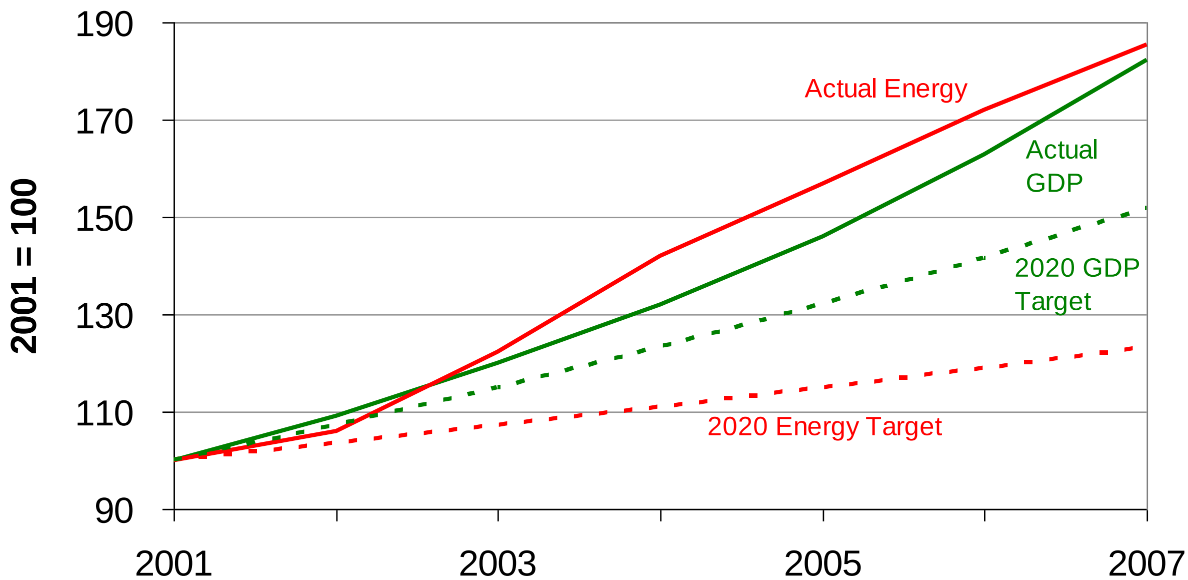
The results of this study show that a CLU-style development path would avoid 430 million tonnes coal-equivalent energy use by 2025. More than 60% of these energy savings would come from reduced activity and production levels. In carbon terms, this would amount to more than a billion-tonne reduction of energy-related carbon emissions compared with the BAU scenario in 2025, though the absolute level of emissions rises in both scenarios. Aside from the energy and carbon savings related to CLU scenario development, this study showed impending saturation effects in commercial construction, urban appliance ownership, and fertilizer application. The implication of these findings is that urbanization will have a direct impact on future energy use and emissions—policies to guide urban growth can play a central role in China's efforts to mitigate emissions growth.

1. Introduction

1.1 Overview

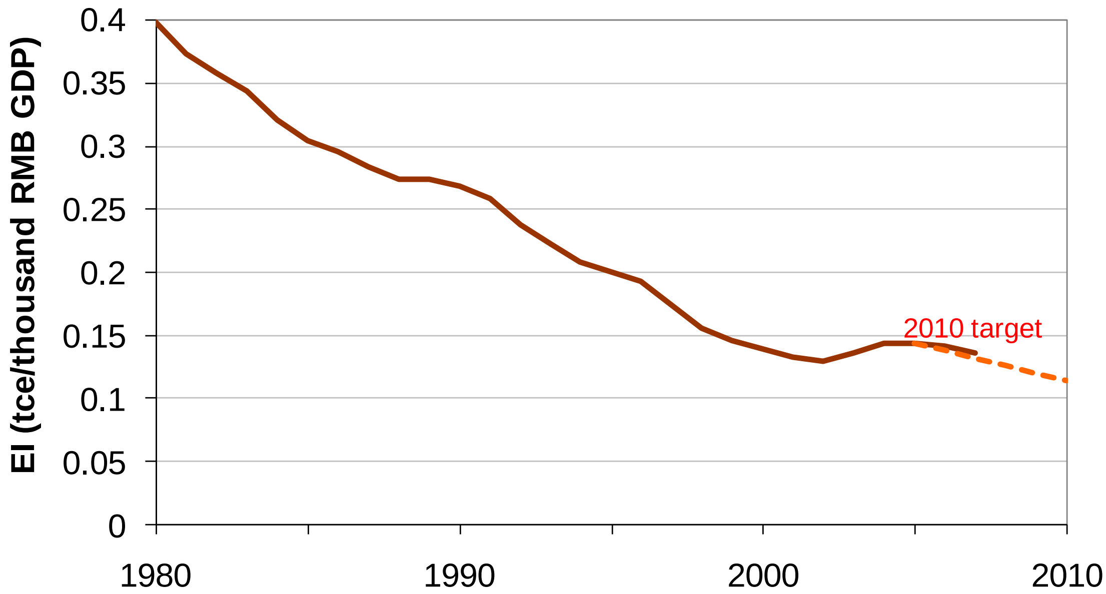
After acceding to the World Trade Organization in December 2001, China entered a highly energy-intensive growth phase fueled by the interlinked processes of industrialization and urbanization. This recent surge of energy consumption was driven largely by structural change in the economy, specifically a steady shift toward heavy industrial production of materials such as steel, cement, and chemicals. Although these energy-intensive industrial sectors have continued to improve their overall efficiency, production volume has grown more quickly and concentrated China's energy consumption and economic growth in the industrial sector. Heavy industry-led growth reversed the post-reform trend of steadily improving energy efficiency, as illustrated by the energy intensity of GDP growth.

Figure 1: China Actual and Targeted Energy Use and GDP, 2001-2007



The post-2001 surge of industrial growth is a story of urbanization and rising export-oriented production. Rural-urban migration has created large demand for buildings, infrastructure, and energy services for new cities. Urban energy use is compounded by international demand for energy-intensive Chinese exports as China's WTO accession cemented its role as global factory. The resulting recent energy consumption growth in China has reversed a twenty-year trend of declining energy use per unit GDP. Within this reform-period historical context, the 20-percent energy intensity reduction target is in fact less aggressive than the 30-year trend of energy intensity reductions as shown in Figure 2.

Figure 2: Historical and Targeted Energy Intensity of GDP Growth, 1980-2010



In light of these pressing trends, this study examines the energy and emissions implications of China successfully returning to its earlier path of energy efficiency improvements and diminishing the size of its heavy industrial footprint through analysis of the physical drivers of these sectors. It specifically uses scenario analysis of urbanization and trade to elucidate the energy and emissions implications of less industry-intensive development between 2008 and 2025. The baseline or business-as-usual scenario assumes a continuation of the industry-intensive growth that defined China's post-2001 surge in energy consumption with constant energy-intensive industrial exports as well as a fast-growing urbanization rate of 65% by 2025. Long-term trends of improved energy efficiency within sectors are expected to continue in the BAU scenario along with ongoing substitution of more efficient fuels. To explore a less export-intensive trajectory, the China Lightens Up (CLU) scenario assumes that urbanization reaches 55% in 2025 and that net exports of energy-intensive industrial products are eliminated by 2025. In order to quantify a less energy-intensive growth path, the CLU scenario also includes accelerated improvement of industrial energy efficiency, achieving world best practice for most industrial sub-sectors before 2025. CLU scenario outcomes would indicate successful implementation of efficiency programs such as the 2010 20% energy intensity reduction target.

The roles of urbanization and industrialization as major drivers of energy consumption are reviewed and then followed with an in depth discussion of the basis for the model and scenario assumptions.

1.2 Urbanization and Energy Implications

For the past three decades, China has witnessed rapid urbanization with growing shares of urban residents and the recent addition of 290 million new urban residents between

1990 and 2007. This urbanization has been associated with rapid population growth in existing cities and the transformation of rural areas into smaller, second- and third-tier cities with infrastructural and construction expansions.

1.2.1 Urbanization Process and Population Changes

The growth of urbanization in recent years has been especially notable given that rural-urban migration was previously restricted by a strict household registration, or *hukou*, system. Under the Chinese *hukou* system, rural residents were discouraged from migrating to urban areas with restricted access to housing, employment, foodstuff, fuel, education and healthcare. The onset of China's economic reform and opening in the early 1980s helped relax the *hukou* system and has subsequently given rise to several different models of urbanization. Specifically, urbanization in China has occurred because of rural-urban migration of workers as well as localized transformation of rural areas. Different regional urban transformation processes can be traced back to diverse local conditions, geography and government reforms. For example, in Southeastern coastal regions surrounding the Pearl River Delta, government-led reform through township village enterprises and special economic zones stimulated investment from Chinese Diaspora and foreigners alike.[1] The resulting regional economic growth, particularly in construction and manufacturing sectors, attracted the migration and in some cases, settlement of rural workers in increasingly urbanized areas. The 2000 national census found that 65% of all temporary migrants moved to urban areas out of self-initiative for pursuing economic activity in industrial, commercial or trade sectors. Compared to the 1990 census, a higher reported proportion of migrants moving to join their family suggest that more rural-urban migrants are bringing their families to cities.[2]

In other regions like Fujian province where foreign investment has only recently began trickling in, local investment from joint-household and township village enterprises were encouraged with supporting local government policies. In turn, in situ urbanization occurred as industrial development helped transform small towns into urban centers with concentrations of industry.[3] In cases like the Sunan area in Jiangsu Province, a central city like Suzhou in a predominantly rural region may even take the lead in urban development by setting up a network of counties. With the decentralization and transfer of administrative power and resources from the state to leading cities, cities like Suzhou can play a more active role in initiating basic infrastructure projects and establishing economic linkages with rural counterparts through subcontracting, technology transfers and production cooperation.[4] Urban transformation of the rural landscape thus followed

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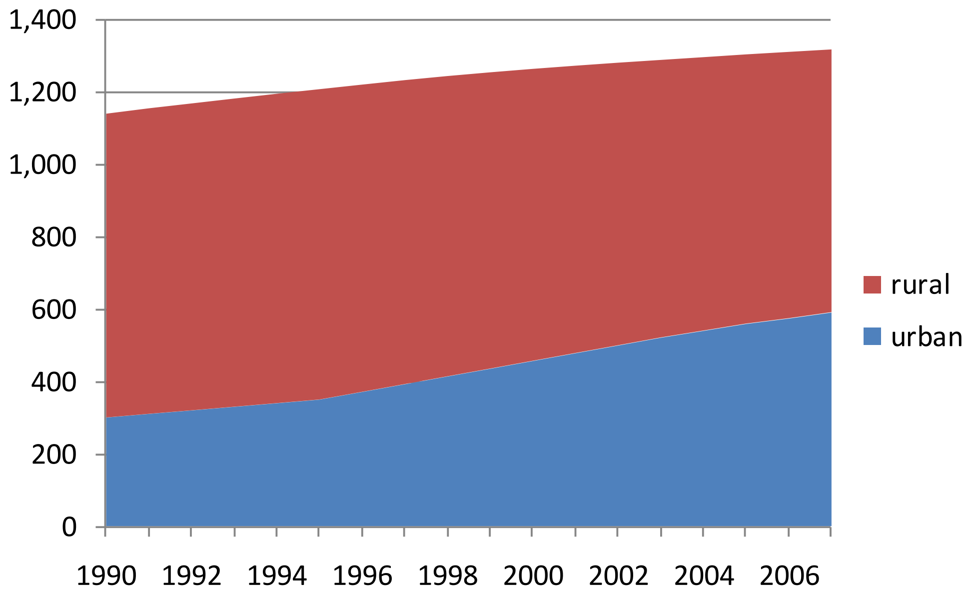
1 Smart, A. and G. Lin. 2007. "Local capitalisms, local citizenship and translocality: rescaling from below in the Pearl River Delta Region, China." International Journal of Urban and Regional Research 31 (2): 280-302.
2 Fan, C. 2007. "Migration, Hukou, and the City." In Yusuf and Saich (eds) China Urbanizes: Consequences, Strategies and Policies. Washington, DC: The World Bank.
3 Zhu, Y. 2000. "In situ urbanization in rural China: case studies from Fujian Province." Development and Change 31: 413 – 434.
4 Tang, W.S. and Him Chung. 2000. "Urban-Rural transition in China." In Li and Tang (eds) China's Regions, Polity and Economy: A Study of Spatial Transformation in the Post-Reform Era. Hong Kong: Chinese University Press.

as towns on the peripheries of leading cities also experienced rapid growth and development.

In terms of population, the urban population growth rate has remained significantly higher than both the rural and total population growth rates. Since the 1980s, the annual growth rate of urban population has been positive and over 2% with a recent high of 6.1% in 1996 while the total population growth rate has remained relatively flat. Of the total urban population growth rate, studies have estimated that as much as 60 to 80 percent can be attributed to net rural-urban migration versus 20 to 40 percent from natural urban population growth.[5] The rural population annual growth rate, in contrast, became negative in 1996 and has remained negative in recent years. As a result, the urban population share has quickly risen from 26% in 1990 with 300 million to 45% in 2007 with 590 million residents (Figure 3).

Figure 3: Urban and Rural Population Shares, 1990 - 2007



Source: NBS

Urbanization and its related processes of net rural-urban migration also have important demographic implications, particularly in terms of the aging population. The U.N. projects that the average proportion of population aged 65+ will quickly climb from 2005 level of 7.6% to 13.4% by 2025.[6] There are, however, important urban and rural differentials in aging trends. While previous studies projected that the share of urban population 65+ will be much higher at in urban areas than in rural areas due to lower

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[5] Zhang, K. and S. Song, 2003, "Rural-urban migration and urbanization in China: Evidence from time-series and cross-section analyses." *China Economic Review* 14: 386 – 400. See also United Nations Population Fund, 2007, "State of World Population 2007: Unleashing the Potential of Urban Growth." Available online: http://www.unfpa.org/swp/swpmain.htm

[6] United Nations Population Division of the Department of Economic and Social Affairs, 2008. "World Population Prospects: The 2008 Revision." Available at: http://esa.un.org/unpp.

urban mortality and fertility rates, the continued shift of a younger "floating population" into urban areas could reverse this trend.[7] In fact, a new study finds that once net rural-urban migration is accounted for, aging in rural China would occur much faster and sooner with similar proportions of population aged 65+ between urban and rural areas by as early as 2009.[8] In essence, the aging population would not have a significant effect on urbanization if urban areas continue to experience the influx of younger migrant workers with families that has occurred in recent years.

However, the ambiguous energy and carbon implications of aging population trends found in recent studies suggest that aging would likely have complex effects on energy consumption. On the household level, a study of cross-sectional U.S. energy consumption trends from 1993 to 1994 found that residential energy use rises consistently with age while transportation energy use peaks at age 51-55 and then declines.[9] On the macroeconomic level, studies have also found differing results. On one hand, recent studies of aggregate data in the European Union have found that an increase in the proportion of population aged 65+ corresponds to an increase in energy consumption, all else equal.[10] In theory, this increase could be attributed to the loss of economies of scale in household energy consumption with aging since older populations tend to live in households of smaller sizes. It could also be due to the influence of changing age structure on economic structure since a expanding proportion of elder population may affect the composition of production and consumption, residents' spatial distribution, transportation infrastructure and other social services.[11] On the other hand, simulations conducted using Population-Environment-Technology Model, a general equilibrium growth model, projects an overall negative combined effect of aging and changes in household size on carbon emissions, with potential emission reductions of 20% compared to reference scenario by 2100.[12]

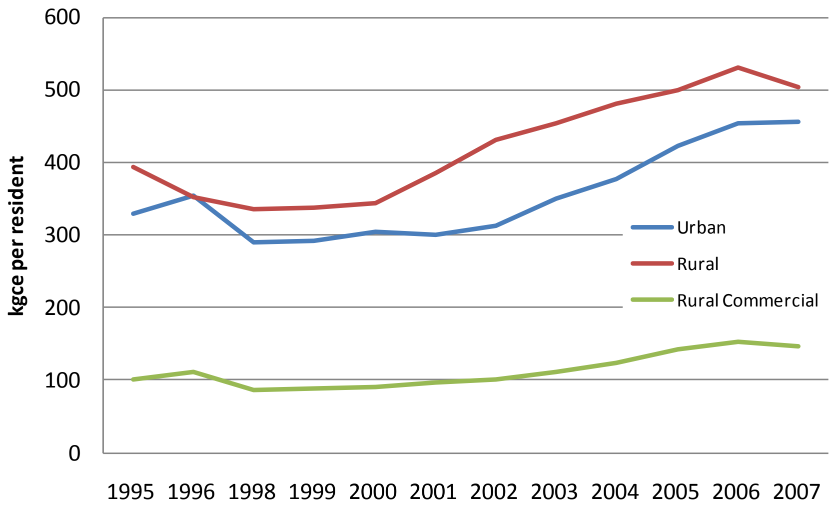
1.2.2 Urbanization and Residential Energy Implications

With urban population growth, urban demand for a variety of energy services like energy-intensive climate control, lighting, appliances, automobiles and long-distance transportation networks is expected to rise. This has been reflected in part by the prevailing disparity between urban and rural commercial energy consumption, as seen in Figure 4 below. For example, per capita primary residential consumption of commercial energy including heat for urban households has been nearly three times that of rural

[7] Chen, F. and G. Liu. 2009. "Population Aging in China". In: Uhlenberg, P. (ed) International Handbook of Population Aging. Springer Netherlands.
[8] Wang F, Mason A. 2007. "Population aging in China: Challenges, opportunities, and institutions." In: Zhao Z, Guo F. (eds) Transition and challenge: China's population at the beginning of the 21st century. Oxford: Oxford University Press.
[9] O'Neill, B. and B. Chen. "Demographic Determinants of Household Energy Use in the United States." Population and Development Review 28: 53-88.
[10] York, R. 2007. "Demographic trends and energy consumption in European Union Nations, 1960 – 2025." *Social Science Research 36*: 855-872.
[11] York, 2007.
[12] Dalton, et. al. 2007. "Demographic Change and Future Carbon Emissions in China and India." Presented at the Population Association of America Annual Meeting in New York.

households since 1995. Yet if non-commercial biomass energy consumption is included, total per capita energy consumption for rural households remained higher than urban.

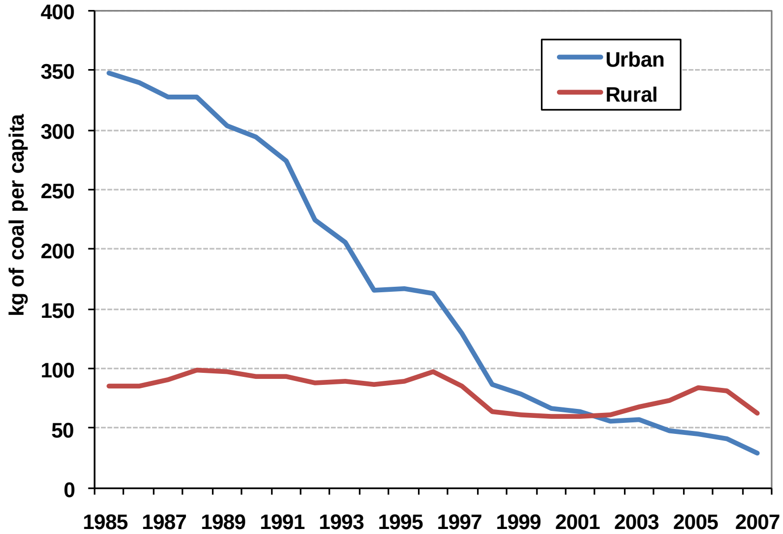
Figure 4: Urban and Rural Residential Per Capita Energy Consumption



Source: NBS

Besides an urban-rural disparity in terms of per capita residential energy consumption, there are also major differences in urban versus rural household patterns of consumption. In terms of primary energy sources, urban households are increasingly substituting solid fuels with natural gas and electricity while rural households continue to rely on solid fuels and biomass with only small shares of electricity and LPG. The subsequent divergent fuel transition patterns are evident in the changing coal consumption trends between urban and rural households. Figure 5 shows that urban residential per capita coal consumption has dramatically decreased at an annual average rate of 9.2% since 1985 whereas rural residential coal consumption has remained fairly steady with some fluctuations.

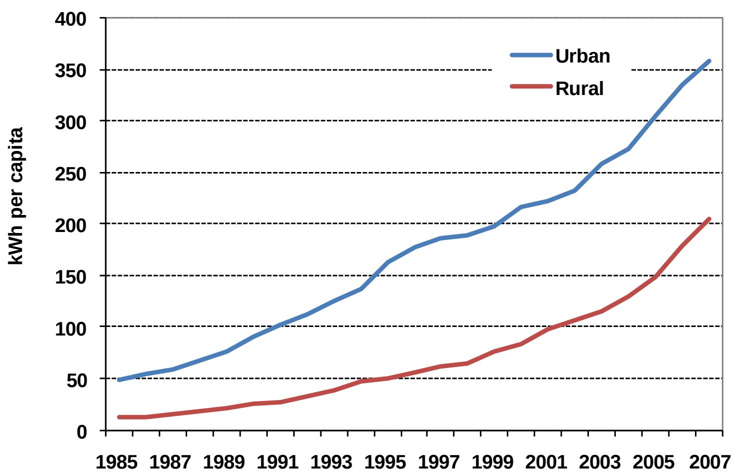
Figure 5: Residential Per Capita Coal Consumption



Source: NBS

Likewise, the urban-rural energy disparity is also readily apparent in residential electricity consumption. As early as 1996, urban households in developed regions like Beijing, Shanghai and Guangdong were using three times more electricity than rural households in less developed regions like Guizhou, Yunnan and Qinghai. By 2006, urban households still used on average doubled the electricity of rural households on a per capita basis. For electricity, greater urban consumption has largely been driven by the acquisition of more energy-consuming durable goods (e.g., appliances), demand for heating and cooling, and rising use of information technology and its related products and equipment. In particular, urban residential per capita electricity consumption grew at a faster average rate of nearly 13% compared to rural average growth rate of 6% (Figure 6).

Figure 6: Residential Per Capita Electricity Consumption

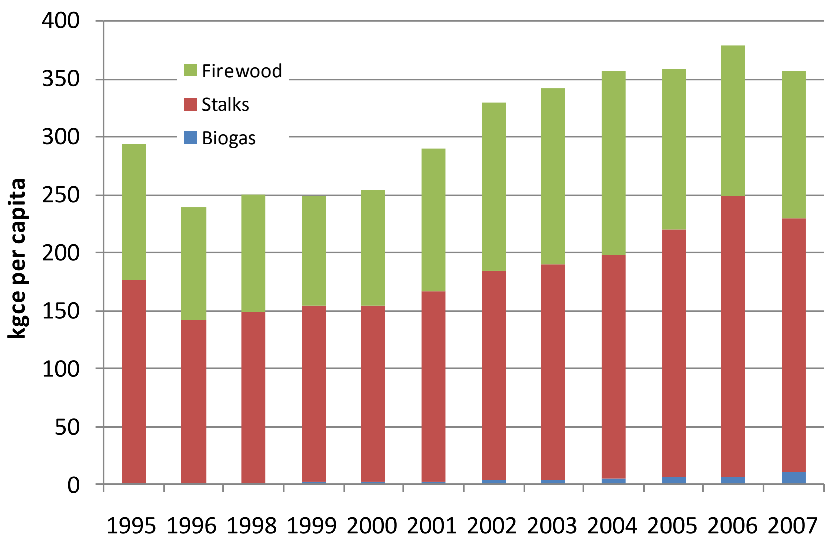


Source: NBS

Besides electricity, urban households are increasingly using liquid petroleum gas and natural gas for its energy consumption while rural households have only recently started using LPG. While rural residents did not start using LPG until the mid-1990s, urban residents started using LPG and natural gas nearly a decade earlier. By 2005, only 12% of rural residents used LPG. More recently, urban residents are beginning to use more natural gas in addition to LPG but natural gas has yet to take hold in the rural residential sector. As a result, urban residents' natural gas and LPG consumption at 33 million tonnes of coal equivalent (Mtce) was more than six times of the LPG consumption of rural residents at a mere 5 Mtce in 2006.

The use of non-commercial biomass energy sources such as firewood, stalks and biogas continues to dominate rural household energy supply. However, non-commercial biomass energy consumption is often overlooked since non-commercial energy sources are not included in aggregate residential energy data. Yet over 60% of rural residents continue to rely on traditional biomass fuels to meet their cooking and heating needs.[13] As a result, per capita biomass energy consumption for rural residents has steadily increased since the late 1990s, with notable growth in biogas and stalks consumption (
Figure 7).

Figure 7: Rural Residential Per Capita Biomass Consumption



Source: NBS

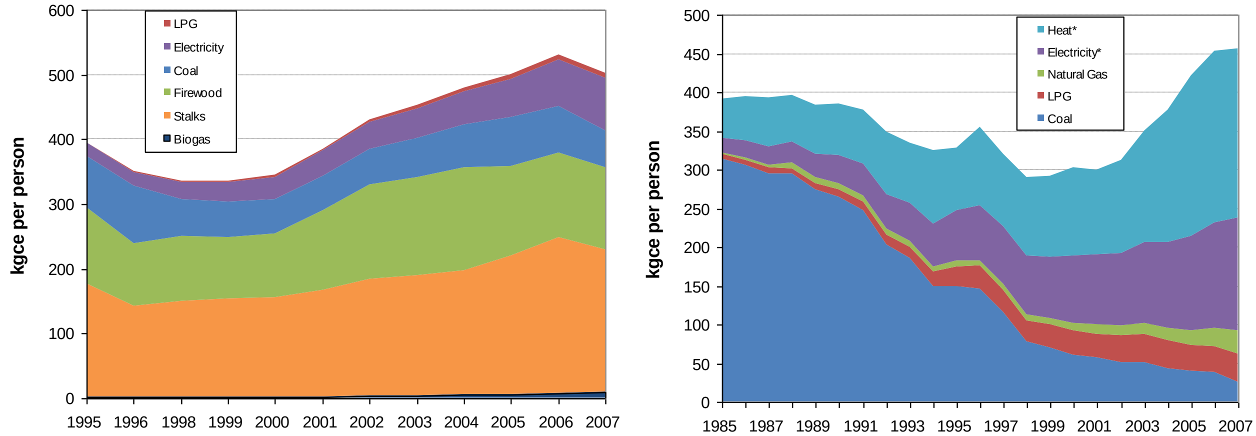
1.2.3 Fuel Transition and Carbon Implications

The divergent energy consumption trends between urban and rural residents imply that all the rural energy services provided by biomass will have to be provided by commercial energy with the rural-urban population shift. This suggests a significant increase in

[13] Pachauri, S. and L. Jiang. 2008. "The household energy transition in India and China." *Energy Policy* 36: 4022-4035.

demand for commercial energy, as non-commercial biomass energy consumption made up 70% to 75% of total annual rural energy consumption between 1995 and 2007. Moreover, total per capita rural energy use has been higher than urban, but is of lower quality due to the heavy reliance on biomass energy (Figure 8).

Figure 8: Rural and Urban Per Capita Energy Use by Fuel



Note: X-axis different for rural and urban per capita energy figures due to lack of rural data prior to 1995.

Source: NBS

Table 1: Rural Energy Shares

	1995	2000	2005
LPG	0.14%	0.8%	1.2%
Electricity	5.1%	9.8%	12%
Coal	20.4%	15.6%	15%
Firewood	29.5%	28.9%	27.6%
Stalks	44.5%	44.3%	42.8%
Biogas	0.32%	0.6%	1.3%

Table 2: Urban Energy Shares

	1995	2000	2005
Heat*	24.6%	37.6%	49.1%
Electricity*	20.1%	28.9%	29.2%
Natural Gas	2.2%	3.1%	4.4%
LPG	7.5%	10.6%	7.7%
Coal	45.5%	19.9%	9.5%

Note: Heat and Electricity given in primary values.

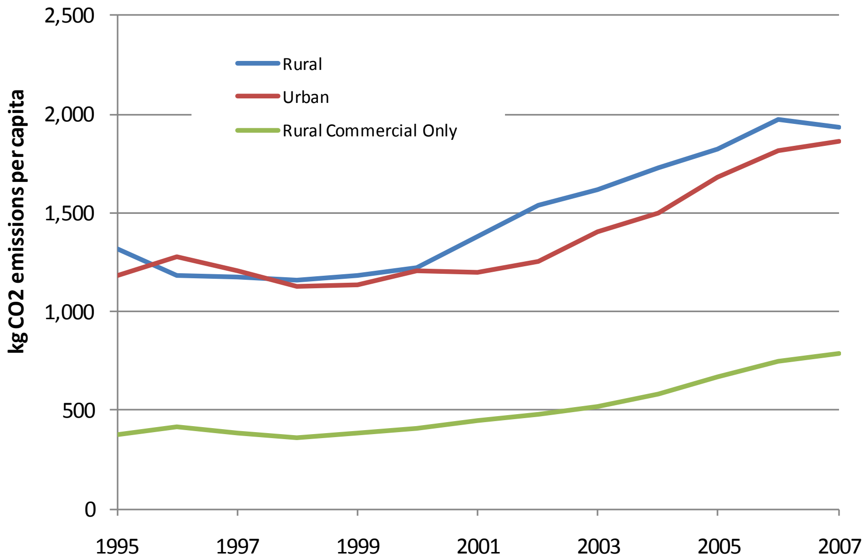
For urban residents, coal end-use consumption has plummeted since the late 1980s with rapidly decreasing shares of total urban residential energy use and residents are increasingly relying directly on heat for its heating needs. For other processed energy sources, 2004 household surveys revealed that 91% of urban versus 54% of rural population used electricity while 61% of urban versus only 12% of the rural population used LPG.[14] This is supported by the increasing but still relatively small share of electricity in rural residential energy use over the last decade and the growing urban share of electricity to nearly 30% of urban residential energy use by 2005.

With rising per capita energy use amongst both urban and rural residents, the associated carbon emissions have increased as well. Using default emission factors from the 1996

[14] Pachauri and Jiang, 2008.

revision of IPCC guidelines and China-specific energy content for each fuel, the estimated per capita carbon emissions for urban and rural residents are shown in Figure 9.

Figure 9: Per Capita Carbon Emissions for Residential Energy Use



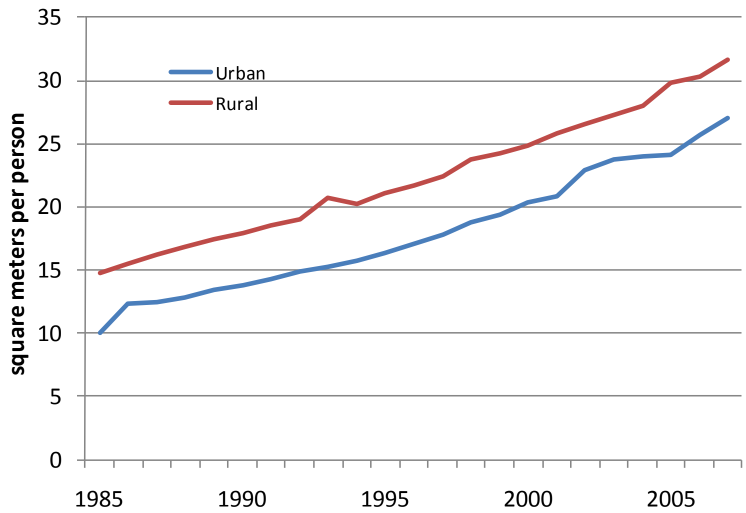
Source: calculated using IPCC default emission factors based on national energy use data.

In general, both rural and urban per capita emissions from residential energy use have been increasing since the late 1990s. From 1996 to 1998, there was a slight reduction in urban per capita emissions due to the sharp decline in residential coal use but emissions have since risen with growing urban demand for heat and electricity. Urban per capita carbon emissions were higher than rural in 1996 and 1997 but have since remained below rural when biomass combustion is accounted for. While the use of biomass is neutral if carbon emissions are taken up in the following year's growth cycle, emissions are included because over-harvesting would create a net carbon gain. If biomass emissions are not included, then urban per capita emissions are two to three times higher than rural per capita emissions. Urbanization and the greater commercial energy demand will thus have important carbon implications.

1.2.4 Rising Energy Intensity of Residential Floor Space

Greater opportunities for economic mobility and increased urbanization have increased urban demand for residential floor space with declining urban household sizes. In China, the surge in new residential buildings has taken place after economic and housing reforms separated employment from housing to create private demand for housing. As a result of this construction boom, residential floor space in both absolute and per capita terms has increased dramatically in both urban and rural regions, through starting points and growth rates differ. Historically, rural per capita residential building space has been higher due to a much larger residential building stock that was nearly five times that of urban building stock in 1985. In the last two decades, rural per capita residential floor space has doubled from 15 to 32 m^2 (Figure 10). This growth has been driven primarily by a doubling in the stock of absolute residential floor space and small overall decrease in rural population. At the same time, urban per capita floor space has grown at similar speeds from a lower starting point of 10 m^2 per person to 25 m^2 per person in 2005. Although urban population has grown considerably during this period, this floor space growth is attributed more to a six-fold increase in total urban stock of residential building space.

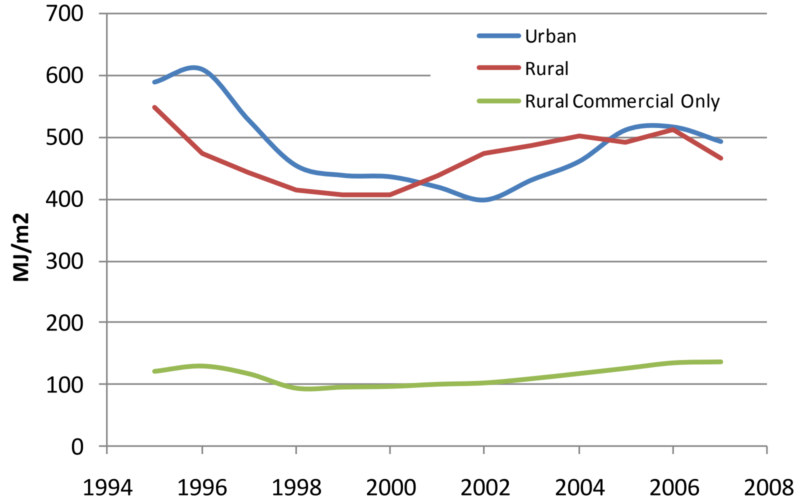
Figure 10: Per Capita Residential Floor Space



Source: NBS

With increased residential floor space, changes in the energy intensity of residential building space in terms of MJ energy consumed per square meter can also be expected. As seen in Figure 11 below, rural energy intensity in terms of commercial energy has actually remained fairly constant in the low 100s MJ/m^2. Urban residential building energy intensity, in contrast, greatly decreased by a factor of three since 1985 as increases in floor space outpaced rising energy use and only began increasing recently in 2003 as residential energy consumption continues to soar.

Figure 11: Energy Intensity of Residential Floor Space



Source: NBS

Although the commercial energy intensity appears much higher for urban than rural residences, urban and rural total energy consumption per square meter of residential building space are actually much closer in magnitude when rural biomass energy consumption is included. Rather than 200+ MJ/m^2 difference between urban and rural residential buildings in the same year, the difference is narrowed to less than 100 MJ/ m^2 for nearly every year from 1995 to 2005. Moreover, like urban residential building intensity, rural residential building energy intensity also began to increase in early 2000s after a short period of decline. Urbanization has therefore been a key driver of increased commercial energy consumption both in terms of residential fuel switching and rising energy consumption per unit of residential floor space.

1.3 Post-2001 Industrialization

After its 2001 WTO accession, China entered a highly energy-intensive growth phase marked by a steady shift towards heavy industrial production and exports of materials such as steel, cement, aluminum and nitrogenous fertilizers. While overall efficiency has improved in many of these energy-intensive industrial sectors, production volume has grown at a faster pace with China becoming the world leader in cement, aluminum, iron and steel, ammonia and nitrogenous fertilizer production.

In 2006, China was responsible for one-third of global steel, aluminum and nitrogenous fertilizer production and nearly half of global cement production (Table 3). This far outpaces U.S. production with global production shares below 10% for all these industrial products. China's new role is related to notable rising production trends since 2001, with cement production increasing six-fold from 2003 to 2007 and fertilizers increasing five-fold from 2002 to 2007. To a lesser extent, production of pig iron and aluminum also more than doubled from 2002 to 2007, while copper manufactured goods increased three-fold.

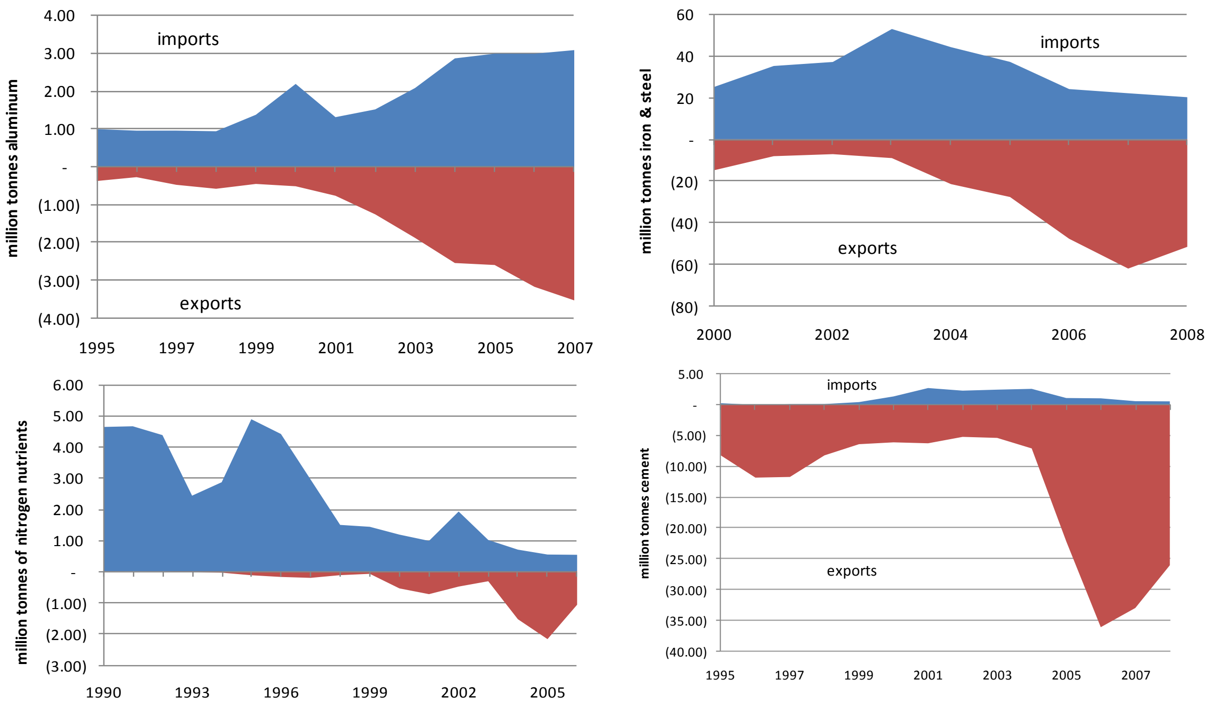
Table 3: 2006 Chinese and U.S. Shares of Global Production

	Steel	Cement	Iron Ore	Copper	Aluminum	Nitrogen Fertilizers	Ethylene
China	34%	47%	21%	17%	32%	32%	6%
U.S.	8%	4%	4%	7%	7%	7%	25%

Source: USGS Mineral Information Commodity Statistics and Information.

As a world leader in industrial production, China has dramatically increased exports of industrial materials such as aluminum, cement, iron and steel and nitrogenous fertilizers since 2001 (Figure 12). In 2007, China was a net exporter of cement, iron and steel, aluminum and nitrogenous fertilizers.

Figure 12: Trade Activity of Major Industrial Products



Source: UN Comtrade Database.

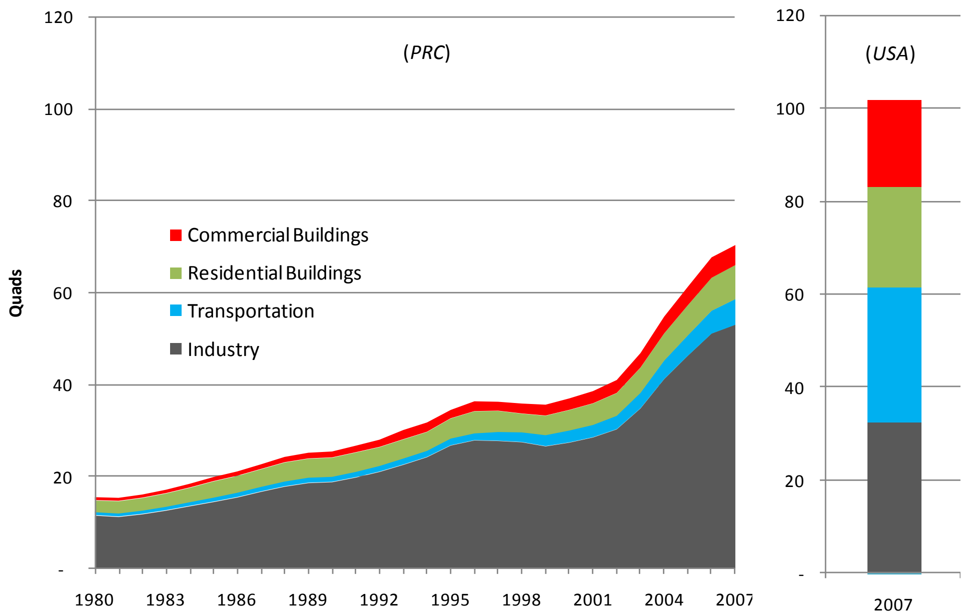
While cement exports escalated from 2005 to 2008, exports nevertheless remained a very small share of total production at only 2 percent, whereas 98 percent of cement production was used to meet domestic consumption in 2008. Similarly, exports composed of only 11 percent and 7 percent of Chinese steel and nitrogenous fertilizer production, respectively, while aluminum composed of a larger share of production at 29 percent. Therefore, China's WTO accession and trade has contributed to heavy industrialization in the last decade but for some materials like cement and steel, urbanization and infrastructure construction appears to be key drivers of domestic consumption.

1.3.1 Industrial Energy Use Trends

Although industry has always been a large energy user in China, its share of total primary energy consumption surged even higher with the post-2001 rise in heavy industrialization. While energy consumption shares by transportation, commercial and residential building sectors have remained steady or even declined, the industrial share actually grew by 8 percentage points from 64% in 2001 to 72% in 2007. This corresponds to a doubling of industrial primary energy consumption from 27 Quads to 53 Quads (

Figure 13). Chinese industries' significant share of primary energy consumption is even more notable when compared to the small U.S. industrial share of 32% in 2007. Unlike the U.S., China's energy consumption is clearly driven by the industrial sector and industry will play a crucial role in determining future energy use trends.

Figure 13: Primary Energy Consumption by Sector

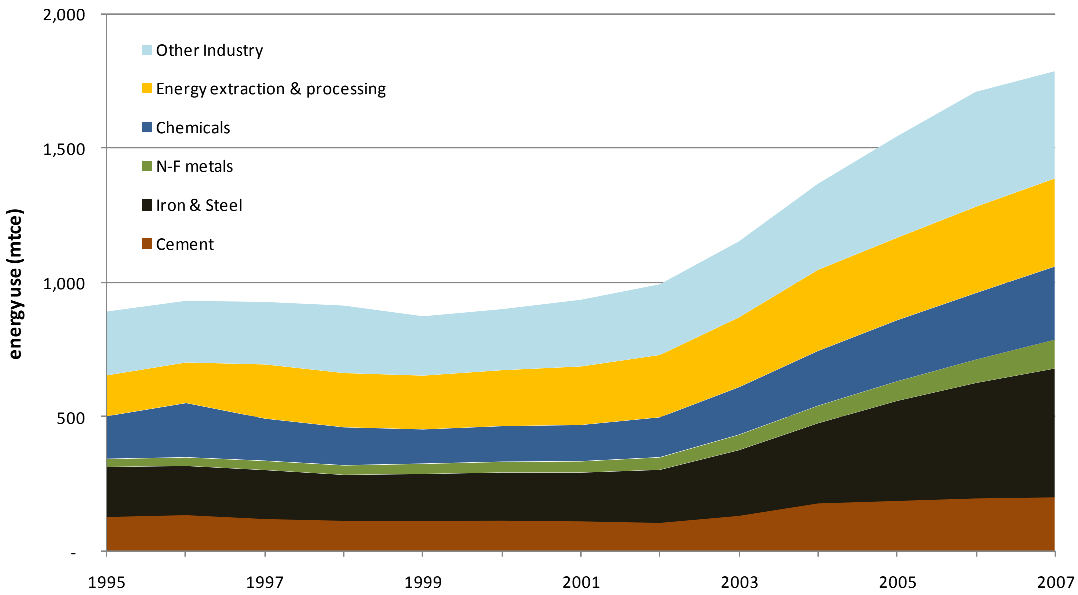


Source: NBS; EIA, AER 2007. China industry includes agriculture and construction.

Besides energy consumption, China's industrial sector also accounts for the majority of China's commercial energy-related CO_2 emissions. Since 2000, industry has accounted for at least 71% of total CO_2 emissions from coal, natural gas, oil and electricity use and this share has since increased to 73.2% in 2007. Compared to the U.S. industrial share of 28% in 2006, China's significantly higher industrial share of CO_2 emissions highlights the country's heavy industrialization based on coal as a transitional economy undergoing rapid development.

Figure 14 shows that of the rise in industrial energy consumption and related CO_2 emissions in the last decade, the majority of it can be attributed to several key industrial sub-sectors including cement, iron and steel, non-ferrous metals, chemicals and energy extraction and processing. In 2007, for example, 72% of total energy use in primary terms was in these five sub-sectors with the remaining 28% in other industries such as glass, paper and manufacturing sectors. Of these five sub-sectors, sharp increases in production and exports since 2001 have fueled a growth in the iron and steel sub-sectors' relative share of energy consumption. From 2000 to 2007, iron and steel sub-sector's share of total industrial energy consumption grew from 24% to 31%. The non-ferrous metal sub-sector's share also grew from 4% to 5.6% while the shares of other sub-sectors remained relatively constant.

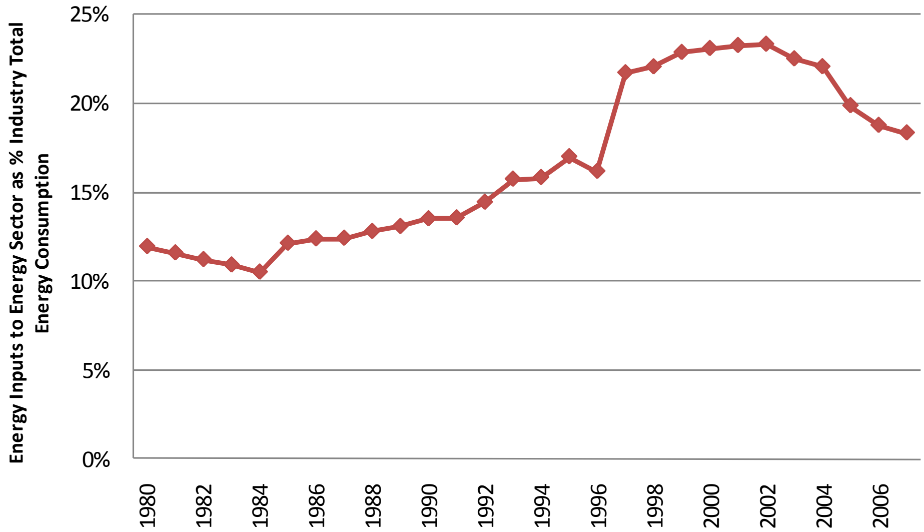
Figure 14: Industrial Energy Use by Sub-sector



Source: NBS.

Moreover, energy extraction and processing is accounting for an increasingly larger share of industrial energy use. As seen in Figure 15, energy inputs to the energy sector's share of total industrial energy consumption has generally been increasing since the mid-1990s and only recently began decreasing in 2002 as energy use in other industrial sectors increased their share of the total.

Figure 15: Energy Extraction Share of Energy Consumption

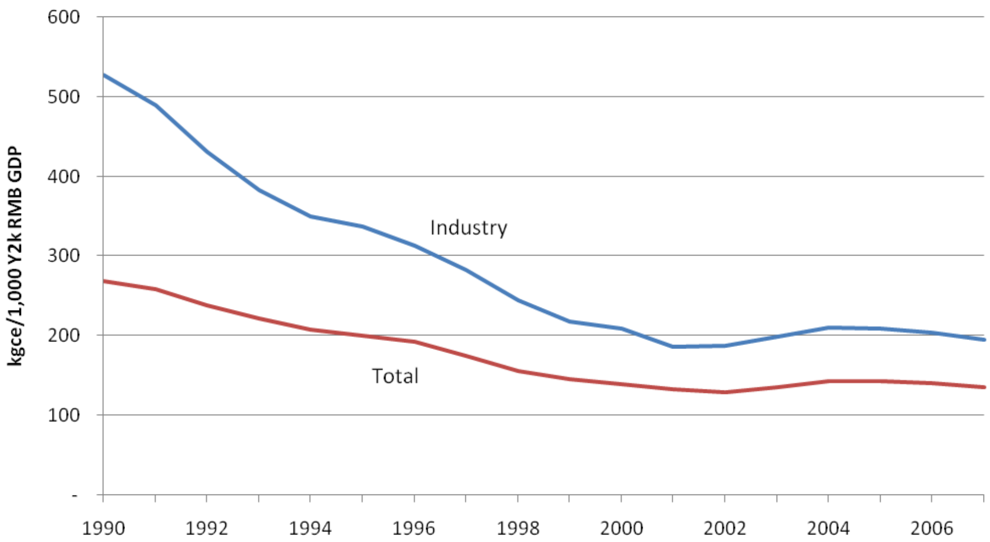


Source: NBS

1.3.2 Industrial Energy and Economic Intensity Trends

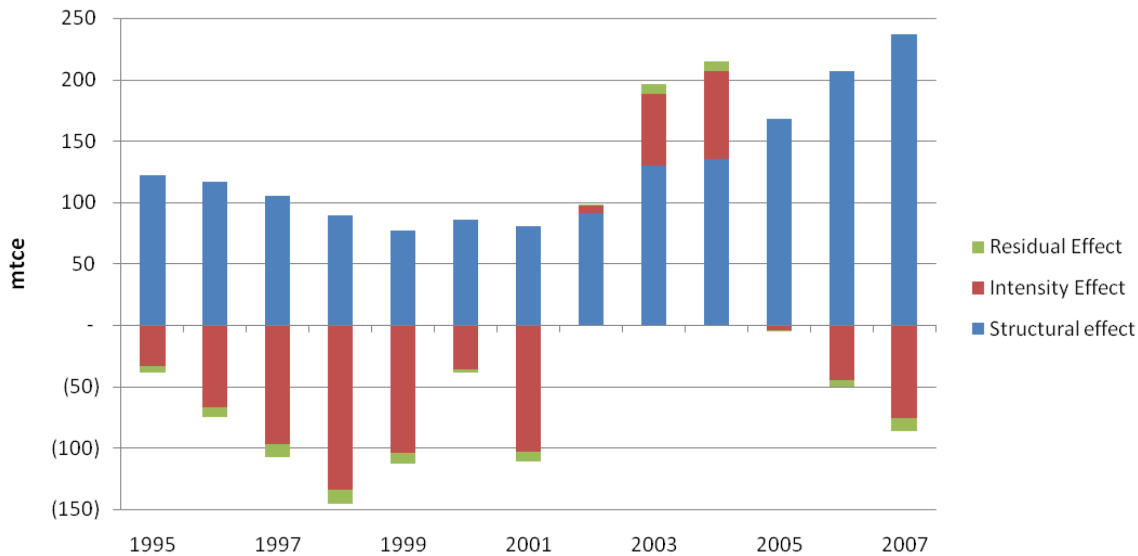
Similar to the rapid growth in the industry share of primary energy consumption, the economic energy intensiveness of industrial production has also risen more quickly than that of aggregate GDP. In spite of government efforts to moderate energy demand, data in Figure 16 shows that the 2007 energy intensity remains above 2001 levels. Whereas industry required an average 187 kilograms of coal equivalent primary energy use for each thousand (deflated year 2000) RMB of GDP produced in 2001, industrial energy intensity of GDP was 195 kgce/1,000 RMB in 2007.

Figure 16: Industry and Total Primary Energy Intensity of GDP, 1990 - 2007



In order to differentiate between efficiency and structural drivers of industry primary energy and intensity changes, the Laspeyres decomposition method has been used to quantify aggregate effects.[15] This method indicates that declines of energy and carbon intensity of GDP during the 1980's and 1990's were largely due to improved industrial efficiency ('intensity effect' in Figure 17).[16] However, energy efficiency improvements were overtaken by structural shifts ("structural effect") to heavy industry such as cement and steel production between 2002 and 2005.[17]
Figure 17 shows how structural effects came to dominate annual changes in China's industry energy consumption after 2001.

Figure 17: Structural, Intensity, and Residual Effects on Industry Primary Energy Consumption, 1995-2007



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[15] The modified Laspeyres equation is expressed as follows,
$E_t = Q_t I(t-1) + Q_t \sum S_i^0\, \Delta I_i + Q_t \sum \Delta s_i\, I_i^0 + Q_t \sum \Delta s_i\, \Delta I_i^0$
where

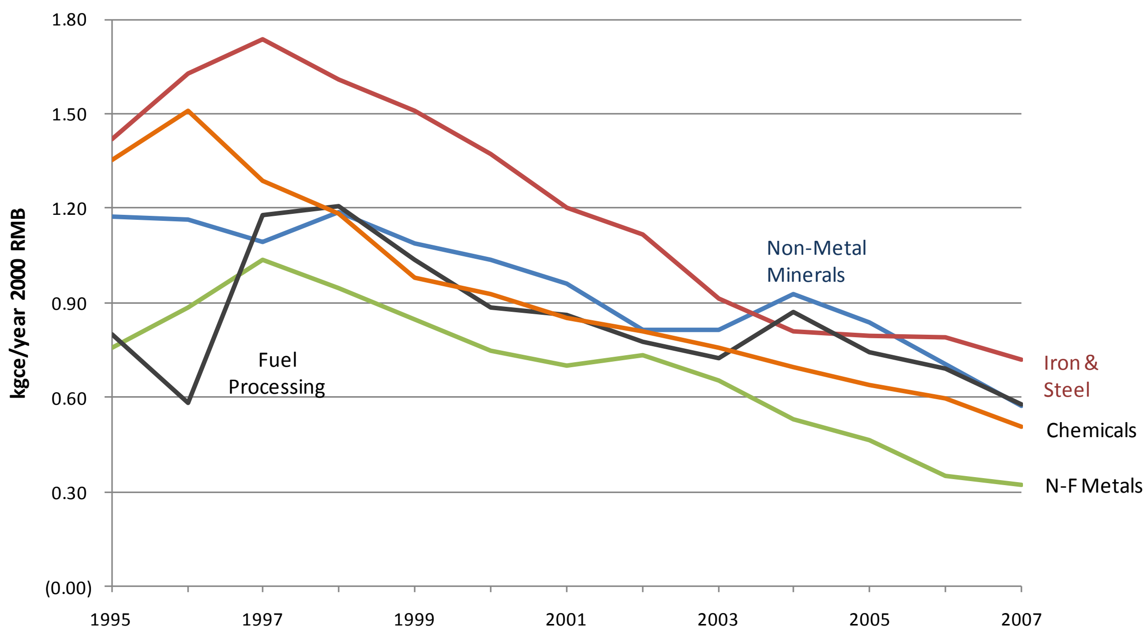
E_t = energy actually consumed by industrial sector (in Mtce) in year t
Q_t = GDP or Value-Added (in 2000 yuan)
I_i = intensity of energy use in the ith sector in year t
S_i = the ith sector's share of GDP
i = reference number for sector
T = the time period.

[16] Sinton JE, Levine MD. 1994. Changing energy intensity in Chinese industry: the relative importance of structural shift and intensity change. *Energy Policy* 22: 239–55.
Zhang ZX. Why did the energy intensity fall in China's industrial sector in the 1990s? The relative importance of structural change and intensity change. *Energy Economics* 25 (2003) 625–38.
[17] Lin J, Zhou N, Levine M, Fridley D. 2006. Achieving China's Target for Energy Intensity Reduction in 2010: An exploration of recent trends and possible future scenarios. *Ernest Orlando Lawrence Berkeley National Laboratory, Report LBNL-61800*, Berkeley, CA: LBNL.

At the same time, the majority of China's energy-intensive industrial sub-sectors have undergone extensive energy efficiency improvements through technology upgrading, management improvements and fuel switching. Yet energy efficiency as measured by economic energy intensity of production actually worsened in the non-metal minerals and fuel processing sub-sectors between 2003 and 2004.

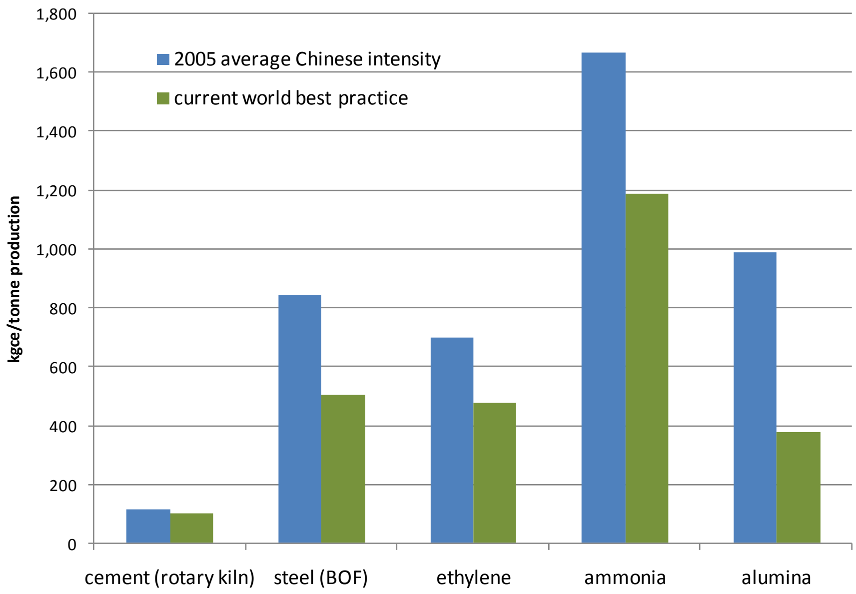
Figure 18 shows that the economic energy intensity of non-metal minerals (primarily cement) production actually increased by 14% between 2002 and 2004. The rapid growth of cement demand during this period likely raised the sector's overall energy intensity by stimulating renewed production in small, inefficient, or obsolete plants.

Figure 18: Economic Energy Intensity of Industry Sub-Sectors, 1995-2007



Heavy industrialization as a major energy consumption driver has also outpaced significant efficiency improvements in the physical intensity of industrial production. In particular, the average Chinese physical intensities of production for major industrial products such as cement, steel, ethylene, ammonia and alumina still lag behind existing world best practice (see Figure 19). More specifically, alumina and steel (basic oxygen furnace) production in China uses over 50% more energy per ton of production than the existing world best practice while ethylene and ammonia used 46% and 40% more energy in 2005, respectively. The greatest improvement in physical intensity of production has been in rotary kiln cement production, with Chinese production using only 23% more energy than the current world best practice methods. These sub-sector differences in production energy intensity and technology and efficiency improvement trends are all taken into consideration in our bottom-up methodology for modeling future industrial energy use.

Figure 19: Physical Intensity of Selected Industrial Products



2. Defining a High-Efficiency, Low Consumption Scenario: China Lightens Up (CLU)

In this study, two scenarios were developed to evaluate the influence of efficiency, urbanization and trade on industrial and residential energy use and related carbon emissions. One scenario is the reference case, or Business as Usual (BAU), scenario while the other scenario is based on a lighter development trajectory known as China Lightens Up (CLU). The CLU scenario outlines the energy and environmental implications of an alternative development trajectory driven by lower urbanization and exports. The areas of divergence between BAU and CLU assumptions include levels of two key production activity drivers of urbanization rate and trade as well as energy efficiency assumptions for production. Explicit differences in transportation and commercial building assumptions for the CLU scenario were excluded as both scenarios have similar assumptions in these two sectors (see Appendix for details on transportation and commercial building sector assumptions and methodology). In essence, varying urbanization and industrial activity in CLU allows it to suggest as a lower bound for Chinese energy consumption under a lighter development strategy.

Scenario analysis was conducted using BAU and CLU scenarios for five energy-intensive industrial sub-sectors including cement, iron and steel, aluminum, ammonia and ethylene. For cement, steel and aluminum, the scenarios were based on major physical driver relationships to build environment requirements for growing urban population, with floor space construction area as a proxy. Ammonia production, in contrast, was modeled as a function of sown area and fertilizer intensity while ethylene production was based on population and per capita demand for plastics. For each sub-sector, we developed projections of process efficiency requirements and technology shift for materials production and examined energy return on energy investment for primary energy producing sectors. The specific drivers and assumptions for each sub-sector are outlined in the next section of the report while the macro-drivers of urbanization, residential building floor space and trade are discussed below.

2.1 Urbanization

One of the key drivers in our bottom-up modeling methodology and scenario analysis is the urbanization rate and growth of the urban population. China as a developing country has and will continue to undergo changes in its physical built environment as a result of rapid urbanization. For example, more mega-cities with populations of 10 million or more and second-tier cities with smaller populations are expected through 2025 (Table 4). China's distinctly large population will also have profound implications for the growth of cities, as illustrated by its projected 2010 comparison to the U.S. While both countries have similar population distribution amongst cities of different sizes, China clearly has many more cities of almost all sizes than the U.S. despite undergoing economic development and urbanization much later. Moreover, rapid growth in the number of cities of all size is expected, with projected increases of 3 more cities with five to ten million residents and 55 with population of one to five million. Urbanization and the related demand for infrastructure and residential energy services will therefore be important driving forces for future energy consumption in China.

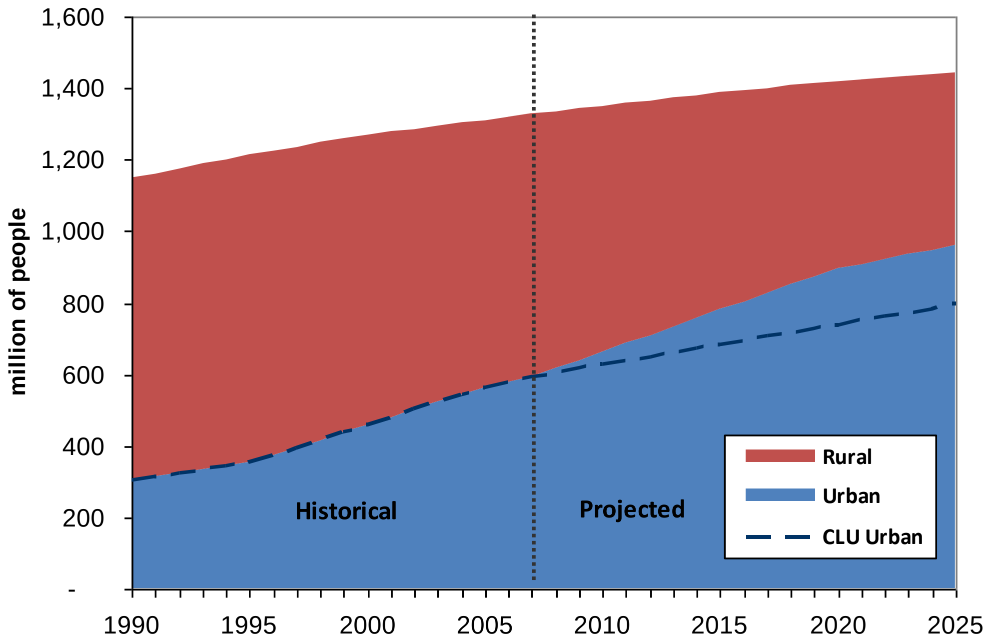
Table 4: Urbanization and Growth in Cities in China, 2005-2025

	2005	2010	2015	2020	2025		U.S. 2010
Cities of 10 million or more	2	2	3	3	4		2
Population (millions)	25	28	41	43	56		32
Percentage of urban population	5%	5%	6%	6%	7%		12%
Cities of 5 to 10 million	5	5	6	7	8		3
Population (millions)	36	39	43	52	55		21
Percentage of urban population	7%	6%	6%	7%	7%		8%
Cities of 1 to 5 million	86	102	115	131	141		37
New Cities		*16*	*13*	*16*	*10*		
Population (millions)	167	202	229	262	282		86
Percentage of urban population	31%	33%	34%	35%	34%		33%
Cities of 0.5 to 1 million	101	107	105	96	91		37
New Cities		*6*	*-2*	*-9*	*-5*		
Population (millions)	73	77	77	71	68		26
Percentage of urban population	14%	13%	11%	9%	8%		10%
Cities of <1 million	-	-	-	-	-		-
Population (millions)	229	261	294	328	362		94
Percentage of urban population	43%	43%	43%	43%	44%		36%

Source: UN, World Urbanization Prospects 2007 Revision

To account for the potential effects of urbanization on energy demand in China, the model included population growth and urbanization, or share of urban population, as macro-drivers in both scenarios. First, linear extrapolation of the United Nations population forecast for China was used to derive total population forecasts to 2025. Second, the Energy Research Institute (ERI) 2050 model assumptions on urbanization were used as the basis for the BAU scenario, which assumes urbanization grows from the 2007 rate of 45% to 67% by 2025. Under the BAU scenario, China's urban population thus grows from 594 million in 2007 to 958 million people in 2025. The CLU scenario is based on a lower urbanization rate of 55% by 2025 with a corresponding urban population growth to 795 million people. This lower urbanization rate is derived by assuming that urban population growth is equal to approximately half the speed of BAU urbanization and is comparable to the United Nations urbanization forecast of 57% by 2025. Figure 20 shows the historical and projected urban population for both scenarios.

Figure 20: Historical and Projected Urbanization for BAU and CLU Scenarios



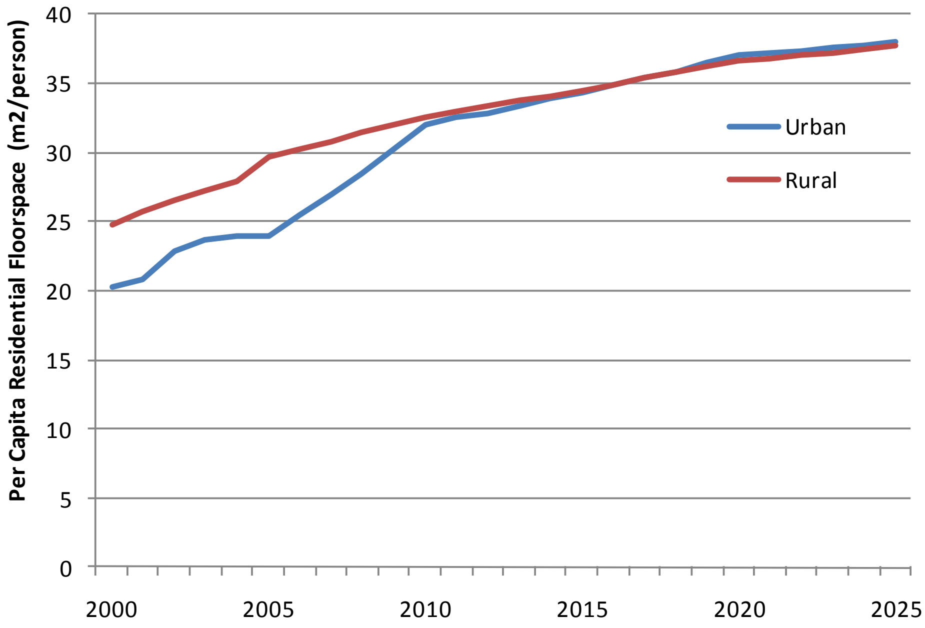
Source: Historical data from NBS. Projections based on United Nations population forecast and Energy Research Institute 2050 Model.

2.2 Building Floor Space

In quantifying the physical built environment needs of a larger urban population and changing demographic trends like household sizes, per capita residential floor space projections were included as a key driver in the model. Specifically, the floor space assumptions used were from the Energy Research Institute 2050 Model and projects that both urban and rural per capita floor space will grow to 38 m^2 per person in 2025 (Figure 21). Although per capita urban floor space grows at a faster pace initially, rural and urban floor space is actually projected to grow at similar rates from 2010 onwards. Overall, urban per capita floor space is projected to grow from 24 m^2 per person in 2005 to 38 m^2 per person in 2025. This rate of growth is actually very similar to the experience of West

Germany, which saw increases in per capita living area from 25 m^2 per person in 1978 to 40 m^2 per person in 2003.[18]

Figure 21: Per Capita Residential Floor Space, 2000-2025



Source: LBNL CLU Model

2.3 Trade

China's role as a net exporter of energy-intensive industrial products can have important implications for its future heavy industrial production and energy consumption trends. To account for trade as an industrial energy demand driver, similar trade assumptions for each scenario were made for the four industrial sub-sectors in which China is a net exporter, namely iron and steel, cement, aluminum and ammonia. More specifically, we assume the level of 2007 net exports by volume is frozen from 2008 to 2025 for those four sub-sectors under the BAU scenario. Under CLU's lighter development trajectory, we assume that China will begin decreasing its energy-intensive industrial exports with a simplified linear reduction from 2007 net export by volume to zero net exports by 2025. The only exception is the ethylene sub-sector, for which China is a net importer and its specific trade assumptions are discussed in the sectoral analysis section of the report. The specific export values assumed for the different industrial sub-sector are described in more detail in the sub-sector summary tables.

[18] Shidlo, Gil. 1990. "Housing Policy in Developing Countries" and Warner, Sven. 2007. "District Heating Possibilities within the European Energy Balance." Presented at IEA Futures Building Forum at Helsinki, March 21-22, 2007.

2.4 Efficiency Improvements

The model also took into consideration changes in energy intensity of production due to continuation of energy efficiency improvements in the industrial sub-sectors, with varying degrees of progress for the two different scenarios. The specific energy intensity and fuel mix assumptions are discussed individually for the sub-sectors below, but in general, the CLU scenario assumes that current world best practice will be reached earlier and before 2025 with more aggressive efficiency improvements than BAU.

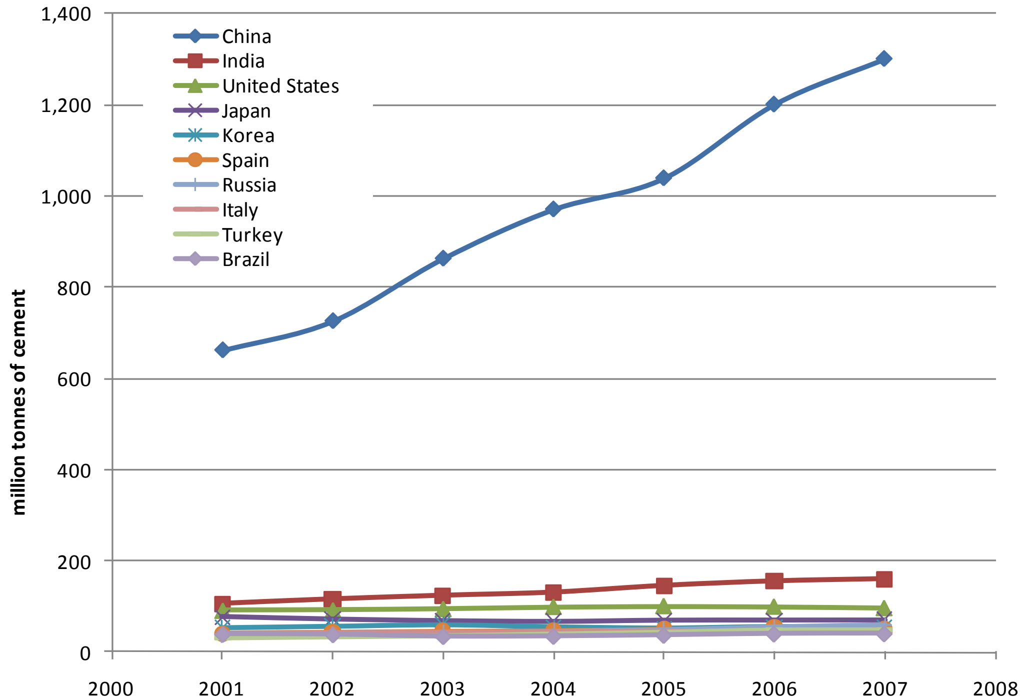
3. Industrial Sub-sector Analysis

3.1 Cement

3.1.1 International Standing

In the last decade, China has undergone rapid growth in cement production and is now the clear dominant cement producer with an output eight times higher than that of India, the next largest producer (
Figure 22). Its production of cement has doubled from 661 million tons in 2001 to over 1300 million tons in 2007. From a global perspective, China's share has grown from 38% of 1.74 billion tons of cement produced globally in 2001 to 50% of 2.6 billion tons of cement produced in 2007.

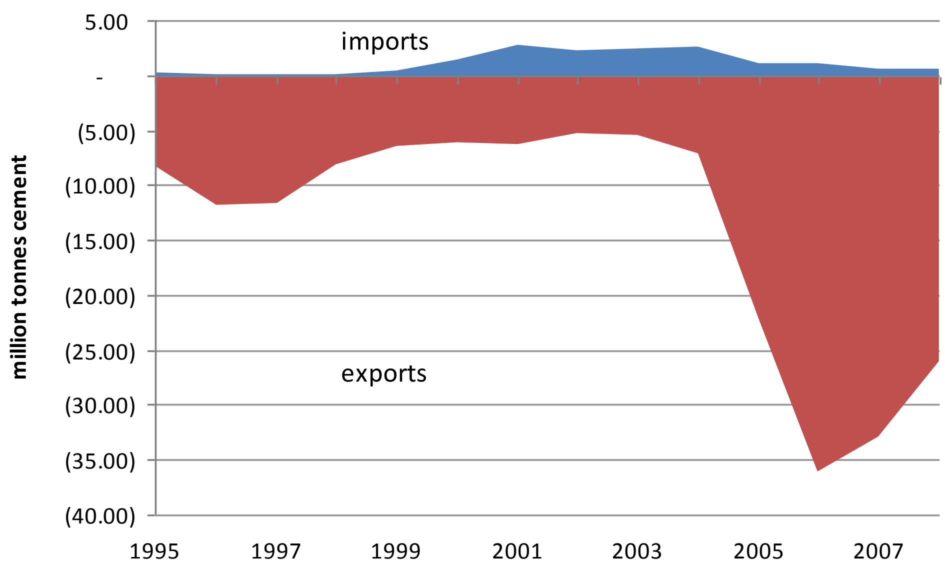
Figure 22: International Cement Production, 2001 - 2007



Source: USGS Mineral Information and Commodity Statistics

China's growing cement output has been paralleled by a significant increase in cement exports from 5.3 million tons in 2003 to 33 million tons in 2007 (Figure 23). This six-fold increase in cement exports follows an overall decline in Chinese cement imports, which contrasts sharply to trends of growing imports in all other top global cement producers. As a net exporter of 25.4 million tonnes of cement, China has been exporting to other major cement producers like the U.S. and Japan. Despite China's quick rise as a major global cement supplier, exports still comprised a very small share of less than 2% of total cement production in 2008. In contrast, domestic consumption was responsible for 98% of the production, suggesting that the key driver in cement production is domestic trends like urbanization rather than trade.

Figure 23: Cement Trade, 1995-2008



Source: UN Comtrade

3.1.2 Technology Trends

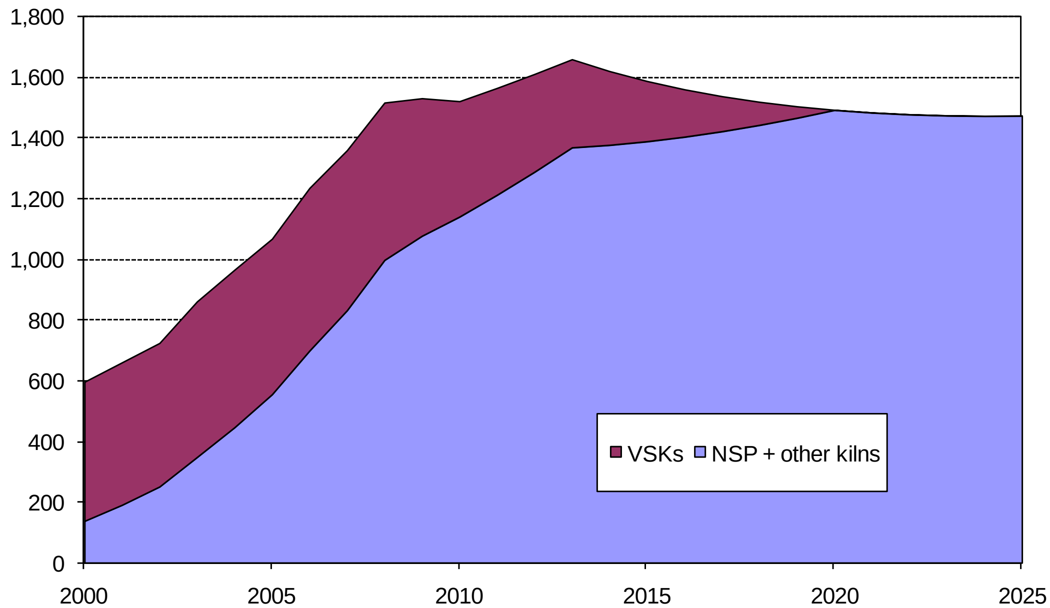
China's cement industry is steadily transitioning from using less-efficient vertical-shaft-kiln to new-suspension-pre-heater (NSP) technology for making clinker—the key ingredient for cement production. In 2007 shaft kilns accounted for 49% of total production—down from a 90% share in 2000.[19] New cement production capacity employs NSP and high-efficiency technology; the overall shift is further accelerated by industry consolidation and closure of small and inefficient kilns. As with most industry in China, clinker production efficiency varies geographically. Zhejiang and Henan province, for example, have already eliminated all vertical shaft kilns in cement production. The year 2007 witnessed the closure of 520 enterprises having backward

[19] Wang Xinchun. 2007. "Improving Energy Efficiency," *China Cement Industry*, August 2007. Estimates of technology share vary by source.

production lines, and the elimination of 57 million tons of cement clinker output, equaling to around 80 million tons of cement output.[20]

Figure 24 shows the breakdown of Chinese cements production by kiln type and highlights the gradual phase-out of inefficient vertical shaft kilns by 2020 for both BAU and CLU.

Figure 24: Historical and Projected Cement Production by Kiln Type, 2000-2025



Another important trend in China's cement industry is the growing prevalence of waste heat recovery. According to Wang Yanjia of Tsinghua University, waste heat generated from one ton clinker can produce 30-40 kWh of electricity, or the equivalent of 1/3 of electricity consumed per ton cement produced. There are more than 800 cement kilns in China that capable of using waste heat technology. Their overall installed capacity can reach 5 GWh, annual power generated amounts to more than 30 TWh, save more than 1.2 million tons of coal equivalent (tce) in energy consumption, and reduce CO_2 discharge by 2.7 million tons.[21]

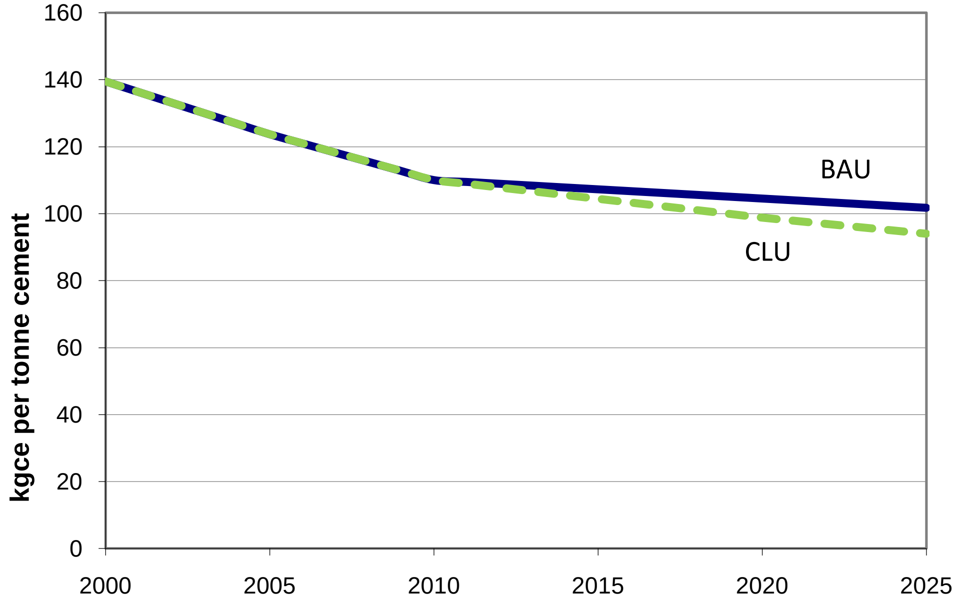
3.1.3 Energy Intensity and Fuel Mix

The final energy intensity of cement production is determined by the proportion of various production technologies, the physical efficiency of production, and the mix of fuel inputs. As a result of the shift from vertical shaft kilns to rotary kilns and endogenous process improvements, the final intensity of cement production declines in both the BAU and CLU scenarios, with CLU having slightly lower final energy intensity

[20] Zeng Xuemin, China Cement Association, 2008. "Current Situation and Prospect of China Cement Industry," Proceedings of the Workshop on *Future Technologies and Innovations in the Cement Sector in China*, 16-17, 2008, Beijing.
[21] Wang Yanjia. 2008. "From 'Potential' to Reality: GEI's Road to Energy Efficiency in Industry."

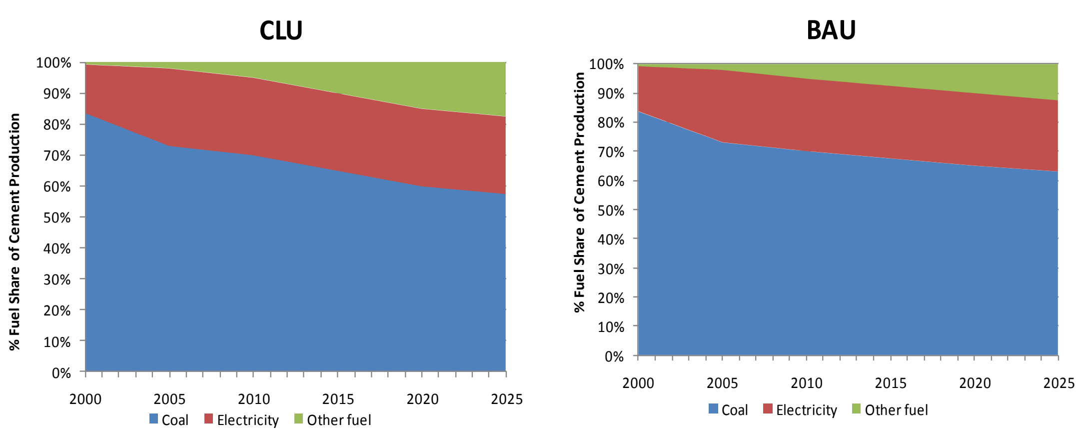
as a result of its more aggressive efficiency improvements. The energy intensity of cement production drops from 110 kilograms of coal equivalent per tonne of cement in 2010 to 102 kgce/t in 2025 in the BAU scenario and 94 kgce/t in the CLU scenario (Figure 25).

Figure 25: Final Energy Intensity of Cement Production, 2000-2025



The assumed fuel mix for BAU and CLU cement production from 2000 to 2025 includes coal, primary electricity and other fuels like waste fuels and even hazardous wastes. As seen below, coal's share of total fuel consumed declines more rapidly under CLU, with a drop from 73% in 2005 to 57.5% in 2025, compared to the BAU scenario's slower decline to 64% in 2025. In CLU, the decline in the cement sub-sector's coal consumption is offset by corresponding increases in the consumption of other fuels.

Figure 26: BAU and CLU Fuel Mix for Cement Production

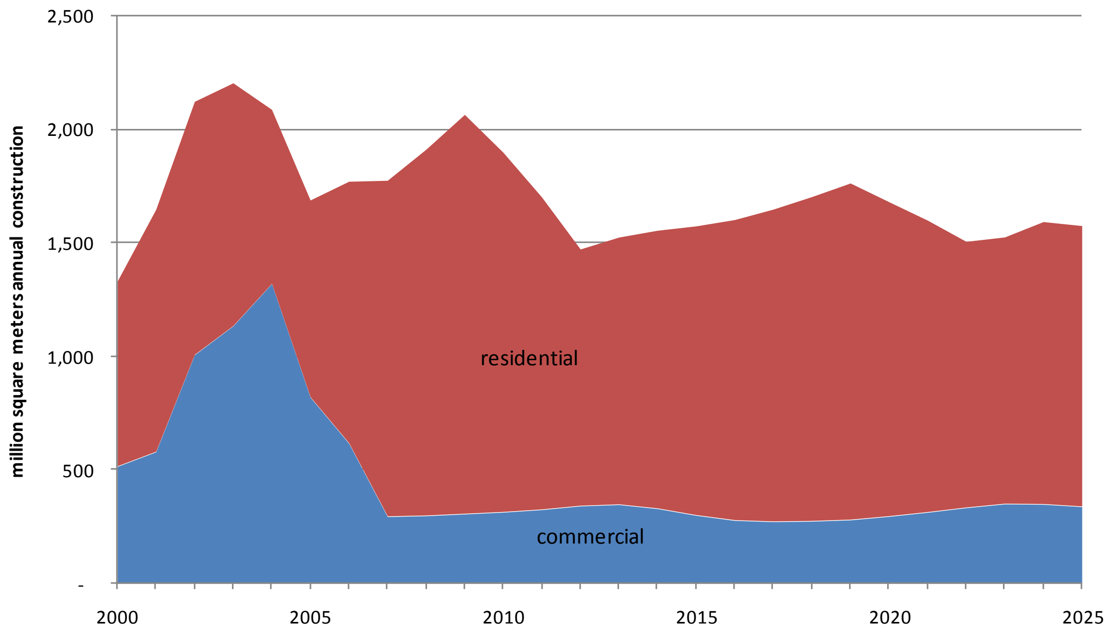


3.1.4 Drivers

In this analysis, future cement production levels are derived based on the amount of cement required to construct China's urban and rural buildings. This methodology takes into account changes in the share of urban construction in total construction over time as well as changes in the average amount of cement used per square meter of construction. Scenarios of future production levels vary based on driver assumptions about the future rate of urbanization and the level of cement exports.

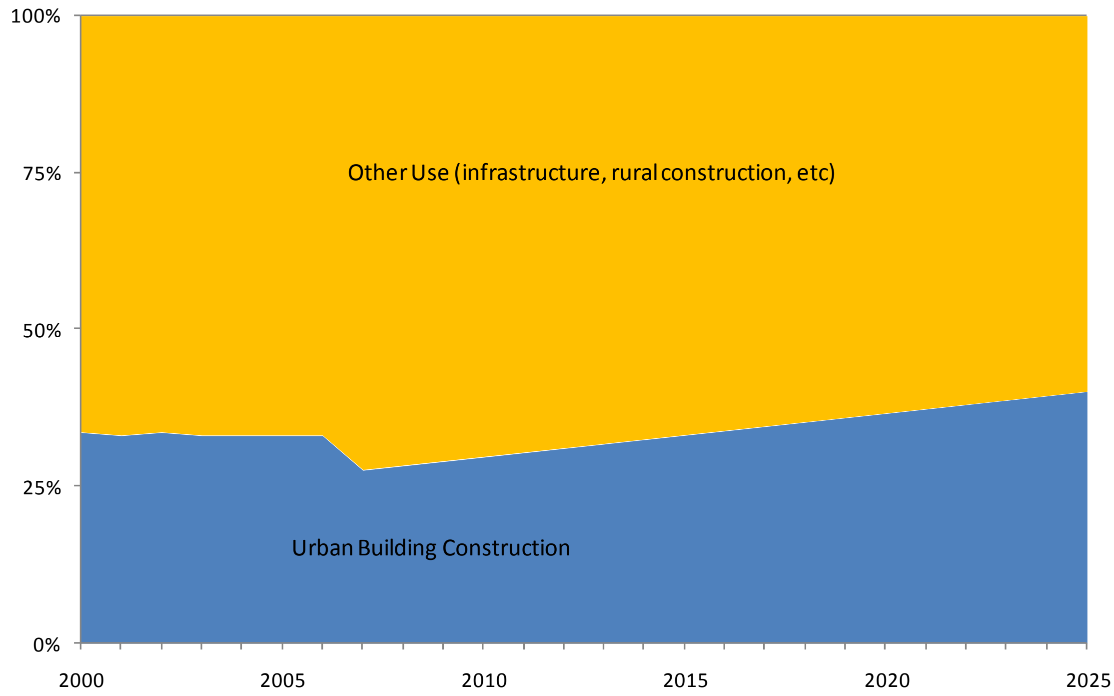
The key drivers for cement demand in this model are urban construction as related to urban population, including both residential and commercial construction, and the cement use structure and intensity in building construction. This analysis uses ERI assumptions for urban per-capita building area and a 40-year average building lifespan to forecast annual urban construction for the BAU and CLU scenarios to 2025. Figure 27 shows the breakdown between residential and commercial construction for the BAU scenario to 2025. In the BAU scenario, urban construction diminishes in 2010 due to commercial saturation effects (total floor space per tertiary sector employee) and total annual construction remains around 1.5 billion square meters through 2025.

Figure 27: BAU Assumptions for Urban Building Construction, 2000-2025



The boom of road and infrastruction construction since 2000 has pushed urban building construction's share of total cement use down to less than 30%. Given the infrastructure emphasis of China's 2008 stimulus package, urban building share of total cement use is assumed to remain around 30% until 2013, when it gradually begins to climb back to 40%.

Figure 28: Breakdown of Cement Use, 2000-2025



Annual urban construction and cement use data are combined with cement intensity to calculate total cement demand. Based on the growing average height of Chinese urban buildings, cement intensity of construction is assumed to grow from 222 kilograms of cement per square meter of new construction to 260 kg/m^2 in 2025. The equation used to calculate total cement production:

*Total Cement = (annual urban construction * cement intensity) / urban share of total cement.*

3.1.5 Scenarios

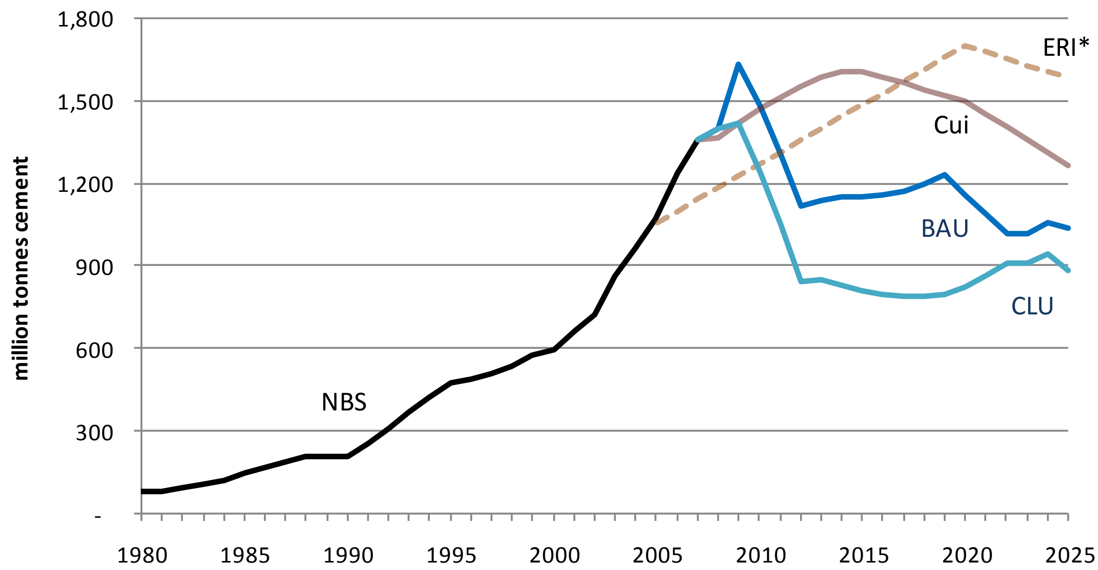
A summary of the drivers and assumptions for cement production in energy use is presented in Table 5.

Table 5: Cement Scenario Variables

<table>
<tr><th colspan="2"></th><th>Business as Usual Scenario</th><th>China Lightens Up Scenario</th></tr>
<tr><td rowspan="5">Production Assumptions</td><td>Urbanization</td><td>67% in 2025</td><td>55% in 2025</td></tr>
<tr><td>Per-capita building area</td><td>24 m2 per capita in 2005; 38 m2 per capita in urban areas in 2025 (ERI assumption)</td><td>Same as BAU</td></tr>
<tr><td>Cement use structure</td><td>Urban construction share of cement consumption grows from 28% in 2008 to 40% in 2025 (infrastructure declines)</td><td>Same as BAU</td></tr>
<tr><td>Cement intensity of building construction</td><td>Average cement intensity of urban construction grows from 222 kg cement per square meter in 2008 to 260 kg/m2 in 2025</td><td>Same as BAU</td></tr>
<tr><td>Exports of cement</td><td>Assume 2007 exports remain constant through 2025.</td><td>Assume exports drop linearly to 0 by 2025.</td></tr>
<tr><td rowspan="2">Energy Assumptions</td><td>Intensity</td><td>Based on meeting 2005 current world best practice of 0.101 tce/t cement for Portland cement by ~2025 and phasing out all shaft kilns by 2020</td><td>Based on meeting 2005 current world best practice of 0.101 tce/t cement for Portland cement by ~2015 and phasing out all shaft kilns by 2020</td></tr>
<tr><td>Fuels</td><td>Steady decline from 2005 coal share of 73% to 63% by 2025</td><td>Steady coal decline from 2005 coal share of 73% to 58% by 2015 and 45% by 2025</td></tr>
</table>

Based on the assumptions and methodology described above, the BAU scenario has cement production rising from 1.36 billion tonnes in 2007 to 1.63 billion tonnes in 2009 and 1.04 billion tonnes in 2025. Figure 29 shows historical and BAU scenario production, along with forecasts from the Chinese Energy Research Institute (ERI) and the Institute of Technical Information for the Building Materials Industry of China (Cui). Whereas the BAU and Cui scenarios are based on annual data, the ERI production levels are a linear extrapolation of three data points; the basic story of the ERI data is that production is expected to peak at 1.7 billion tonnes around 2020 before declining. Given the BAU adoption of other ERI assumptions, the ERI cement production forecast appears to imply that rural and infrastructural use of cement will diminish rapidly. All scenarios include a decline of Chinese cement production by 2025.

Figure 29: Historical and Future Cement Production, 2000-2025



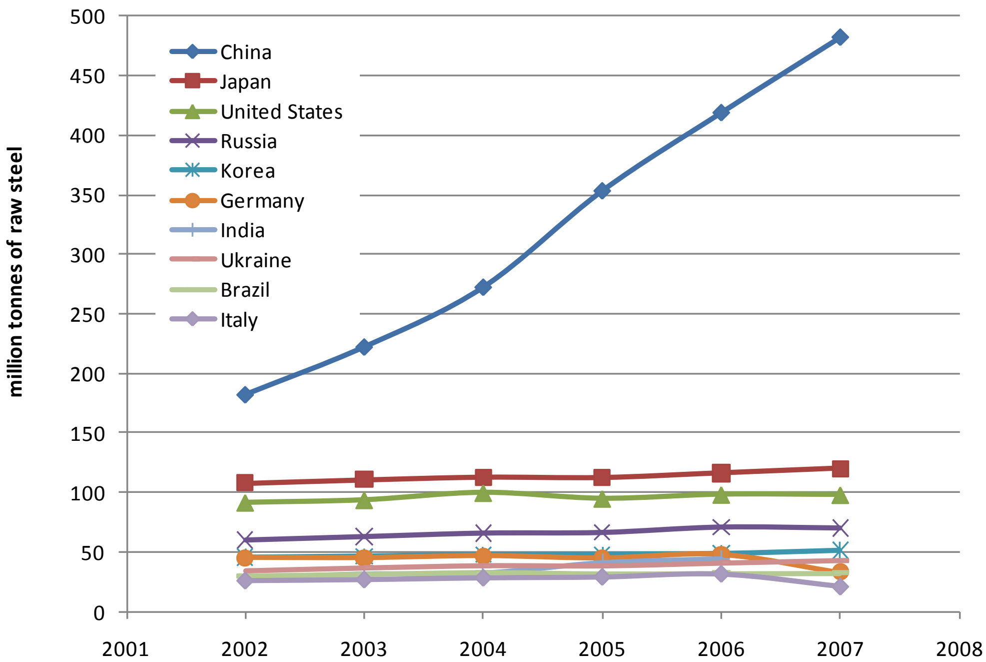
3.2 Iron & Steel

3.2.1 International Standing

China has become a major producer of iron ore and raw steel in last decade. China's growing iron ore production has been complemented by a rapid increase in its iron ore and concentrates imports, more than tripling from 111 million tons in 2002 to 382 million tons in 2007. Chinese exports, on the other hand, are negligible and remained below 10 thousand tons annually prior to 2007.

In steel production, however, China has differentiated itself as the largest raw steel producer in both total quantity and rate of increase in output. On one hand, China has solidified its position as the largest producer with rising shares of 20.1% in 2002 to 36.5% of global steel output in 2007. During this period, China achieved an average annual growth rate of 21% in raw steel production, rapidly expanding from 182.3 million tons to 482 million tons of production. China's dominance as the largest global producer is further exemplified with its production outpacing Japan, the second largest producer, by four fold in 2007 (
Figure 30).

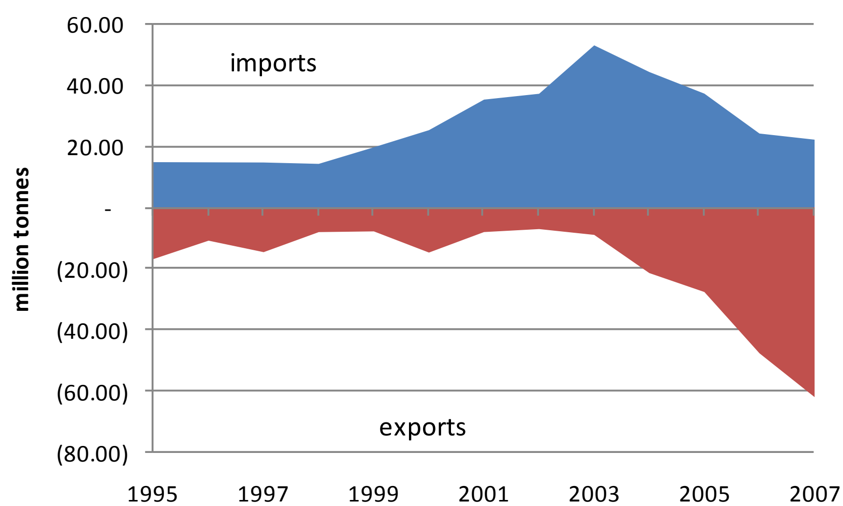
Figure 30: International Raw Steel Production, 2002-2007



Source: USGS

As the dominant global producer of steel, China has also remained a net exporter of crude steel and steel products. Exports of steel have grown particularly dramatically after 2001, with six-fold increase in the total quantity exported between 2002 and 2007 (Figure 31). With 40 million tons of net iron and steel exports in 2007, China has exported to other main steel producers in the world, including Japan, the U.S. and Korea.

Figure 31: Volume of Iron & Steel Trade, 1995-2007



Source: UN Comtrade Database

3.2.2 Technology Trends

In the first and most energy-intensive stage of iron and steel processing, iron ore is converted into pig iron through blast furnaces. In China, coal-based blast furnaces are used to produce the majority of pig iron, including 92.2% of national production in 2004. Large and medium enterprises tend to use coke-based blast furnaces more than other enterprises, with coke-based blast furnace having a larger share of 95.6% versus 80% in smaller enterprises.[22] Additional energy saving technology such as pulverized coal injection and oxygen-enriched air technology can be used to reduce blast furnaces' energy demand for coke making and use. Top gas pressure recovery turbine with power generation savings of 30 kWh per ton of iron have also been installed in more than 60 blast furnaces throughout China. From 2000 to 2007, for instance, the share of blast furnaces with installed top pressure recovery turbines grew from 50% to 96%.[23]

The two primary crude steel-making routes include using basic oxygen furnace (BOF) or the more efficient electric arc furnaces (EAF). In 1997, 73% of crude steel in China was produced using the BOF route and only 18% using the EAF route, which is more efficient and can use steel scrap or sponge iron as raw materials. Compared to the world crude steel average share of 34% production by EAF, China's EAF utilization is much lower and suggest more room for efficiency improvements. In more recent years, EAF's share of steel production has actually declined as it fell to 16% in 2000 and 14% in 2003. In 2004, the national average for EAF use in steel production was 15%, with slightly lower use amongst large and medium enterprises and higher uses of 20% in other enterprises.[24]

Another efficiency improvement in the steelmaking process is the use of continuous casting, which reduces the consumption of energy and other materials by eliminating the reheating step for semi-finished steel prior to being cast. Continuous casting has additional benefits in improved yield from liquid to finished steel and better steel quality. For example, the use of continuous casting in China has been linked to energy savings of 200 kgce per ton of steel billets with 12% increase in finished product.[25] In the main steel-making countries around the world, continuous casting is already a very popular technology option with over 95% of crude steel being continuous cast.[26] In China, continuous casting is also playing a bigger role in steel production with quickly rising shares of 61% in 1997 to 82.5% in 2000 and 98.9% in 2007.[27]

3.2.3 Energy Intensity and Fuel Mix

As a result of growing shares of recycled steel and process improvements, the final energy intensity of steel production declines for both BAU and CLU scenarios. Energy

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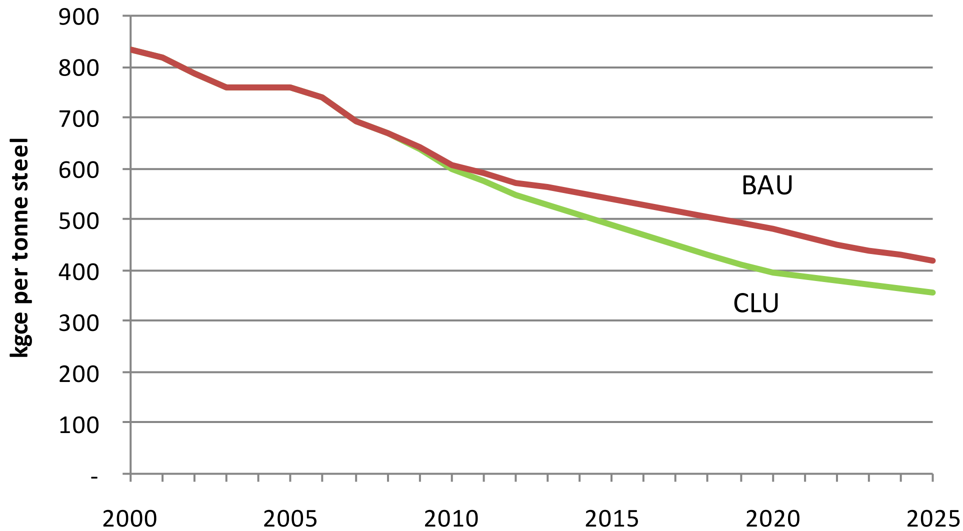
[22] China Iron and Steel Association, 2005, China Iron and Steel Statistical Yearbook 2005.
[23] Fei, F. and J. Wang. 2009. "Midterm Evaluation of Implementation of the Work of Energy Conservation and Emission Reduction during the Eleventh Five-Year Plan and Policy Directions under New Situation."
[24] CISA, 2005.
[25] Fei and Wang, 2009.
[26] Ma, et. al. 2002. "Technical efficiency and productivity change of China's iron and steel industry." *Int. J. Production Economics* 76: 293-312.
[27] Fei and Wang, 2009.

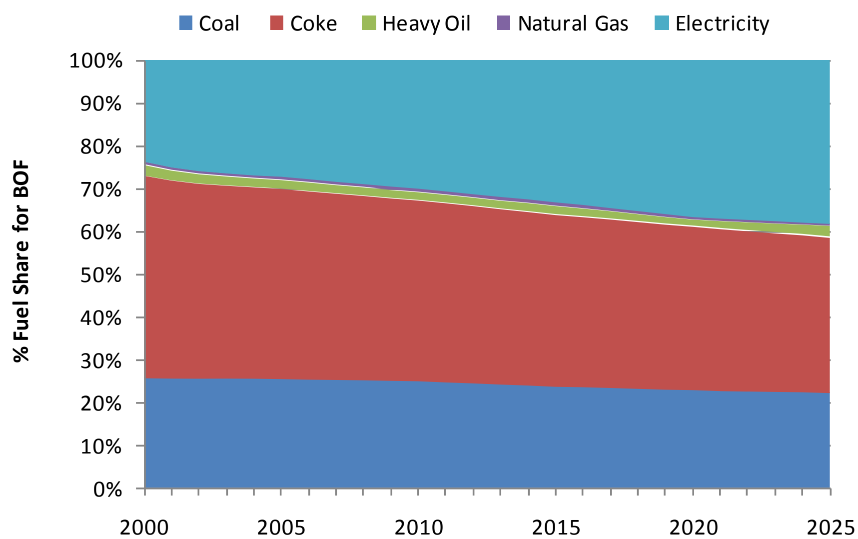
intensity of steel production drops from a weighted average for total production of 669 kg coal equivalent per tonne of steel production in 2005 to 419 kgce per tonne in the BAU scenario and 356 kgce per tonne in the CLU scenario (Figure 32).

Figure 32: Final Energy Intensity of Steel Production, 2000-2025



For BAU and CLU scenarios, the same assumptions about changing fuel shares of electricity, natural gas, heavy oil, coke and coal were assumed for BOF steel production. As seen in Figure 33, the coal and coke fuel shares decreased significantly from 26% and 47%, respectively, in 2005 and to 22% and 36% in 2025. At the same time, the electricity shares increased from 24% to 38% while the natural gas and heavy oil shares remained relatively constant.

Figure 33: BOF Production Fuel Share



For EAF steel production, frozen shares of 98% electricity and 2% natural gas are used for both scenarios.

3.2.4 Demand Drivers

Steel demand is separated into structural steel that is used, for example, to reinforce cement in construction, and product steel used for final consumption, such as appliance casings. Structural steel demand grows according to the construction scenarios described in Section 3.1.4 above. Between 2007 and 2025 the ratio of structural steel to cement use was assumed to rise from 0.17 to 0.25 kg steel per kg cement. Manufacturing growth assumptions were based on ERI projections while steel intensity trends were based on recent international trends.

3.2.5 Scenarios

Future structural steel production levels are scaled off of construction and infrastructure growth, especially as related to cement consumption while product steel levels are modeled based on international trends in the manufacturing sector, where long-term trends suggests a halving of energy consumption per unit of value added produced; in this model, it is assumed that steel intensity of manufacturing will fall by the same amount over this period. Scenarios of energy use vary based on assumptions regarding the share of primary (BOF) steel to secondary (EAF) steel and the level of steel exports. The energy intensity of steel production varies by assumptions regarding technology development and the expected date when Chinese steel production reaches current world best practice (

Table 6).

Table 6: Variables for Steel Scenario Analysis

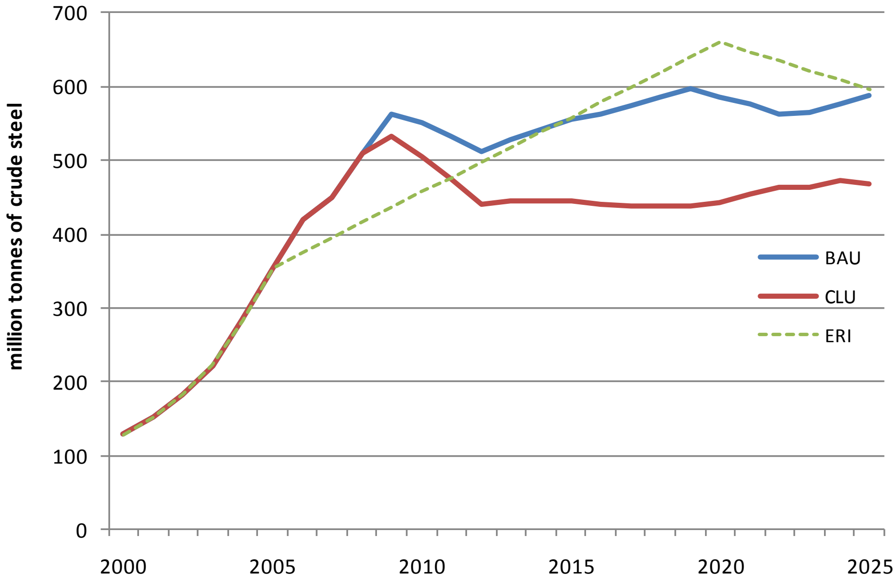
		Business as Usual Scenario	China Lightens Up Scenario
Production Assumptions	Urbanization	67% in 2025	55% in 2025
	Per-capita building area	24 m2 per capita in 2005; 38 m2 per capita in urban areas in 2025 (ERI assumption)	Same as BAU
	Production process	Assumes share of primary (BOF) steel grows from 84% in 2000 to 87% in 2010, then declines to 75% in 2025.	Assumes fixed amount of recycled steel production capacity (EAF) based on BAU scenario, with remainder as BOF production.
	Steel use	Structural and product steel are modeled separately, based on construction and manufacturing	Same as BAU

		growth	
	Exports of steel	Assume 2007 exports of 40 million tons remain constant through 2025.	Assume exports drop linearly from 40 million tons in 2007 to 0 by 2025.
Energy Assumptions	Intensity	For 2000-2020: based on Scenario 1 of Ke Wang et al. (2007), reduced to take out non-steelmaking energy use based on comparison of 1995/6 data from Price et al. (2002) to 1995/6 data from Ke Wang et al. (2007). Assumes that China does not reach 2005 international best practice intensity of 505 kgce/t steel for blast furnace >> basic oxygen furnace >> thin slab casting before 2025.	Assumes that China reaches 2005 international best practice intensity of 505 kgce/t steel for blast furnace >> basic oxygen furnace >> thin slab casting and best practice intensity of 88 kgce/t steel for electric arc furnace steel around 2025.
	Coking coal	Steady decline from 2005 share of 46% to 35% by 2025	Steady decline from 2005 share of 46% to 32% by 2025
	Power coal	Steady decline from 2005 share of 25% to 22% by 2025	Same as BAU

Based on the drivers and assumptions described above, Chinese steel production grows from 449 from 449 million tonnes in 2007 to 588 million tonnes in 2025 under BAU and to 469 million tonnes million tonnes under CLU (

Figure 34). For BAU, steel production peaks around 2020 with almost 600 million tonnes while CLU production remains below 500 million tonnes through 2025. The ERI production levels are a linear extrapolation of three data points; the basic story of the ERI data is that production is expected to peak at 660 million tonnes around 2020 before declining to 597 million tonnes in 2025.

Figure 34: BAU and CLU Steel Projections

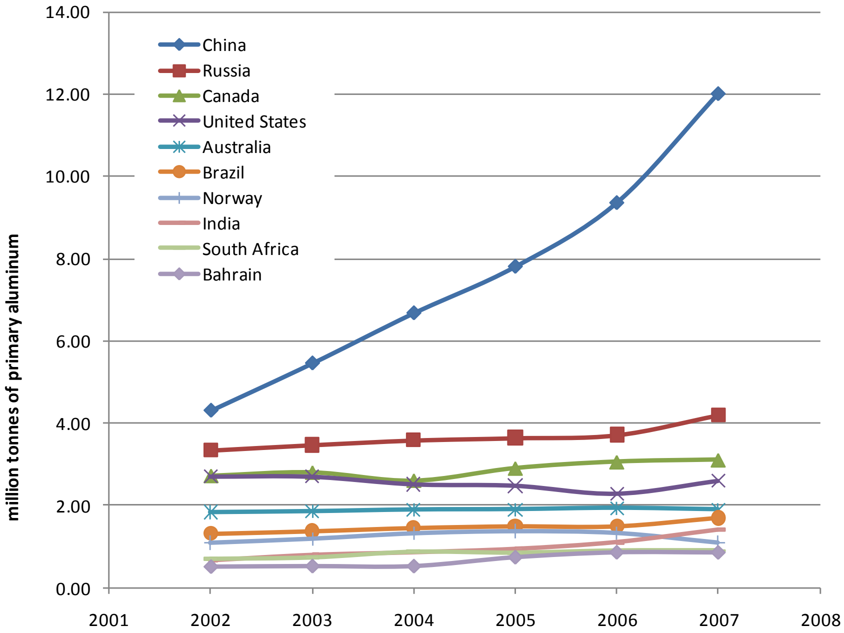


3.3 Aluminum

3.3.1 International Standing

As reflected by its aluminum ores and concentrates production trends (Figure 35), China is and has been the foremost producer of primary aluminum in the world. From 2002 to 2007, China's annual primary aluminum production output has almost tripled in absolute terms while its share of global production has doubled. More specifically, China produced 12 million tons of primary aluminum in 2007 at 32% share of global production compared to 4.3 million tons at 16% global share in 2002. In other words, China's annual production of primary aluminum has undergone annual growths of over 20% and has dominated China's non-ferrous metals production in terms of both production volume and energy use (Figure 36 and
Figure 37).

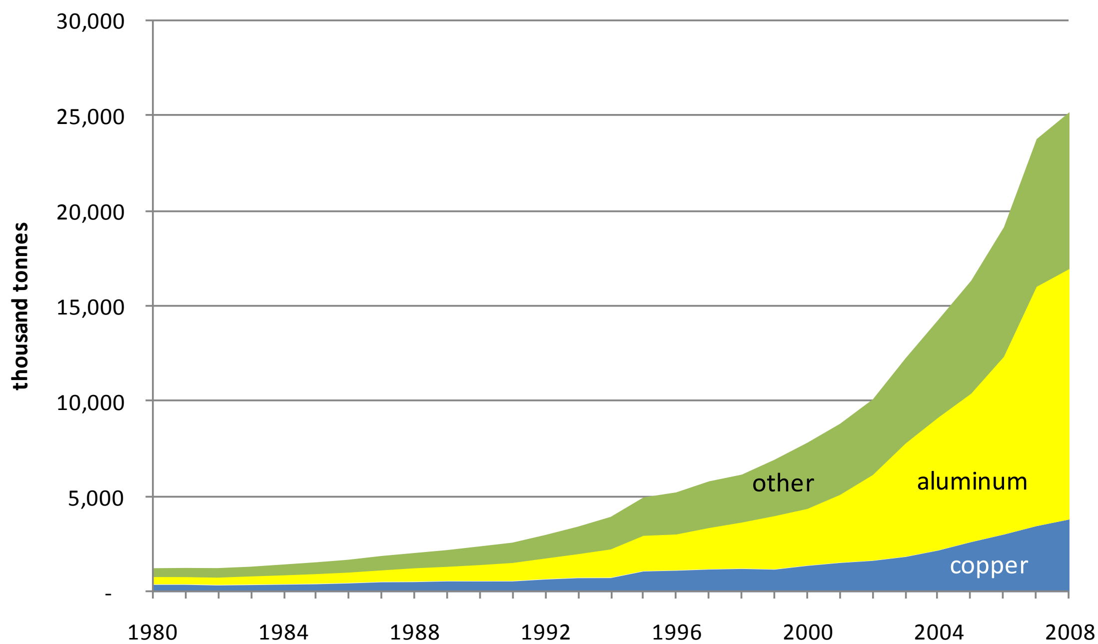
Figure 35: Primary Aluminum Production in Selected Countries, 2001-2007



Source: USGS

Aluminum comprises the largest share of China's non-ferrous metals industry, both in terms of annual production and energy use. In 2008, aluminum accounted for 52% of non-ferrous metals production—up from 38% in 2000.

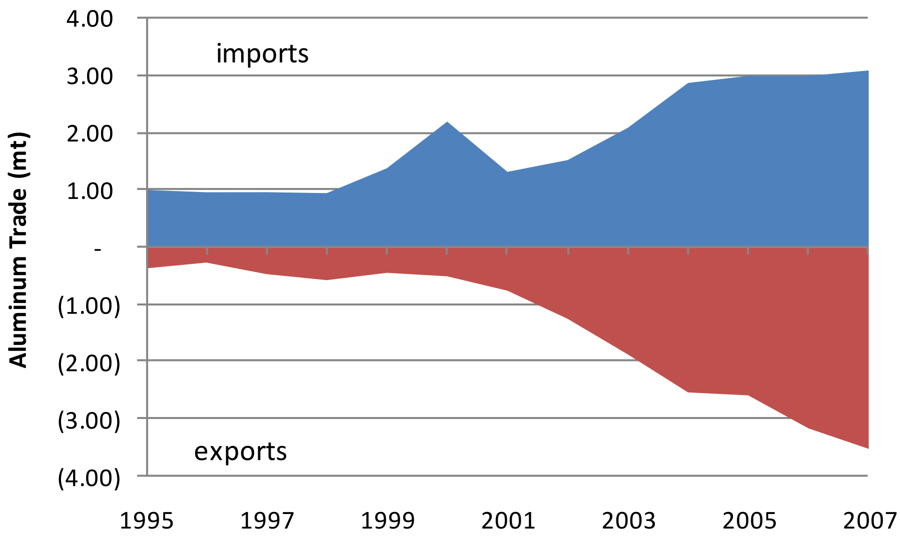
Figure 36: China Non-Ferrous Metals Production, 1980-2008



Source: NBS

Corresponding to increased primary aluminum production, China has reversed its position as a net importer to net aluminum exporter within the last six years. In 2007, China exported a net 400,000 tonnes of aluminum (
Figure 37). Globally, China's recent growth in aluminum exports puts it third in export volume behind Russia and Canada.

Figure 37: China International Aluminum Trade, 1995-2007



Source: UN Comtrade Database.

3.3.2 Technology Trends

China has been active in both the primary and secondary production of aluminum, with the aluminum production majority share of primary production projected to decline over time. Primary production of aluminum first occurs through bauxite ore mining and alumina refining, where the bauxite ore is crushed and dissolved in hot sodium hydroxide solution. Next, the ore is precipitated out and calcinated to produce anhydrous alumina. The alumina is then converted to aluminum through an electrochemical conversion process known as the Hall-Heroult process. In China, the aluminum smelting process is done using pre-baked cell technology and to a lesser extent, more energy-intensive self-baked anode cell technology. More efficient pre-baked cell technology is playing a bigger role in China with the potential for achieving electricity savings of 9% for capacity greater than 160 kA. Specifically, large-scale pre-baked cell technology has increased from 52% of Chinese production in 2000 to 83% in 2007.[28]

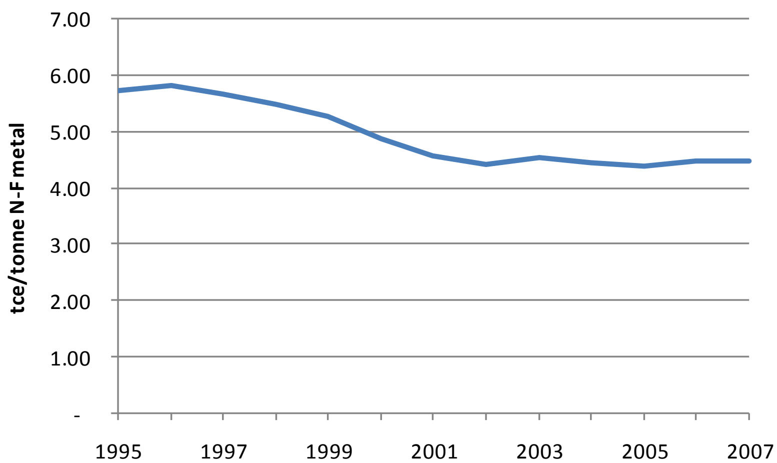
Secondary production of aluminum involves extracting aluminum from recycled materials and has become increasingly popular amongst aluminum manufacturers. Producing aluminum from recycled materials generally involves metal scrap pretreatment and smelting and refining and is much more energy efficient than primary production. With potential efficiency gains, our model projects that primary aluminum production will decline from 73% of total production in 2005 to 45% in 2018 and 30% in 2025, with corresponding increases in the share of secondary aluminum production.

[28] Fei and Wang, 2009.

3.3.3 Energy Intensity and Fuel Mix

Aluminum production is one of China's most energy-intensive industries. Overall energy intensity has been gradually improving since the mid-1990s, though the primary energy intensity of non-ferrous metals production (in aggregate) remained flat around 4.5 kilograms coal equivalent per tonne of production between 2001 and 2007 (
Figure 38). Improved efficiency and reductions in physical energy intensity of production is expected to continue since the average physical intensity of alumina production is still much higher than current world best practice.

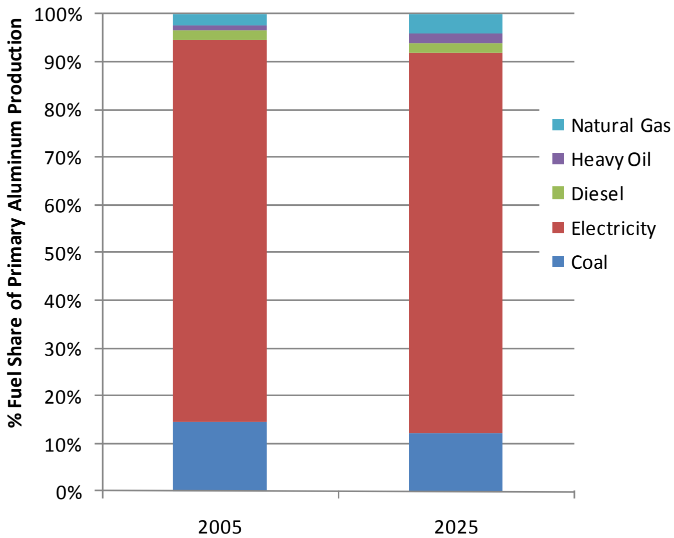
Figure 38: Physical Energy Intensity of Non-Ferrous Metals Production, 1995-2007



In terms of fuel mix, both BAU and CLU scenarios had the same assumed fuel shares for primary and secondary aluminum production with only slight changes between 2005 and 2025. For primary production, electricity has the largest fuel share at 80% followed by coal, natural gas and heavy and diesel oil (

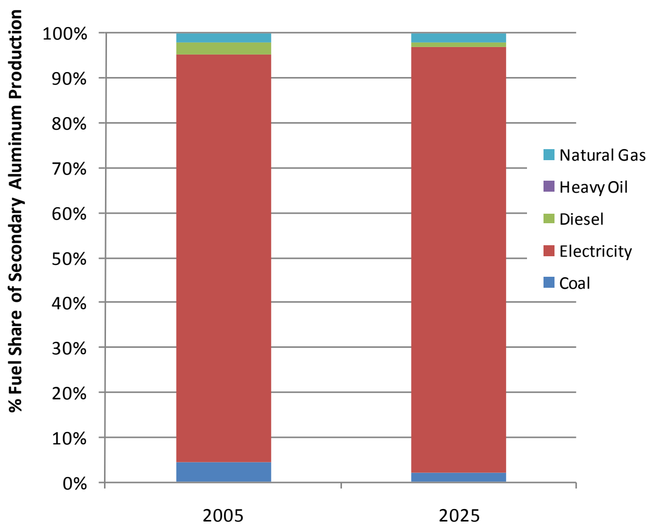
Figure 39). Between 2005 and 2025, there was a slight increase in the shares of natural gas and diesel and corresponding decrease in coal's fuel share.

Figure 39: Primary Aluminum Production Fuel Mix



For secondary aluminum production, electricity has an even larger fuel share of 91% that increases to 95% by 2025 (Figure 40). This is followed by small and decreasing shares of coal and diesel, while the fuel share of natural gas remains relatively flat between 2005 and 2025.

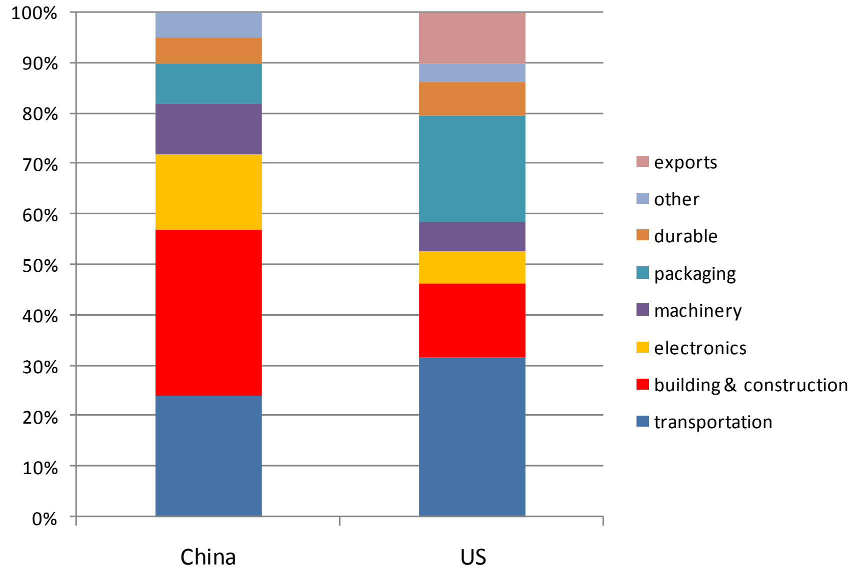
Figure 40: Secondary Aluminum Production Fuel Mix



3.3.4 Demand Drivers

In contrast to the United States, building and construction use (e.g. aluminum window framing) constitutes the highest fraction of aluminium consumption (Figure 41), followed by transportation use and electronics manufacturing in China. For this study the construction portion of domestic aluminum use is expected to drop from 35% in 2007 to 30% in 2025 as a result of increased manufacturing and transport use.

Figure 41: Demand Drivers of Aluminum in China and the United States, 2002



Source: Hunt, Warren H. (2004) "The China Factor: Aluminum Industry Impact," *Journal of Metals*, Vol 56 (9):21-24.

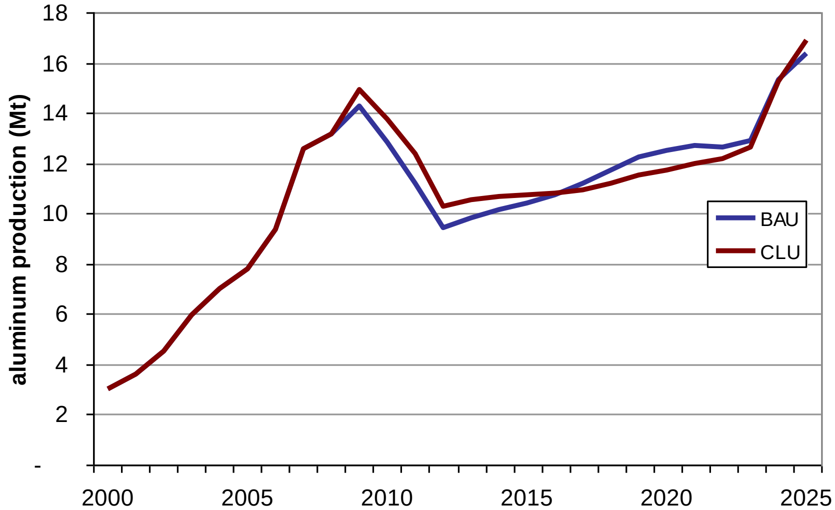
3.3.5 Scenarios

As suggested by the construction sector's role as a key aluminum driver in China, aluminum production under the BAU and CLU scenarios is driven primarily by residential and commercial floorspace and trade activity. In particular, aluminum production was projected using the equation: *Total production = [(residential + commercial floorspace)*aluminum intensity of production]/construction share of total aluminum production + net export.*

For both scenarios, the aluminum intensity of construction linearly increases from 2.0 to 2.2 kilograms per square meter while the construction share of total aluminum production declines from 35% in 2009 to 30% in 2025. As with other industrial sub-sectors, the differences in production projections for BAU and CLU scenarios result from differing urbanization levels and subsequently different construction floorspace assumptions as well as different trade activity. For aluminum, China is assumed to be a net exporter with frozen exports at 2007 levels through 2025 for BAU and linear reduction to zero exports by 2025 for CLU scenario.

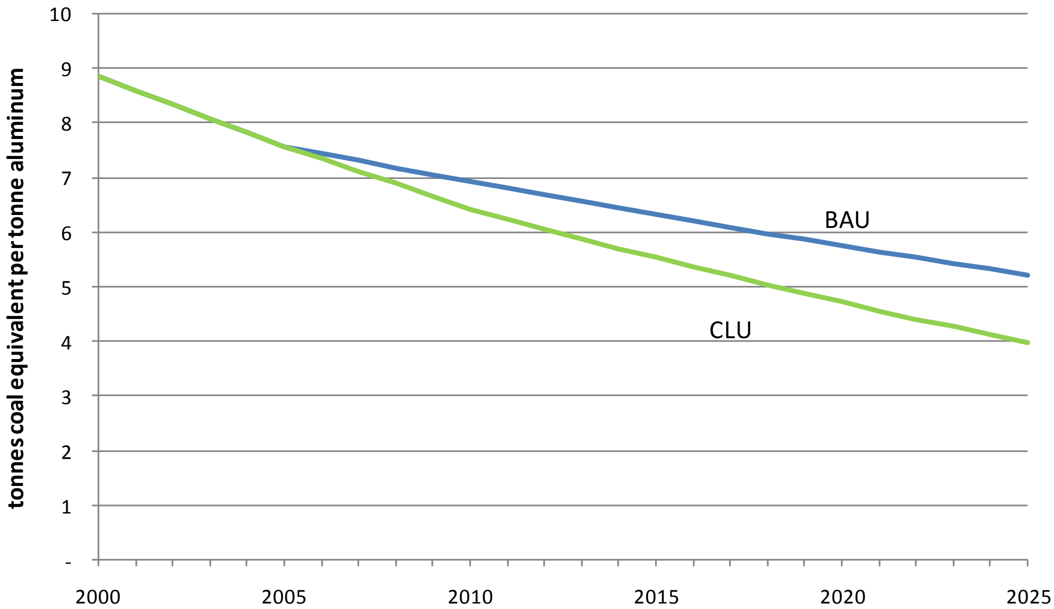
China's total aluminum production from 2000 to 2025 under the BAU and CLU scenarios are shown in Figure 42.

Figure 42: BAU and CLU Aluminum Production, 2000-2025



Total energy intensity of aluminum production steadily declines in both scenarios as a result of technical improvements and a rising share of secondary production, i.e. recycling. In the BAU scenario, total final energy intensity decreases from 8.9 tonnes coal equivalent per tonne aluminum in 2005 to slightly greater than 5 tce per tonne in 2025. In the CLU scenario, final energy intensity of production drops to 3.9 tce per tonne by 2025 (Figure 43).

Figure 43: BAU and CLU Final Energy Intensity of Aluminum Production, 2000 - 2025



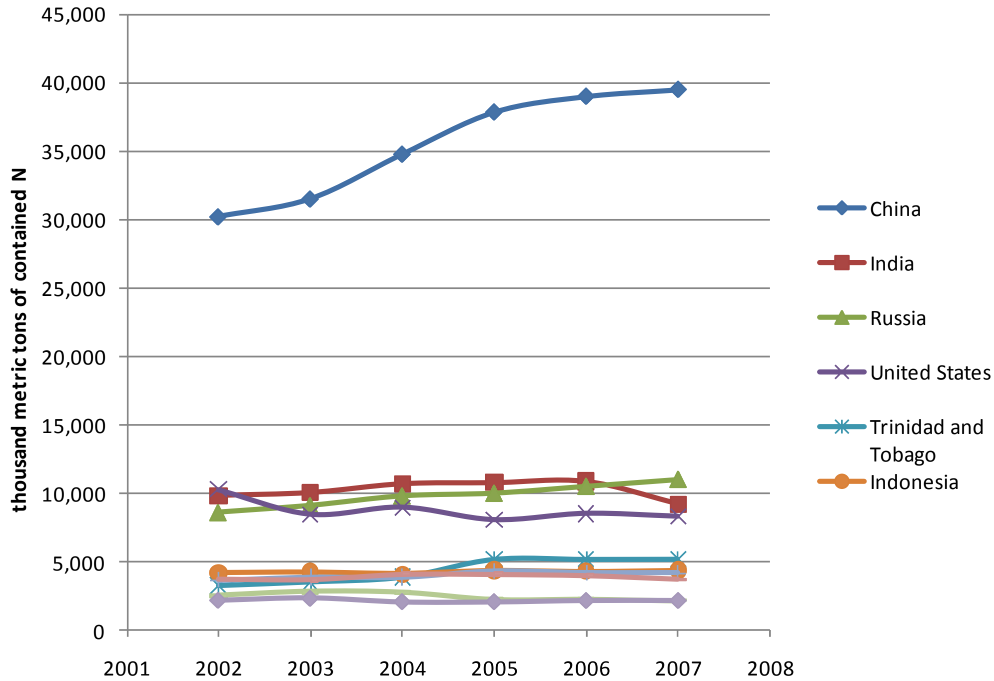
3.4 Ammonia

3.4.1 International Standing

China's important role in the production of key fertilizers is reflected in its dominating and continually increasing production of nitrogen nutrients. In 2002, China already had the world's largest nitrogen nutrient production at 27.6 million tons of nitrogen or 31% of total global production. By 2006, Chinese nitrogen nutrient production increased to 35.3 million tons with over 36% share of global production. As seen in

Figure 44, production increased most notably between 2005 and 2006 with additional production of nearly 5 million tons of nitrogen.

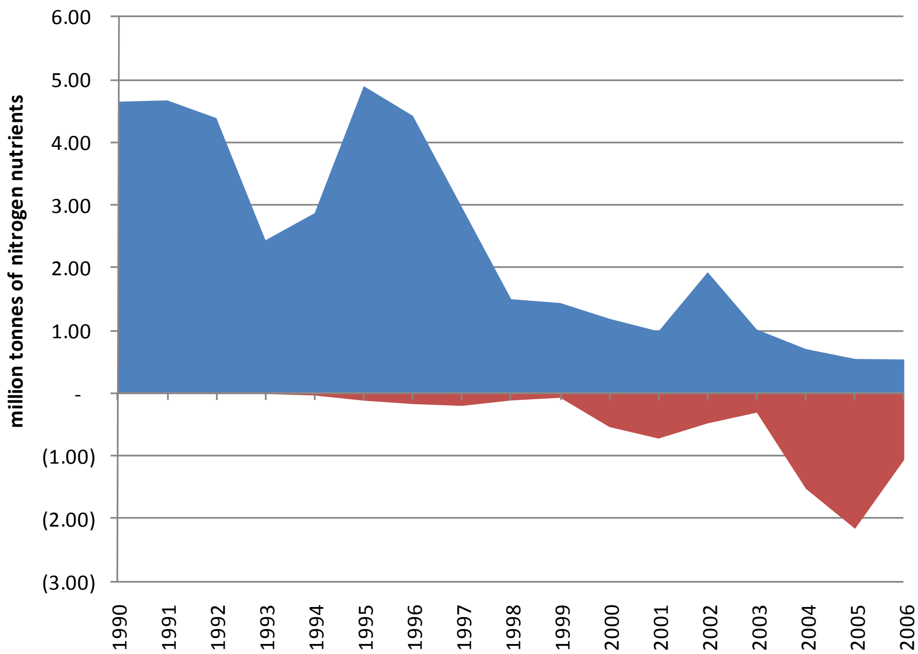
Figure 44: Global Nitrogenous Nutrient Production



Source: USGS

With its large production scale, China's nitrogen fertilizer imports have decreased while its exports have increased in recent years. From 2002 to 2006, for instance, imports of nitrogen nutrients were reduced by 1.3 million tons to 527 thousand tons. Despite decreases some years, the overall export of nitrogen nutrient fertilizers have increased, with notable increases of 1.7 million tons of exports between 2003 and 2005 (Figure 45). In 2006, China ranked as the fifth largest exporter of nitrogen nutrients, behind Russia, the U.S., Canada and Saudi Arabia, respectively, with a net 2 million tonnes of chemical fertilizer exports in 2007.

Figure 45: Volume of Fertilizer Trade, 1995-2007



Source: UN Comtrade Database

3.4.2 Technology Trends

The most energy-intensive step in producing nitrogenous fertilizers is manufacturing ammonia by combining nitrogen and hydrogen under the Haber-Bosch process. The Haber-Bosch process is powered by high-pressure synthesis gas that produces hydrogen. For China specifically, the feedstock for synthesis gas in 2004 included 70.3% coal, 22.7% natural gas and 7% oil.[29] For Chinese ammonia plants that use coal as feedstock, a coal gasifier is used to convert coal to synthesis gas. However, the more recent plants that opened in Nanjing in 2003, Jilin and Haolianghe in 2004 and Hubei, Anqing and Donting in 2006 all use Shell or ChevronTexaco gasification technology.

3.4.3 Energy Intensity and Fuel Mix

Although China's current ammonia production energy intensity lags behind the world best practice and FYP goals, the national FYP goals for 2010 and 2020 are actually lower than current world best-practice energy intensity. For example, the 2020 energy intensity goal of 29.3 GJ/ton NH_3 is much lower than the current world best practice intensity of 34.8 GJ/ton NH_3.[30]

In terms of fuel mix, the study used the same assumed ammonia feedstock composition and production fuel shares for both scenarios. Based on reported data for China's 2005 feedstock composition, we assumed constant feedstock shares of 70% coal, 20% natural

[29] Worrell, et. al. 2008. "World Best Practice Energy Intensity Values for Selected Industrial Sectors." LBNL Report.

[30] Worrell et. al., 2008, "World Best Practice Energy Intensity Values for Selected Industrial Sectors." Lawrence Berkeley National Lab Report LBNL-62806.

gas and 10% oil through 2025. Constant fuel shares of 68% coal, 20% natural gas, 10% heavy oil and 2% electricity were also used for calculating energy consumption and emissions in the two scenarios.

3.4.4 Drivers

The rapid urbanization experienced in China since the early 1980s has corresponded to overall changes in cultivated land. From 1986 to 2000, 30% of cultivated land was converted to grassland, 17% converted to forest area and 40% converted to built area with new construction projects.[31] The concurrent conversion of forests, grasslands and other areas into newly cultivated area has resulted in notable fluctuations in cultivated or sown area over the last three decades.

Rapid urbanization has also driven ammonia demand by affecting changes in specific types of agricultural production. Specifically, with rising incomes in urban households, greater demand for meat-based diet has increased the demand for animal feed from maize and soybean production. Increased maize production is often linked to corresponding reductions in land sown for wheat and rice. Growing urban demand and a readily available labor supply have also increased the labor-intensive production of fruits and vegetables. With China as one of the largest global fruit and vegetable producer, vegetable acreage alone has increased by 2.3 million hectares from 2000 to 2004. From 1992 to 2002, China's fruit and vegetable exports tripled with China producing nearly half of the world's vegetables, 16% of the world's fruit and 36% of the world's apples.[32] These increases in fruit and vegetable production have direct linkages to greater demand for nitrogenous fertilizers, as the average fertilizer application rate for fruit and vegetable production is doubled that for cereal production. In fact, about half of the increase in China's recent fertilizer demand has been attributed to increased fruit and vegetable production.

3.4.5 Scenarios

For both the BAU and CLU scenarios, key assumptions about sown area, fertilizer application rates and exports are used to derive China's total ammonia production through 2025. These assumptions were based on extensive literature review of China's agricultural land change and fertilizer application, as well as close examination of historical data for each of the three categories. Further assumptions about the overall energy intensity of ammonia production and the energy shares of primary fuels formed the basis for estimating the total energy required for ammonia production and the corresponding primary energy form.

Sown Area

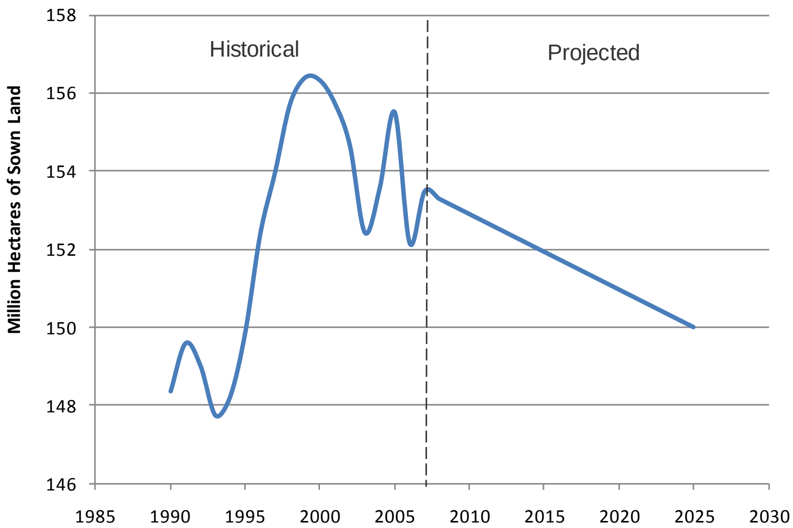
As a unique Chinese categorization of total area of land on which crops are planted and from which harvest is expected unique, sown area is typically larger than cultivated area since land is frequently sown two or more times a year. The total sown area in China has

[31] Deng, X., J. Huang, S. Rozelle and E. Uchida. 2006. "Cultivated Land Conversion and Potential Agricultural Productivity in China." *Land Use Policy* 23: 372 – 384.
[32] Crook, F. W. and W. H. Colby, 2006, "The Future of China's Grain Market." U.S. Department of Agriculture Economic Research Service Report AIB-730.

fluctuated between a low of 144 million hectares and a high of 156 million hectares in the last 30 years (

Figure 46) with annual growth rates ranging from a 2.48% decrease to a 3.3% increase in sown area.

Figure 46: Total Sown Area in China, 1978 - 2007



Source: Historical data from NBS; Projections from LEAP Model.

Based on these historical fluctuations and a literature review of projected Chinese arable land loss related to urbanization, the model assumed a net decrease of 3.46 million hectares, or 2% in sown area, from 2007 to 2025 with 150 million hectares of total sown area by 2025. This assumption was applied to both the BAU and CLU scenarios.

Nitrogenous Fertilizer Application Intensity

For the BAU scenario, assumptions about future fertilizer application intensities were based on the development experiences of South Korea, a comparable agriculture-dominated country in Asia. Korea serves as a valuable guide to China's future agricultural situation because of similarities in agricultural system and the relationship between nutrient outputs and inputs, as illustrated in a 2003 paper using Korea as a nutrient balance model for China. [33] At the same time, Korea has a more highly developed agricultural industry that could forecast the Chinese industry's future conditions, including its higher application intensity of 224.92 kg N nutrients per hectare that was assumed to be true for China by 2025 under the BAU scenario.

For the CLU scenario, our assumption was informed by data on China's application intensity of nitrogenous fertilizers in recent years, with small growth from 138.3 kg

[33] Sheldrick, et. al., 2003, "Soil nutrient audits for China to estimate nutrient balances and output/input relationships." *Agriculture, Ecosystems and Environment* 94: 341-354

nitrogenous fertilizer per hectare to 149.7 kg per hectare between 2000 and 2007.[34] Under CLU's lighter development trajectory, it was projected that China will not increase its fertilizer application intensity and thus remains constant at the 2005 rate of 200.79 kg N nutrients per hectare (including N nutrients in compound fertilizers).

Trade
Since China has been a relatively small importer of nitrogen nutrients in recent years, we assume that China maintains self-sufficiency through 2025 for both the BAU and CLU scenarios. For exports, however, we assume that China will maintain constant exports equal to its annual exports in the base year of 2005 under BAU. For CLU, we assume that China will gradually reduce its exports in its efforts to lighten its industrial sectors, with a linear drop from 2005 export levels to zero net exports by 2025.
A summary of ammonia's drivers and assumptions behind the two scenarios are presented below.

Table 7: Variables for Ammonia Scenario Analysis

<table>
<tr><th colspan="2"></th><th>Business as Usual Scenario</th><th>China Lightens Up Scenario</th></tr>
<tr><td rowspan="5">Ammonia Production Assumptions</td><td>Sown Area</td><td>Linear extrapolation assuming total sown area is reduced from current levels to 150 million hectares by 2025</td><td>Same as BAU</td></tr>
<tr><td>Application intensity of nitrogenous fertilizers</td><td>Assume China reaches Korea's 2005 application intensity of 224.92 kg N nutrients/ha by 2025</td><td>Assume China's 2007 application intensity of 200.79 kg N/ha remains constant through 2025</td></tr>
<tr><td>Total ammonia required for domestic use</td><td>Product of sown area and application intensity of nitrogen nutrients, with chemical conversion to units of NH3</td><td>Same as BAU</td></tr>
<tr><td>Exports of ammonia</td><td>Assume 2005 exports of 2.164 million tons remain constant through 2025.</td><td>Assume exports drop linearly from 2.164 million tons in 2005 to 0 by 2025.</td></tr>
<tr><td>Total production of nitrogenous fertilizers</td><td>Calculated by adding total ammonia required for domestic use and exports, assuming China is a net exporter of ammonia with zero imports</td><td>Same as BAU</td></tr>
</table>

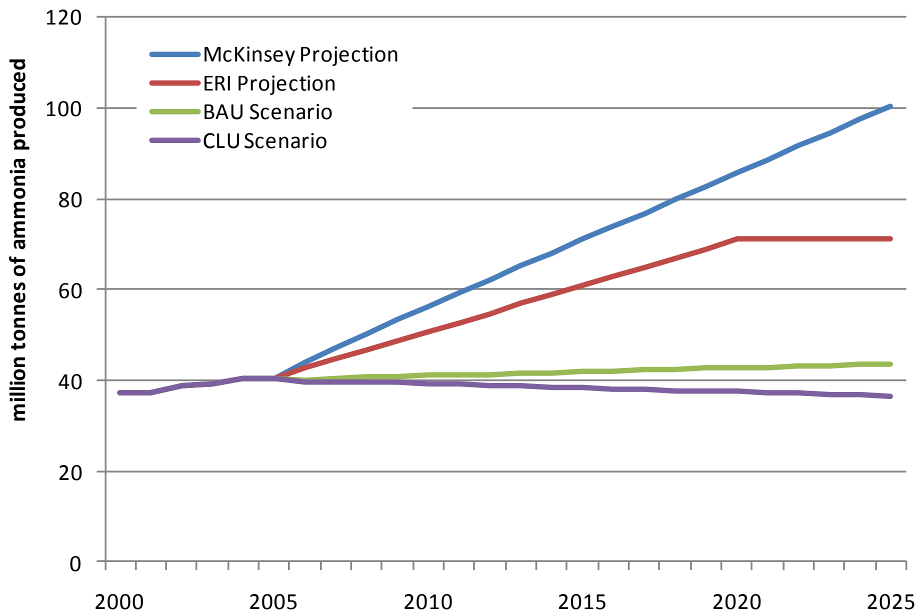
[34] Note: These numbers are lower than the numbers reported by United Nation's FAOSTAT database and used in the modeling analysis because Chinese data are reported in units of nitrogenous fertilizers that does not include nitrogen nutrients used in compound fertilizers.

Production Energy Assumptions	Overall ammonia production energy intensity	Assumes 2005 energy intensity constant from 2000 - 2005. After 2005, linear extrapolation assuming China reaches current world best practice intensity of 34.8 GJ/ton or 1189 kgce/ton by 2025	Assumes 2005 energy intensity constant from 2000 - 2005. After 2005, linear extrapolation based on China's Five-Year Plan goals of 1372 kgce/ton for 2000, 1210 kgce/ton for 2005, 1140 kgce/ton for 2010 and 1000 kgce/ton for 2020
	Primary energy forms required for ammonia production	Assume 2005 fuel mix of 70% coal, 20% natural gas, and 10% oil is frozen through 2025.	Same as BAU
	Total energy required for ammonia production	Calculated by multiplying overall ammonia production energy intensity by total domestic production.	Same as BAU

Projections for Total Ammonia Production

For both scenarios, projections for China's total ammonia production for domestic use were calculated using the equation: *(sown area*fertilizer intensity) + net exports*. The subsequent projections are presented below in the context of other projections by ERI and the McKinsey Institute.

Figure 47: BAU and CLU Scenarios of Chinese Ammonia Production, 2000-2025

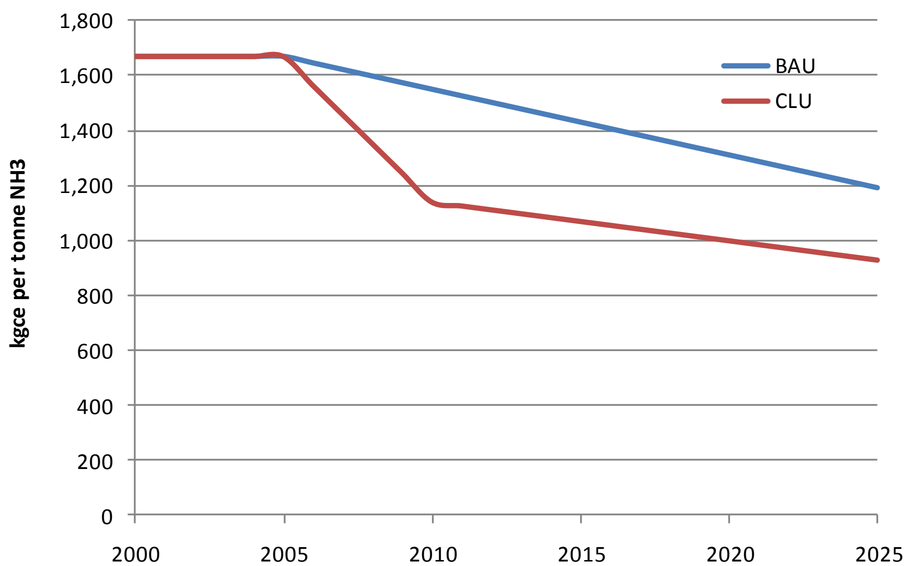


As seen in Figure 47, there is a larger difference in projected ammonia production between the BAU and CLU scenarios over time due to growing production under BAU and declining production under CLU. Consequently, the total potential production savings from the CLU scenario in comparison to BAU scenario is 74.1 million tons of ammonia.

Energy Intensity and Primary Fuels of Ammonia Production

Unlike other sub-sectors where future FYP goals lag behind world best practice, ammonia's energy intensity assumption is the reverse in that BAU assumes China reaches the current world best-practice (with coal as a feedstock) by 2025 while CLU scenario assumes the FYP targets are achieved.

Figure 48: Energy Intensity of Ammonia Production, 2000-2025 (BAU and CLU)

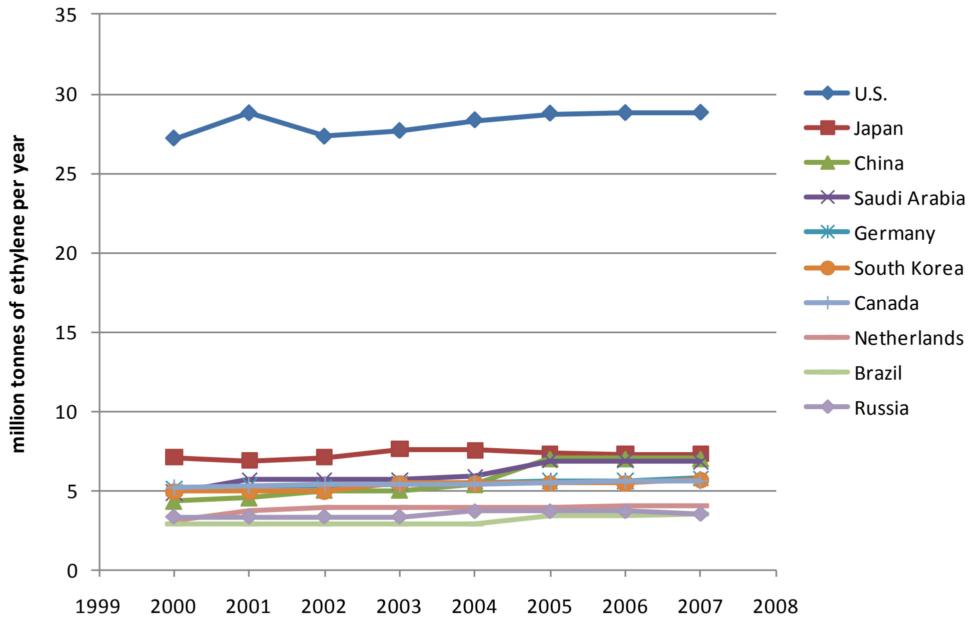


3.5 Ethylene

3.5.1 International Standing

While most of the other major ethylene producers have not expanded their production capacity within the last decade, China's production capacity has grown notably in recent years, along with Saudi Arabia. In 2000, China's share of global ethylene production capacity in 2000 was only 4.2%, or one-sixth of U.S. production capacity. From 2000 to 2005, however, China's ethylene production capacity increased by 2.7 million tons per year. With an annual production capacity of 6.8 million tons of ethylene per year from 2005 to 2007, China is ranked as third amongst the top ten producers with a 5.8% global share of capacity (Figure 49).

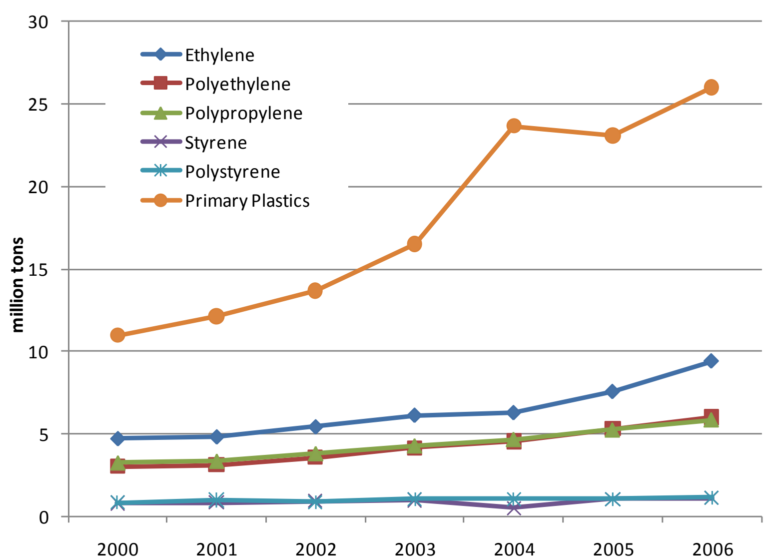
Figure 49: World Ethylene Production Capacity, 2000 - 2007



Source: *Oil and Gas Journal*, various years.

Similarly, China's production of primary plastics, polyethylene, polystyrene and polypropylene have all increased within the last ten years. Most notably, Chinese production of primary plastics more than doubled from 2000 to 2004, increasing from annual production of 10.97 million to 23.66 million tons. Polyethylene and polypropylene have both grown at similar rates as ethylene, with production of each polymer increasing from 3 million to nearly 6 million tonnes from 2000 to 2006. In contrast, polystyrene and styrene have grown at a slower pace, with production of each polymer increasing by 300,000 tonnes during the same period.

Figure 50: China's Ethylene Polymers Production



Source: NBS

At the same time, China's ethylene imports have undergone astounding growth on the order of a six-fold increase from 85 thousand tons in 2002 to 510 thousand tons in 2007 while exports have fluctuated between 22 thousand tons and 129 thousand tons. Besides Germany, China is the largest ethylene importer amongst the ten countries with the greatest ethylene production capacity. In terms of total plastics (ethylene and ethylene derivatives), China imported a net 14 million tonnes of plastic in 2007.

China is also a major importer of high and low density polyethylene, polypropylene and styrene, with imports outpacing exports by between two to four orders of magnitude. For high density polyethylene and polypropylene, imports doubled from 2000 to 2007 with increases from 1.2 to 2.4 million tons for polyethylene and 1.6 to 3.0 million tons for polypropylene. Exports, while increasing over time, have remained below 38,000 tons for polyethylene and below 32,000 tons for polypropylene. For low density polyethylene, imports have fluctuated between 773,000 and 2.4 million tons while exports have stayed below 15,600 tons during the same period. For styrene, imports have fluctuated between 3.1 and 3.8 million tons while exports have generally increased from 96,000 tons to 356,000 tons.

3.5.2 Technology Trends

As with other petrochemical refining, ethylene is produced through a thermal or steam cracking process where the feedstock, e.g., ethane or naphtha, is heated to high temperatures of 750 – 900°C for cracking and then quenched to lower temperatures to stop the reaction. There are typically four steps in the production process, including thermal or steam cracking, gas compression and treatment, production separation and refrigeration. The two most common types of feedstock are ethane and naphtha, with naphtha becoming increasingly dominant in China. As a heavier feedstock however, naphtha requires more energy for the cracking process, as much as double a lighter feedstock like ethane.

Another important technology trend in Chinese ethylene production is the increase in production unit size both in terms of newer units coming online and capacity expansion of existing units. The average production unit size has nearly doubled from 260,000 tons/year in 2001 to 460,000 tons/year in 2006.[35] The new major units that have recently come online belong to Sinopec and CNPC, including one 1 million ton/year unit, two 700,000 tons/year unit and one 650,000 tons/year unit for Sinopec and two 700,000 tons/year units and one 600,000 tons/year unit for CNPC. By 2007, there were a total of 21 ethylene production units with unit production capacity ranging from 140,000 tons/year to 1 million tons/year.

3.5.3 Energy Intensity and Fuel Mix

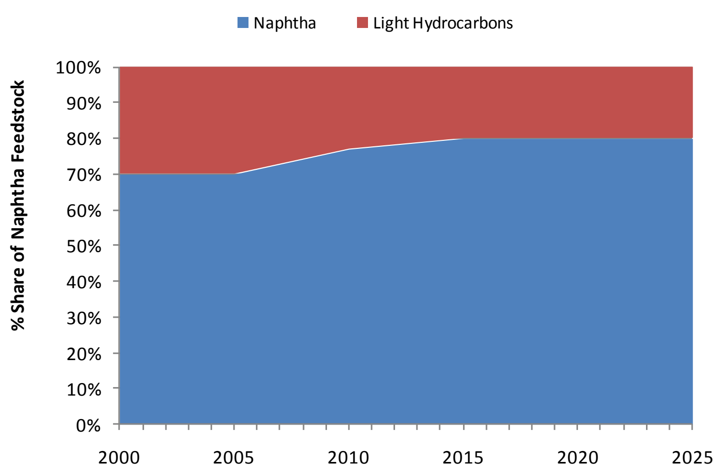
World best practice energy intensities for different steps of the ethylene production process with naphtha as a feedstock are available in the Worrell, et. al. paper. In the absence of actual data for Chinese ethylene production energy intensity, the overall intensity targets set by Five-Year Plans and the Medium and Long-Term Plan for Energy

[35] Yu Jing. 2007. "China Economic Outlook and Market for Olefins." China Chemical Reporter, Oct. 6th issue, 18 -21.

Conservation are used. China's 2020 target energy intensity value is significantly higher than the current world best practice because of its high reliance on naphtha, compared to more ethane-based production in other countries.

As ethylene is produced from feedstock that varies in energy requirements, the same assumptions for ethylene feedstock composition were used for both BAU and CLU scenarios. Based on a literature review of existing projections for Chinese shares of ethylene feedstock, we assumed increasing naphtha share in feedstock, growing from 70% in 2005 to 80% in 2015 and remains constant thereafter.[36] The remaining share of feedstock is grouped together as lighter-end hydrocarbons, which includes gas oil, hydrocracking tail oil and other light hydrocarbons.

Figure 51: Naphtha Feedstock Fuel Mix



Source: Projections based on data from *Oil and Gas Journal*.

3.5.4 Demand Drivers

With growing urbanization, ethylene demand is driven largely by greater demand for polymers such as high and low-density polyethylene, polypropylene and styrene. High demand for polyethylene is likely with continued urbanization given their applicability to be substituted for non-synthetic, nondurable goods like grocery and garbage bags, food packing and shipping containers. Polypropylene will also continue to be in great demand due to its applications in the production of mechanical parts, containers, fibers and films and as a popular substitute for non-plastic materials such as paper, concrete and steel. In fact, 33% of new capacity additions for propylene are expected to take place in Asia.[37]

Finally, growth of demand for styrene and polystyrene is also driven by urbanization and its related increase in construction. In fact, recent legislation mandating the increased use of polystyrene has driven out competition from other chemicals in the construction

[36] Wang and Wu, 2004, "China's ethylene sector continues to expand, attract foreign investment." *Oil and Gas Journal* 102 (1): 46 – 54.
[37] Eramo, M. 2005. "Ethylene, propylene demand will experience increased growth in 2005-10." *Oil and Gas Journal* 103 (45): 52-60.

industry.[38] As a result, China has started importing large amounts of styrene monomer and derivatives in recent years.

3.5.5 Scenarios

For both scenarios, the total projected ethylene production is derived from key assumptions about population, per capita demand for primary plastic and ethylene, ethylene imports. The total energy demand for producing ethylene is then derived from assumptions about the overall energy intensity and primary fuel mix for ethylene production.

Per capita demand for primary plastic & ethylene

For per capita demand of primary plastic and ethylene, the BAU and CLU scenario projections were based on the consumption experience of Japan, a comparable developed country in Asia. For BAU, we assume that China reaches Japan's 2007 primary plastics demand of 107.95 kilograms per person by 2025 while for CLU, we assume that China reaches a lower plastic demand level of 75 kilograms per person by 2025.[39] Historical data on per capita plastics and ethylene consumption collected from various Chinese statistical yearbooks contextualized these assumptions given the rapid increase from 8.65 kilograms of plastics per capita to 24.10 kilograms per capita by 2007.

Since no comparative international data was available for per capita ethylene demand, the estimated per capita primary plastics demand was used to estimate per capita ethylene demand based on recent shares of ethylene in the production of primary plastics. From 2000 to 2007, the ratio of ethylene to total primary plastics ranged from 0.27:1 to 0.43:1 with an average ratio of 0.36:1. Therefore, projections for per capita ethylene demand were derived on the basis that the ethylene to plastic ratio will remain at 0.36:1.

Trade

Since Chinese imports of ethylene has outpaced exports by two to three orders of magnitude and domestic demand is expected to continue increasing, we assume zero net exports as China will export a negligible amount, if any, of ethylene in the near future. Given China's limited ethylene production capacities, it is also unlikely that all domestic demand can be fulfilled without any imports in the near future. For BAU and CLU scenarios, China is projected to freeze its ethylene imports at the 2005 level through 2025 because imports have stayed around 5 million tons in the last eight years.

[38] 2003. "Styrene industry poised for an up cycle." *Oil and Gas Journal* 101 (8): 64-67.
[39] Japanese plastic consumption data collected from Japan Plastics Industries Association, "Sales of Plastic Materials 2007 Japan."

Table 8: Assumptions of Ethylene Scenario Analysis

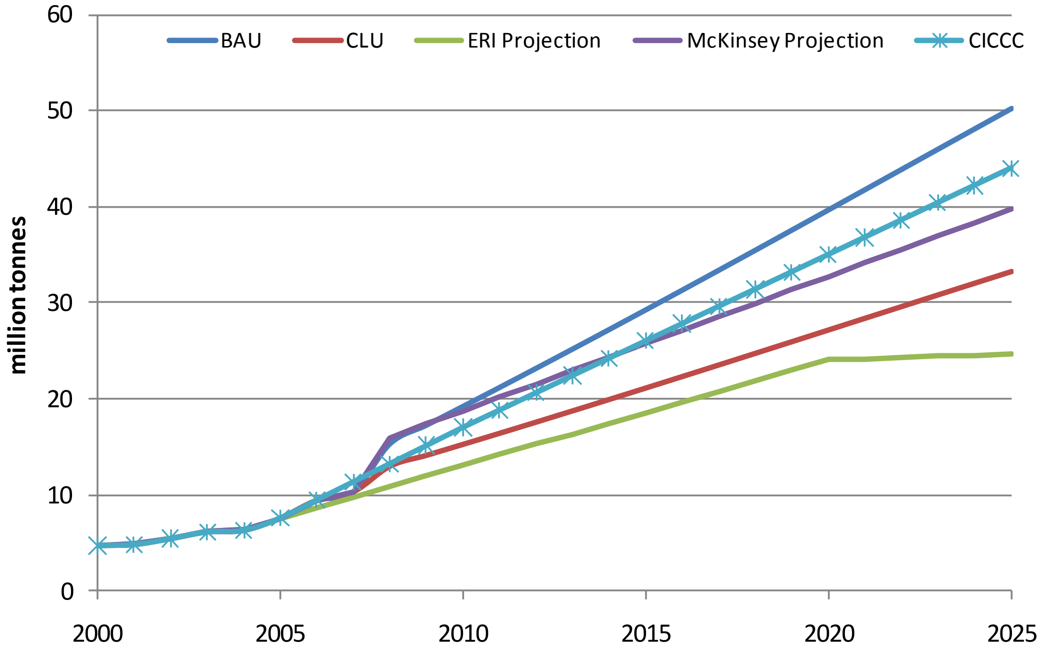
		Business as Usual Scenario	China Lightens Up Scenario
Ethylene Production Assumptions	Population	Linear extrapolations based on UN Population Database projections	Same as BAU
	Per capita demand for primary plastic	Linear extrapolation based on assumption that China reaches Japan's 2007 plastics demand of 107.95 kg/person by 2025	Linear extrapolation based on assumption that China reaches a lower plastic demand level of 75 kg/person by 2025
	Estimated per capita demand for ethylene	Proportional share of per capita demand for primary plastic, assuming a historical average ratio of 0.36:1 for ethylene:plastic holds through 2025	Same as BAU
	Imports of ethylene	Assume Chinese 2005 annual imports of 5.71 million tons remain constant through 2025	Same as BAU
	Total domestic production of ethylene	Calculated as (population*per capita plastic demand*plastic demand as share of total ethylene demand) – (net imports)	Same as BAU
Production Energy Assumptions	Overall ethylene production energy intensity	Linear extrapolation based on China's Five-Year Plan goals of 848 kgce/ton for 2000, 700 kgce/ton for 2005, 650 kgce/ton for 2010 and 600 kgce/ton for 2020	Linear extrapolation assuming China reaches 2007 world best practice intensity of 478 kgce/ton by 2025
	Primary energy forms required for ethylene production	Linear extrapolation assuming naphtha share reaches 70% in 2005, 77% in 2010 and stays constant at 80% after 2015. Assume remaining share is from lighter-end hydrocarbons.	Same as BAU
	Total energy required for ethylene production	Calculated by total production*energy intensity for given year.	Same as BAU

Projected Total Production of Ethylene

For both scenarios, total domestic production of ethylene is estimated by the equation: *(population*per capita plastic demand*plastic demand as share of total ethylene demand) – (net imports).*

The resulting scenario productions for BAU and CLU are presented in Figure 52, along with existing projections made by ERI, the McKinsey Institute, and the China International Chemical Consulting Company (CICCC).

Figure 52: Chinese Ethylene Production Scenarios

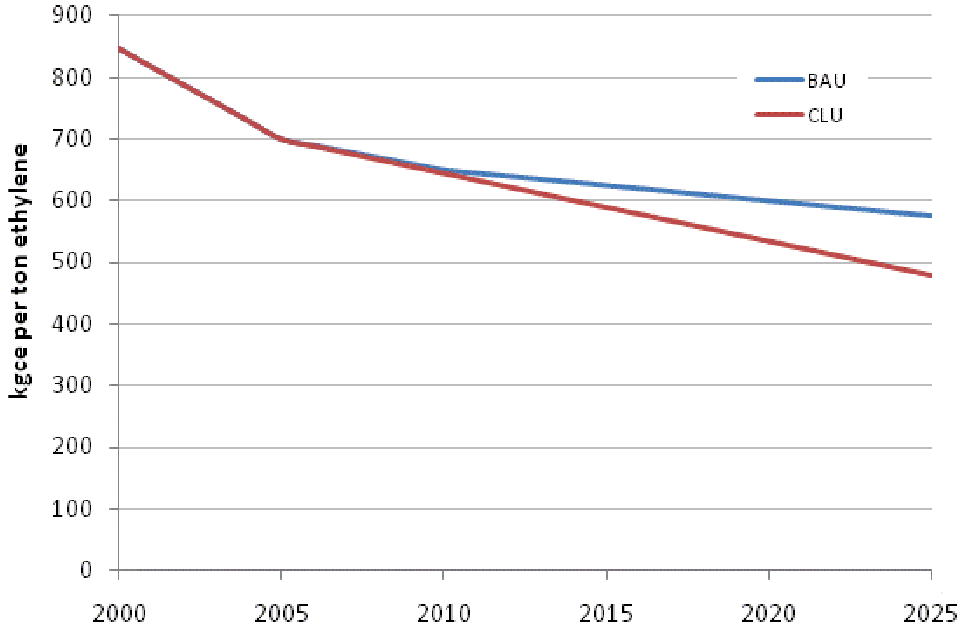


As seen above, the projected BAU and CLU scenario production are well within the range of existing projections of 2005 – 2025 ethylene production. While the BAU scenario sets the upper bound for production, the CLU scenario represents a lower bound with the lowest range of production after ERI projections. Interestingly, only the ERI projection expects ethylene production to flatten out after 2020.

Energy Intensity and Primary Fuels for Ethylene Production

BAU and CLU future ethylene production intensity trends were based on China's stated goals for energy intensity and current world best practice energy intensity values. Since the world best practice primary energy intensity for ethylene production is much more stringent than China's current levels and future targets, the BAU scenario assumes that China only reaches its targeted energy intensity values for 2010 and 2020. For the CLU scenario, in contrast, it is assumed that China follows the more ambitious path of reaching world best practice by 2025 (
Figure 53).

Figure 53: BAU and CLU Energy Intensity for Ethylene Production



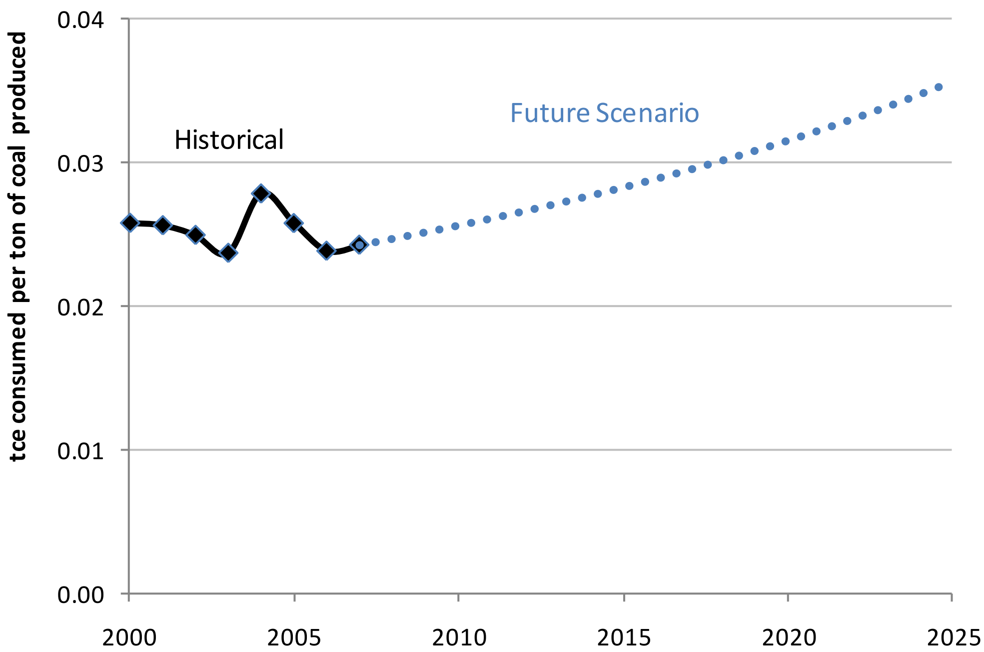
3.6. Efficiency of Energy Extraction & Transformation

In addition to different scenario assumptions about energy efficiency improvements in energy-intensive industrial material production, the model also included assumptions about the energy intensiveness of energy extraction, processing and transformation. Assumptions for Energy Return on Energy Investment (EROEI) ratio, or the quotient of usable acquired energy from coal, oil and natural over energy expended, were included for coal mining and oil and natural gas extraction was used to project. Additional assumptions about conversion and transformation efficiency levels for coke, oil refining and electricity generation were also included for both scenarios.

3.6.1. Coal Mining

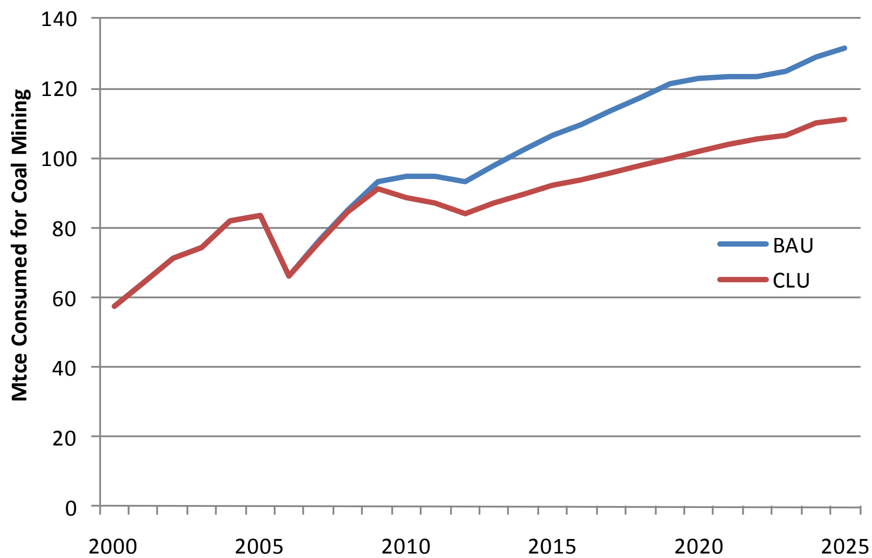
For coal mining, this study assumes that the final energy intensiveness per ton of coal produced will increase after 2006 with continued extraction from existing reserves (Figure 54). In other words, more energy will be required as an input to coal extraction as existing resources become depleted over time. The inverse of energy intensiveness or EROEI is expected to decline over time for a non-renewable resource such as coal. In this study, the EROEI for final energy in coal mining is assumed to decrease from 27.67 in 2005 to 20 in 2025.

Figure 54: Final Energy Intensiveness of Coal Mining



The total final energy consumed in coal mining can be calculated by dividing total coal production by EROEI, and the model results for energy inputs to coal mining is depicted below. With lower coal consumption under the lighter CLU development scenario, lower total energy input is required for coal mining. In 2025, coal mining under CLU requires 20.6 mtce less energy than BAU coal mining.

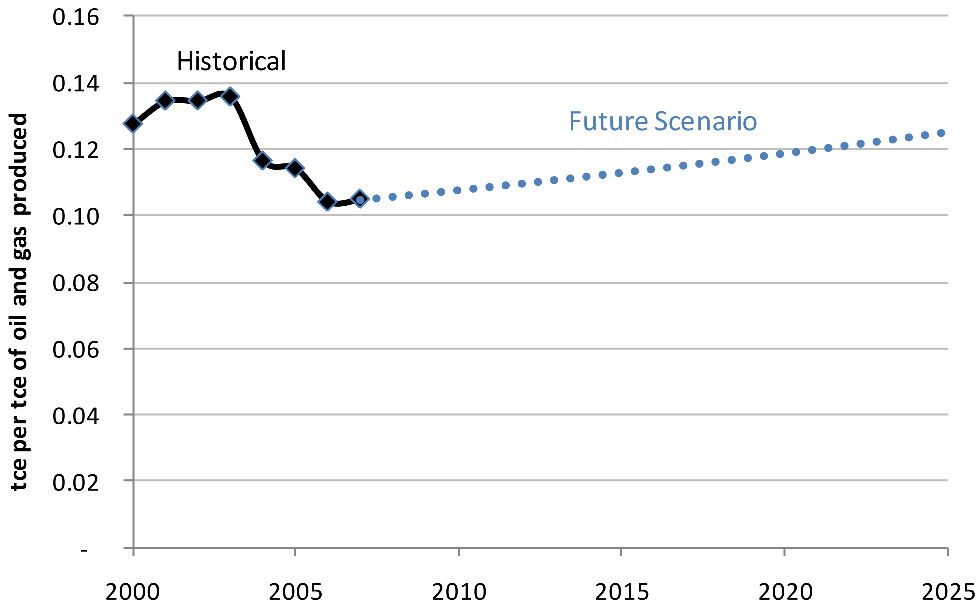
Figure 55: Total Final Energy Consumed in Coal Mining



3.6.2. Oil and Natural Gas Extraction

As with coal mining, the final energy intensiveness of oil and natural gas extraction are expected to increase over time with a declining EROEI (Figure 56). For both scenarios, the final energy intensiveness of oil and natural gas extraction is expected to increase from 0.10 in 2007 to 0.13 tce per tce of oil and gas produced in 2025. At the same time, the EROEI for oil and natural gas extraction declines from 9.54 in 2007 to 8 in 2025.

Figure 56: Final Energy Intensiveness of Oil & Natural Gas Extraction



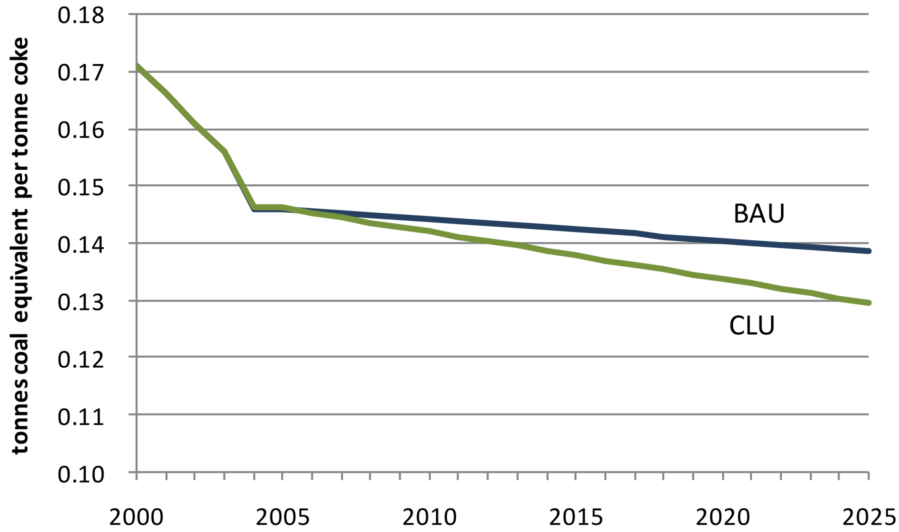
The total energy input to oil and natural gas extraction will increase gradually from 22 Mtce in 2006 to 24.7 Mtce in 2015 before declining to 19.6 Mtce in 2025 as production of oil and gas decline.

3.6.3. Coking

From 2005 to 2025, the energy input to producing coke is expected to drop dramatically from 0.17 to 0.145 tce per tonne of coke. After 2005, the energy input to coking will continue to decrease but at a much slower speed for both the BAU and CLU scenarios (

Figure 57). The CLU scenario will have a slighter greater decline in energy input than BAU scenario, reaching 0.13 tce per tonne of coke rather than 0.14 tce per tonne of coke.

Figure 57: Coke Energy Intensity Trends, 2000 - 2025

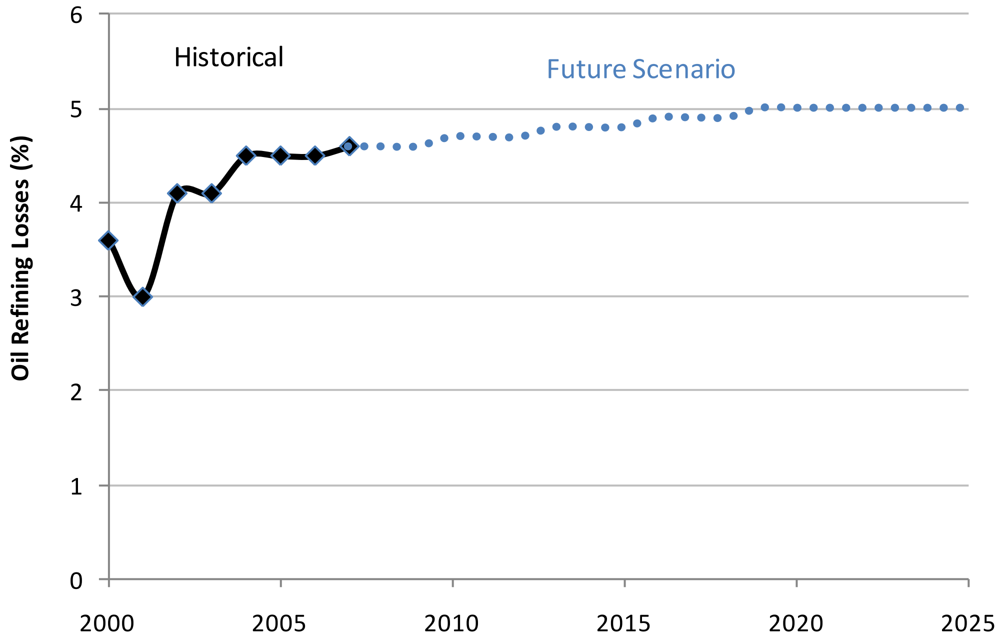


3.6.4. Oil Refining

The efficiency of the oil refining unit process is also expected to decrease slightly during the next decade with rising refinery energy use as suggested by Japan's recent experience with unit refining fuel use increase by 34% from 1990 to 2007.[40] In the Japanese case, rising refinery energy use was primarily the result of a shift towards lighter oil product yield that is more energy intensive and improvements in fuel quality. As China is also expected to increase production of lighter oil products and improve fuel quality for environmental reasons, both the BAU and CLU scenarios are assumed to have decreasing efficiency in oil refining unit process at rates similar that what Japan has experienced (Figure 58).

[40] Japan Petroleum Energy Center, 2008. "Our Background and Objectives: Focus on Climate Change Policy in Japan and Petroleum Industry."

Figure 58: Oil Refining Losses, 2000-2025



3.6.5 Power Generation

The projected power generation fuel mix and capacity by type are shown in Figure 59 and

Figure 60. The majority of power generation will continue to come from coal, with growing shares in more efficient nuclear and natural gas fired generation and in wind and other renewables. By 2025, wind power and nuclear installed power capacity will both reach 83 GW while coal-fired installed capacity reaches nearly 1000 GW and hydropower reaches 300 GW. This follows increases in the installed capacity of all types of power generation, except oil fired generation units that are displaced after 2010.

Figure 59: Power Generation and Fuel Mix, 2000-2025

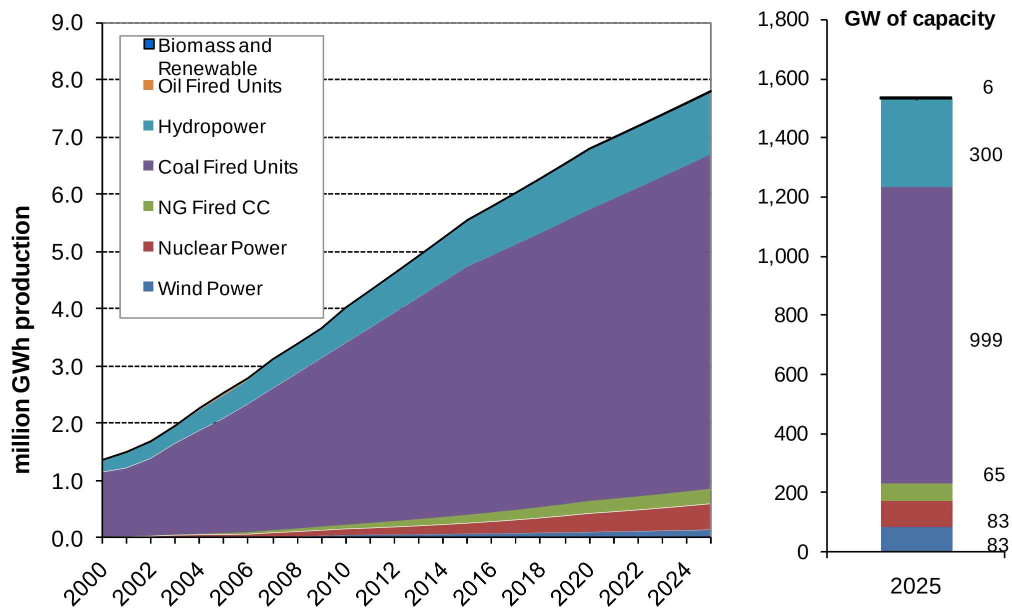
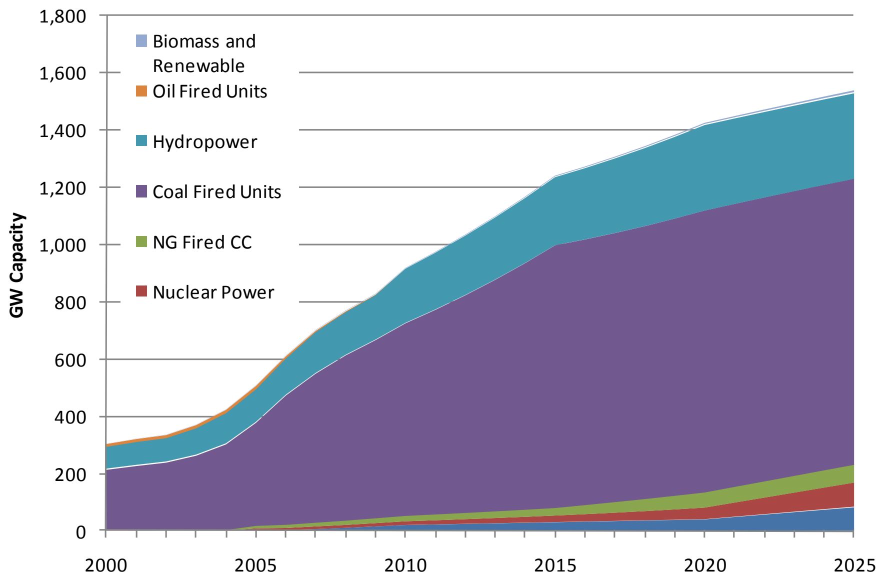
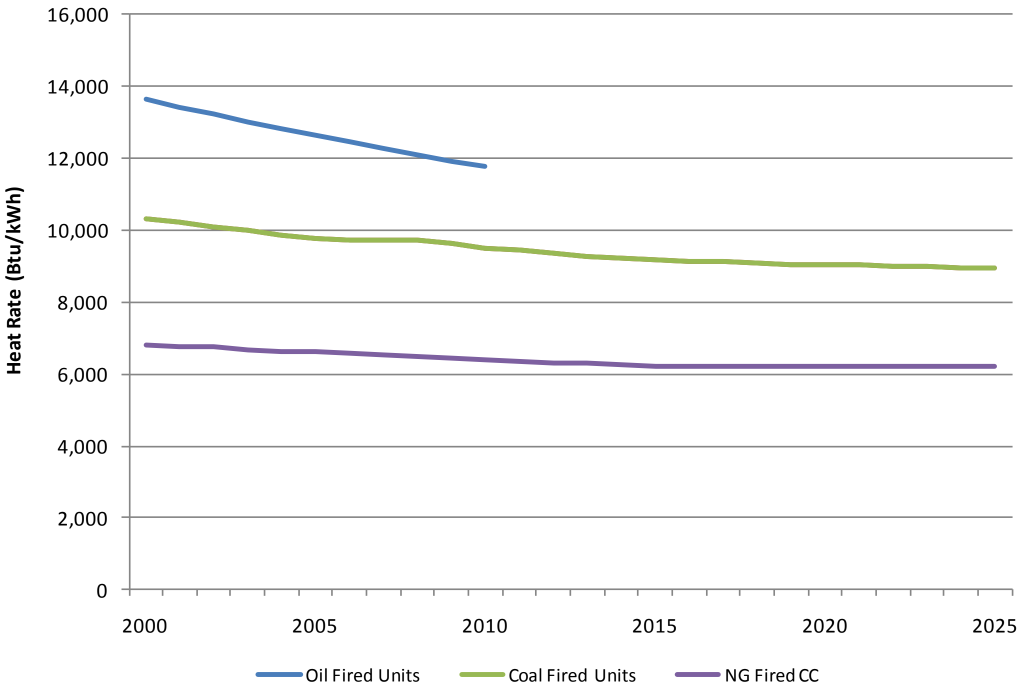


Figure 60: Power Generation Capacity, 2000 - 2025



Besides total generation capacity, the projected heat rate of energy output per unit of feedstock energy consumed for each type of generation are also reflected in the model (Figure 61). The heat rate for nuclear power and coal-fired units both decline over time to 9000 Btu/kWh by 2025. Similarly, the natural gas generation heat rate also declines slightly from 6600 Btu/kWh in 2005 to 6200 Btu/kWh in 2025.

Figure 61: Power Generation Heat Rates, 2000 - 2025

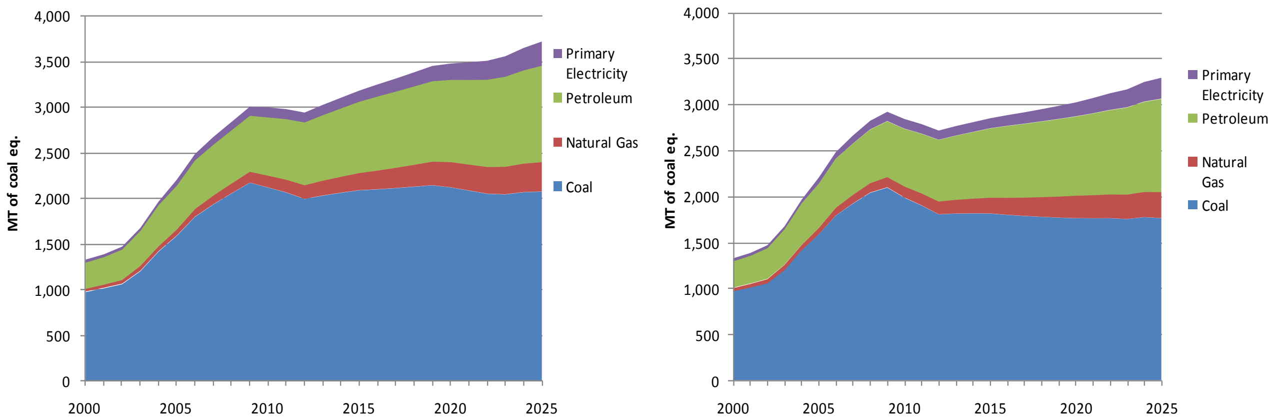


4. Results

4.1 Overall Results

The LEAP model results show that under BAU scenario, China's total energy use in primary terms will continue to rise sharply from 2213 Mtce in 2005 to 3004 Mtce in 2010 before continuing a slower rise to 3726 Mtce in 2025 (Figure 62, left). Under CLU scenario with lower urbanization levels and export activity, total energy use dips slightly between 2010 and 2014 before rising at a slower pace to 3296 Mtce by 2025 (Figure 62, right). On average, the LEAP model projects that a 1% increase in urbanization corresponds to an increase of 13 Mtce in energy consumption from both the residential building and industrial sectors. Under both scenarios, the total primary energy consumption will largely be supplied by coal with growing shares of petroleum and natural gas. Specifically, coal share of primary energy will decline from 72% in 2005 to 56% and 54% in 2025 for BAU and CLU, respectively, while petroleum share increases from 22% to 29% (or 31% for CLU) and natural gas share increases from 3% to 8% in both scenarios.

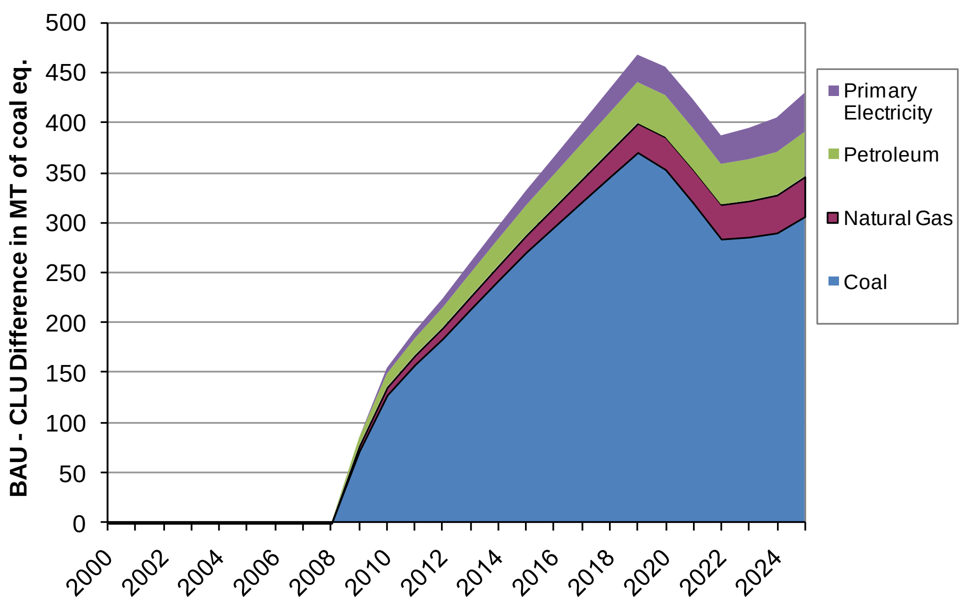
Figure 62: BAU and CLU Scenario Total Energy Use



Source: LBNL CLU model

LEAP results also show that the lower urbanization levels and exports modeled for CLU scenario together reduces total annual energy use by 430 mtce in 2025, or cumulative energy reduction of 5.7 billion tonnes of coal equivalent from 2008 to 2025 (Figure 63). The vast majority of primary energy reduction under the CLU scenario will be in the form of coal, followed by similar shares of savings from primary electricity (hydro, nuclear and renewable electricity), petroleum and natural gas.

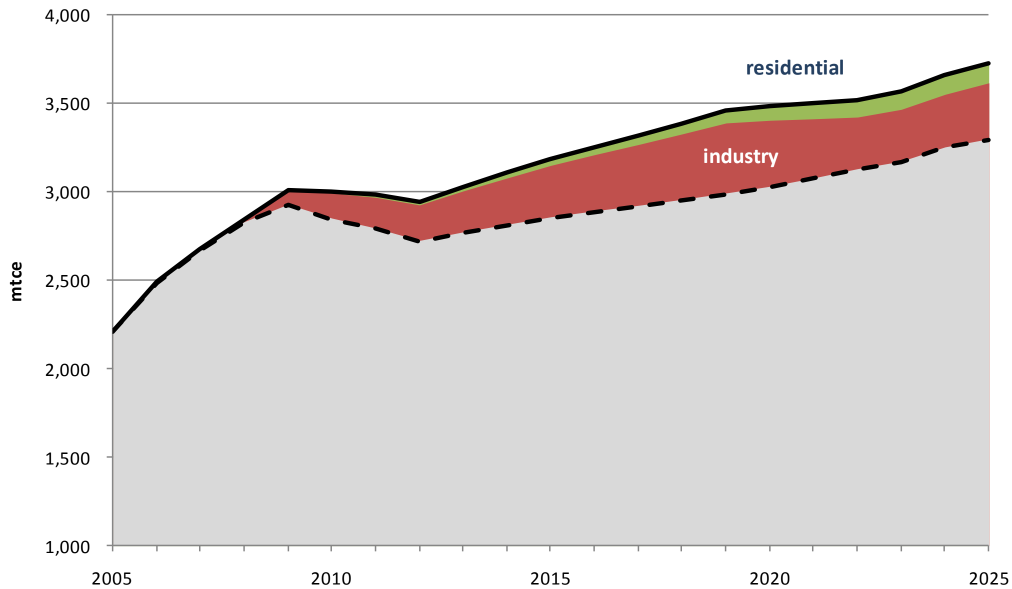
Figure 63: Energy Consumption Difference between BAU and CLU by Fuel



Source: LBNL CLU Model

Of the 430 mtce reduction in primary energy use under the lighter CLU development trajectory, a majority can be attributed to lower industrial energy use while the remaining share is from lower residential energy use as a result of lower urban population growth (Figure 64). In 2025, for instance, 320 mtce or 75% of total reduction is in the industrial sector while the remaining 110 Mtce or 25% of reduction is in the residential sector.

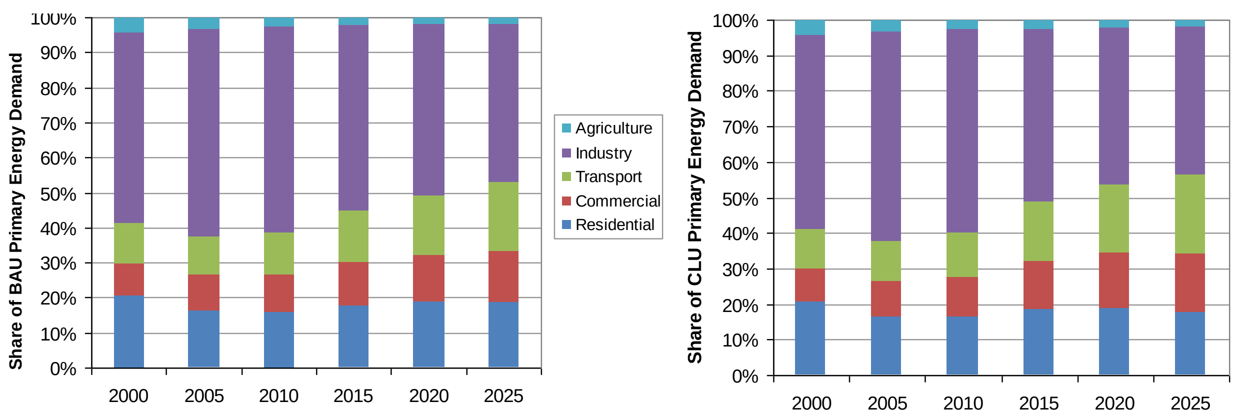
Figure 64: Total Energy Use under BAU and CLU Scenarios



Note: Y-axis not scaled to zero.

While the industrial share of primary energy demand notably declines under both scenarios, the decline occurs at a faster pace under CLU due to earlier efficiency improvements and decreasing exports (Figure 65). Whereas the industrial share of primary energy demand declines from 59% in 2005 to 53% in 2015 and 45% in 2025 under BAU, it declines to 49% by 2015 and 42% by 2025 under CLU. In both scenarios, the residential sector's share of primary energy use decreases slightly from 2000 to 2010 before rising again from 2010 to 2025.

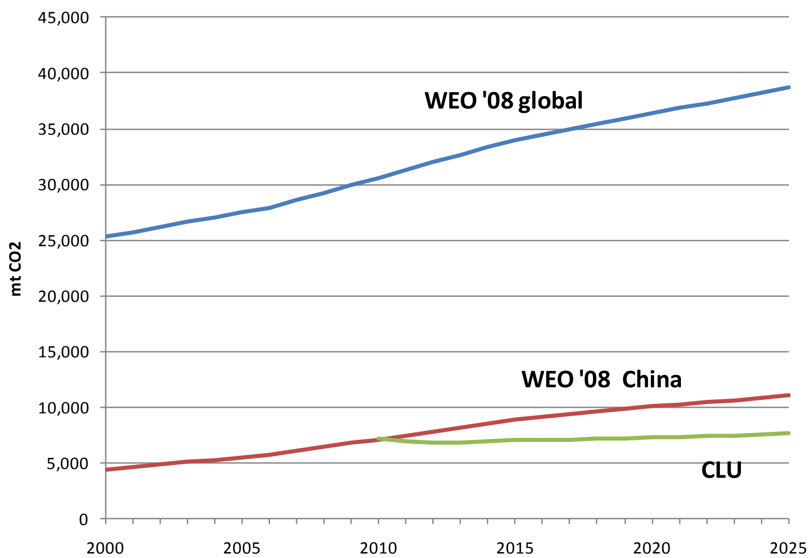
Figure 65: BAU and CLU Sector Shares of Total Primary Energy Use



Source: LBNL CLU model

With significant energy use differences between BAU and CLU scenarios, urbanization and related industrial production implications can have an important impact on China's CO_2 emission trajectory. In this study, the CLU scenario serves as a lower bound for possible Chinese energy and emission pathways as it is well below the 2008 World Energy Outlook's projection (Figure 66).

Figure 66: China CO_2 Emissions in Global Context

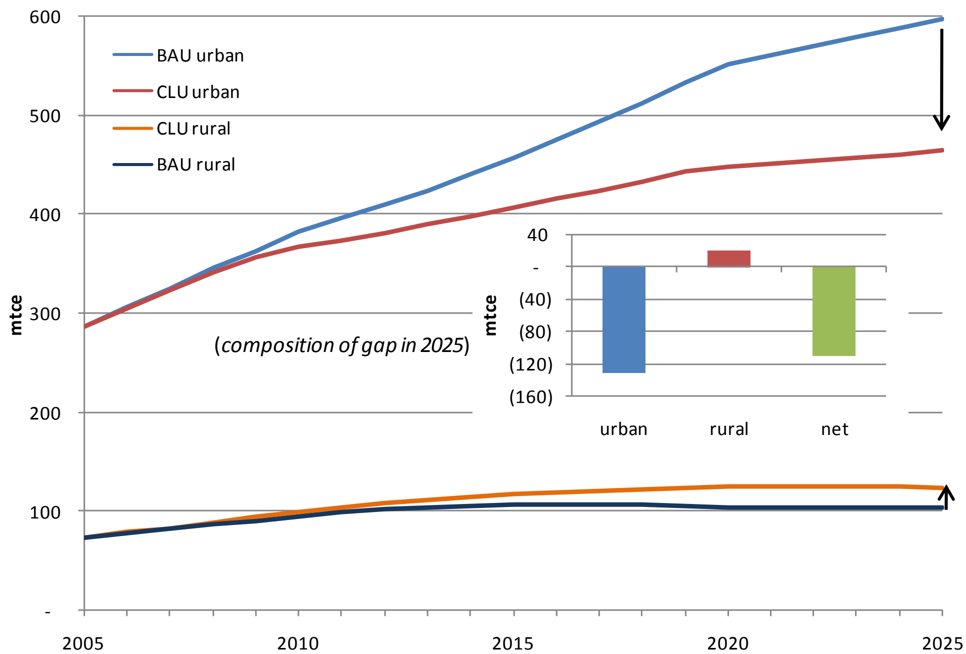


Source: IEA, 2008 World Energy Outlook; LBNL CLU Model.

4.2 Residential Sector Results

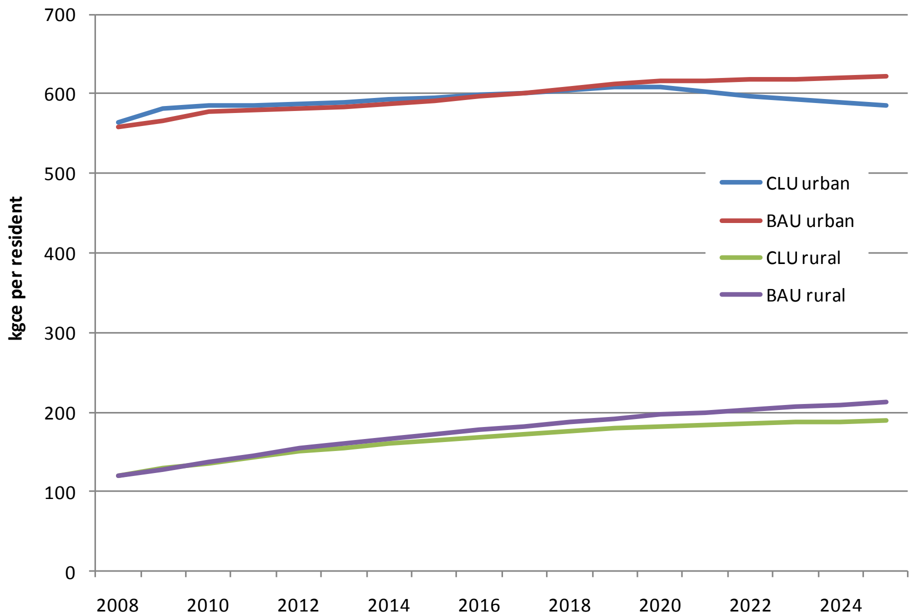
As a key driver of energy demand, the different urbanization rates underlying each scenario resulted in different projected residential commercial energy consumption trends. This is reflected in the higher net residential energy consumption of 110 Mtce in the BAU vs. CLU scenario. In other words, CLU development trajectory's lower urbanization level of 55% and correspondingly lower urban population could result in reductions of 132 Mtce in urban residential energy use and corresponding increases of 22 Mtce in rural residential energy use (Figure 67).

Figure 67: BAU and CLU Total Residential Commercial Energy Consumption



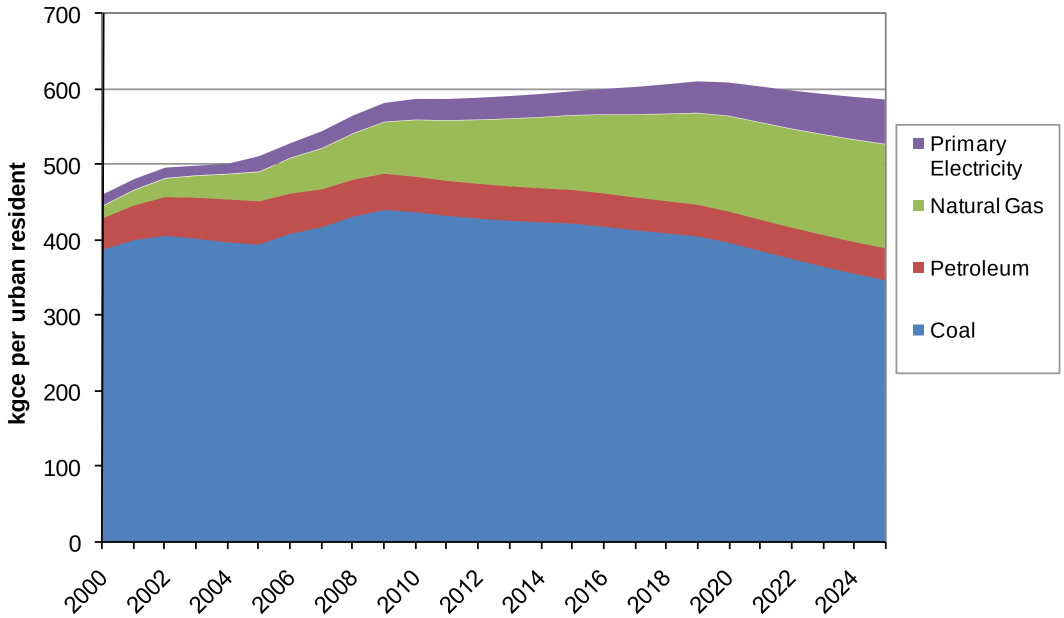
On a per capita basis, however, both rural and urban residential commercial energy consumption are slightly higher under the BAU than CLU scenario (Figure 68). This suggests that BAU scenario's much higher total urban residential energy consumption is due to both higher per capita energy use and higher urban population with greater urbanization. In contrast, the rural per capita energy consumption is actually lower under CLU but results in a higher CLU total rural energy consumption because of higher rural population.

Figure 68: BAU and CLU Per Capita Residential Commercial Energy Use



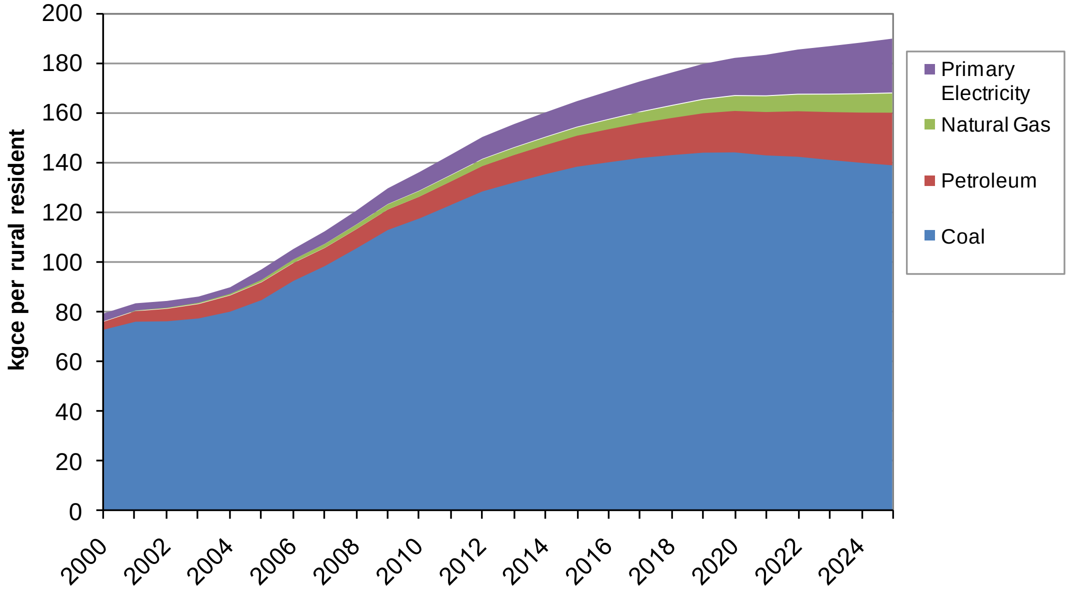
In terms of fuel shares for per capita residential primary energy use, there are significant differences between urban and rural residents as illustrated in the CLU scenario. For urban residents, coal fuel shares have historically been the highest as urban demand for coal-based electricity and heat generation has been rising dramatically. From 2007 onwards, however, the coal fuel share begins to decline from 77% (or 417 kgce per person) to only 59% (or 347 kgce per person) in 2025 (Figure 69).

Figure 69: CLU Urban Per Capita Residential Primary Energy Use by Fuel, 2000-2025



Rural residents, in contrast, are expected to consume more of every primary commercial fuel source as per capita residential energy consumption rises from 112 kgce in 2007 to 190 kgce in 2025. In other words, rural commercial energy use will rise to about one-third of the urban per capita level by 2025. Similar to urban residents, rural residents are expected to undergo a similar fuel transition with decreasing shares of coal consumption from 87% in 2007 to 73% in 2025 to increasing shares of primary electricity from 4.5% to 11% and petroleum from 6.5% to 11%. These results suggest that in addition to the rise in commercial energy use to meet the new energy service needs of rural-urban migrants, rural residents themselves will also increase commercial energy consumption in their fuel transition.

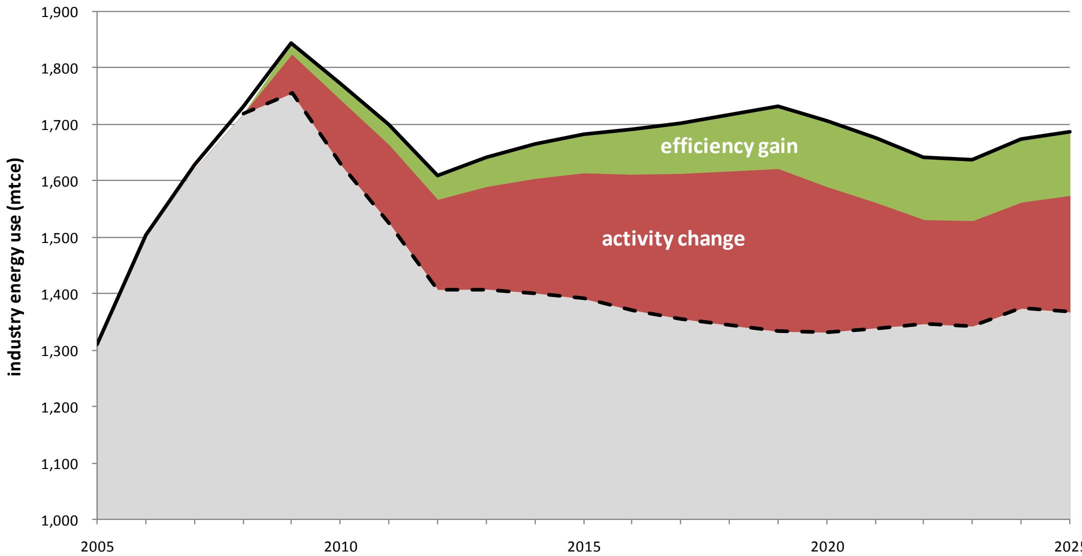
Figure 70: CLU Rural Per Capita Residential Primary Energy Use by Fuel, 2000-2025



4.3 Industrial Sector Results

The model results for projected BAU and CLU industrial energy use reflect key differences in total production and efficiency improvements, with a 324 mtce reduction in energy use under the CLU scenario in 2025. As seen in Figure 71, the disparity between BAU and CLU scenarios increases after 2010, with the CLU trajectory using 404 mtce less energy for industrial production than BAU in 2019. In order to attribute CLU's projected industrial energy reduction to efficiency gains and activity changes accordingly, the LEAP model was run with an alternative CLU scenario with greater efficiency improvements but same industrial production levels as BAU. With efficiency improvements as the only difference between BAU and the CLU alternative, any resulting energy reduction from the model can then be attributed solely to efficiency gains.

Figure 71: Industry Energy Use in BAU and CLU Scenarios

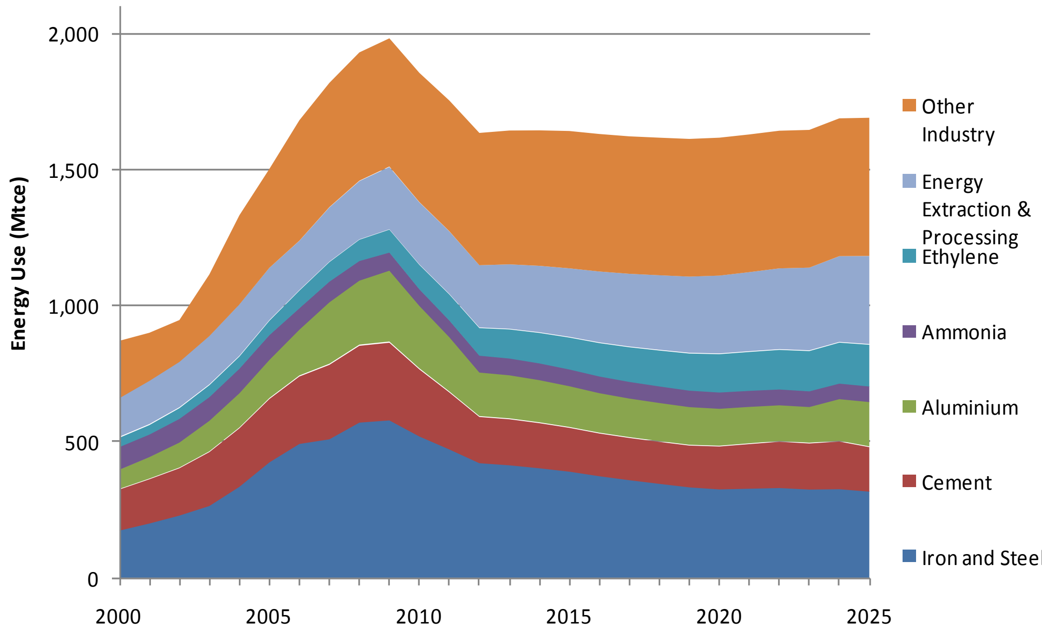


Note: Y-axis not scaled to zero.

In essence, the CLU reduction in industrial energy use primarily stems from lower production as efficiency gains account for only about one-third of the difference between BAU and CLU. This suggests that activity change in production output will a very important factor for adjusting future industrial energy use. To analyze where potential energy reductions may come from amongst the five key industrial sub-sector, the model results are further broken down by sub-sector with CLU scenario results presented (Figure 72).

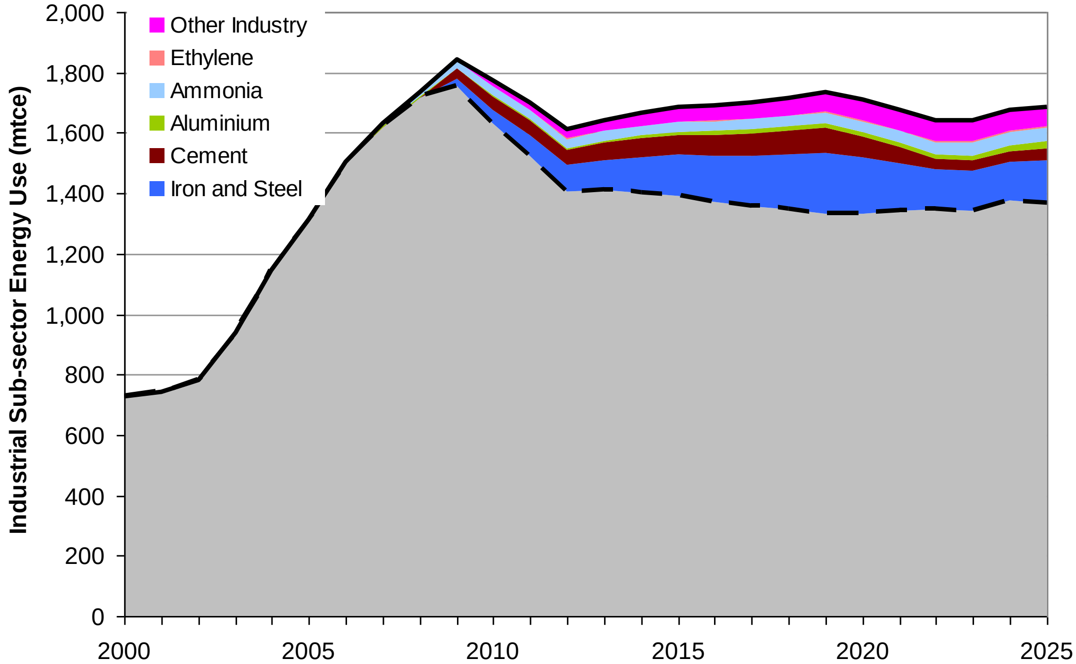
After the "other industry category" that includes paper, glass and manufacturing sub-sectors, iron and steel followed by cement and aluminum sub-sectors are the major industrial energy consumers. However, the energy use of each of these sub-sectors in absolute terms all decline modestly over time. The only exception is in energy use by the ethylene sub-sector, which grows notably from a 4% share of total industrial energy use in 2005 to 11% share in 2025.

Figure 72: CLU Scenario Industrial Sub-sector Energy Use



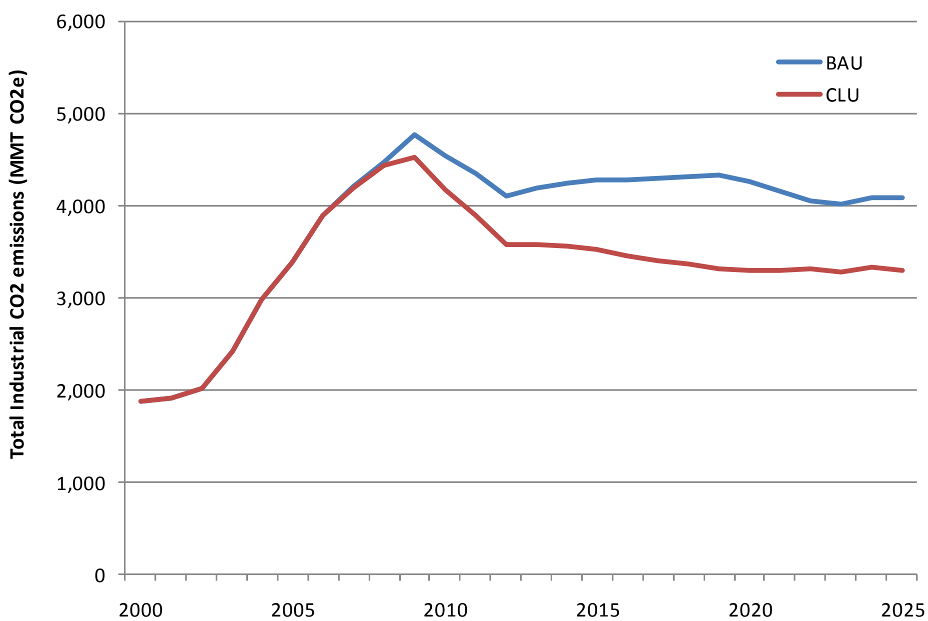
The lighter CLU development trajectory has differing impacts on energy reduction in each of the five industrial sub-sectors, as illustrated in Figure 73 below. Although the iron and steel sub-sector uses a relatively small share of industrial energy consumption in the range of 25-35% between 2000 and 2025, it has the largest energy reduction potential under CLU when compared to other sub-sectors. In fact, at its peak around 2020, the iron and steel sub-sector alone has energy use reduction on a scale nearly equal to all other sub-sectors combined. After the iron and steel sub-sector, the industries with the largest energy use reduction potential in the lighter development scenario is cement, followed by other industry and ammonia. As the sub-sector with relatively low production and net imports, ethylene has the smallest energy use reduction under CLU.

Figure 73: CLU Scenario Industrial Energy Use Reduction by Sub-sector



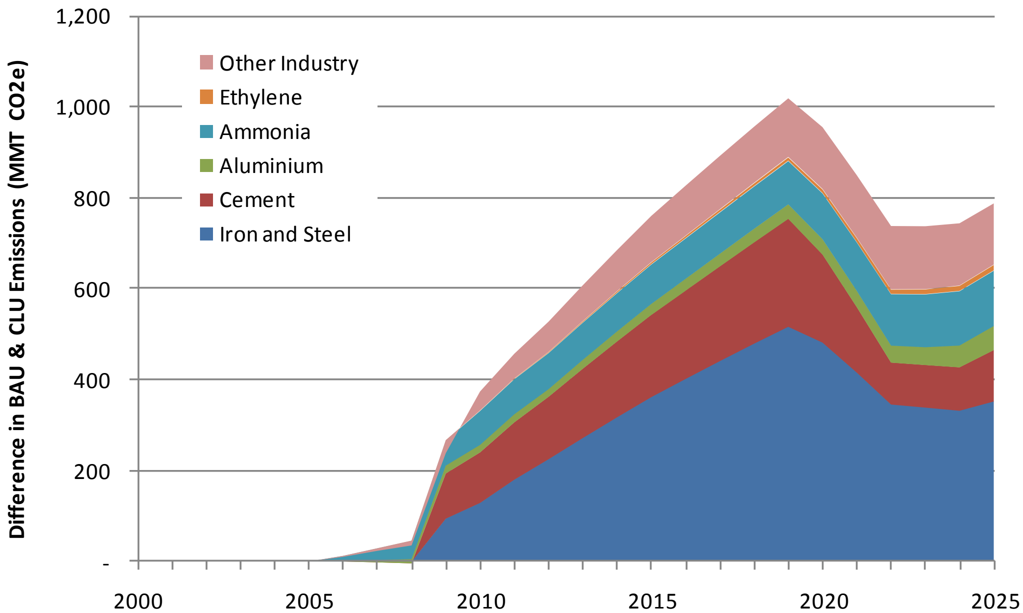
As with total industrial energy use, lower urbanization and trade as well as more aggressive efficiency improvements under CLU also have different carbon implications than BAU. (Figure 74). Specifically, the industrial energy use reduction in CLU corresponds to 786 million tonnes less industry CO_2 emissions in 2025. From 2010 to 2025, the cumulative potential emission reduction under the CLU trajectory would sum up to nearly 12 billion tonnes of CO_2 emissions.

Figure 74: BAU and CLU Industrial CO_2 Emissions, 2000-2025



Of the CO_2 emission reduction associated with the lighter CLU trajectory, a large portion of it can be attributed to the iron and steel sector (Figure 75). In fact, half of the CLU emission reduction, or 478 out of 954 million tonnes of emissions in 2018 were found in the iron and steel sector. In contrast, the CLU reduction in ethylene industrial emissions remained below 2% of total emissions reduction from 2005 through 2025.

Figure 75: Emissions Difference between BAU and CLU by Industrial Sub-sector, 2000-2025



5. Conclusions

Since the initiation of reforms in 1978, urbanization has served as a major driver of China's energy and economic development. Energy demand growth was further spurred by the boom in infrastructure construction and by the boom of export-oriented industry after China's accession to the World Trade Organization (WTO) in 2001. This study used scenario analysis to understand the energy and environmental impacts of lower levels of urbanization growth and of energy-intensive exports to 2025. Within industry and building sectors of the economy, the effect of 55% urbanization—as opposed to the 67% expected by Chinese and international analysts—in addition to more aggressive assumption of energy efficiency gains in industry is a 12% reduction of total primary energy demand. The "lightness" of the CLU scenario may be mitigated by higher levels of total non-commercial energy, i.e. biomass consumption, and by the transportation impact of higher population dispersion, as seen in the sub-urban development of the United States; these are questions for further study. Nevertheless, this study shows that industry primary energy demand would be 19% lower in 2025 if China's development path aimed for a lower level of urbanization as described in the CLU scenario.

Aside from urbanization and its concomitant expansion of residential construction, commercial construction, fertilizer use, and appliance ownership also effect energy demand. In each of these areas energy demand is likely to level off due to saturation effects: commercial floor space per tertiary sector employee appears to have reached developed-country levels, nitrogenous fertilizer application rates are already among the highest in the world, and urban appliance ownership is already very high, suggesting that new growth will come from new urbanization and further rural development.

In total, development resulting in a lower 55% level of urbanization in 2025 would reduce annual energy consumption in that year by 430 million tonnes coal-equivalent compared to a 67% urbanization rate. More than 60% of these energy savings would come from the consequent reductions in industrial production, particular that of steel. In carbon terms, this would amount to more than a billion-tonne reduction of energy-related carbon emissions compared with the BAU scenario in 2025, though the absolute level of emissions rises in both scenarios.

This study suggests that China's urbanization goals—a key component of its overall social development goals—will underpin a steady rise in energy consumption through 2025. China recognizes, however, that the emissions implications of energy consumption growth, which will remain primarily based on increased coal use, are to further exacerbate climate change, the impacts of which are already being acknowledged in China. Unlike its developed counterparts in the global discussion over GHG emissions limits, who are for the most part already highly urbanized (over 80% in the US), China faces additional challenges to agreeing to such limits because of its desire to pursue urbanization as part of its national development. This in turn suggests that if urbanization is a given in China's development future, that other means to mitigate the increase—such as development of low-carbon cement and other building materials, optimization of urban form development to reduce overall metabolic energy consumption, further aggressive increases in equipment energy efficiency standards, implementation of renewable energy in cities (such as expanded solar water heaters and solar PV panels), and other measures will be needed.

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Appendix 1. LBNL China Lightens Up Model

1.1 Sectoral Modeling Approaches

Integrated assessment models have been used to project both baseline and alternative scenarios. Results of these scenarios are typically presented for end-use sectors, such as industry, transport, and buildings. We quantified the underlying energy consumption for the each sector in China associated with projected macro-level energy-related emissions.

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 in providing insights on the technologies that would be used, including energy-intensity and saturation levels, to reach the energy consumption levels envisioned. A Business-as-Usual (BAU) scenario that incorporates targets stated in China's official plans and business-as-usual technology improvement was developed first and a China Lightens Up (CLU) alternate scenario of lighter industrial development and urbanization was created. To examine the specific influence of slower urbanization and lighter industrialization, only urban population levels and key industrial sub-sector production demand drivers were changed. To keep the consistency of the storylines, the other macroeconomic driver variables were kept the same.

Besides the detailed urbanization and industrial sub-sectoral approaches described above, the model also consisted of sectoral assumptions for:

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

Sectoral energy consumption data are available in statistical compilations. We used China's energy statistics to prepare a time series (1971-2007) of primary energy use. After building the model from bottom-up, we calibrated the data by comparing the results of energy use with the statistical data for 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.

1.2 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. Within the locales, end uses were broken out into space heating, air conditioning, appliances, cooking and water heating, lighting, and a residual category.

The enduses 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 the North and the Transition (central China) 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 (2005) and future values based on analysis of government plans, trends, and comparisons to other countries. Changes in energy demand in the model are mostly functions of driver variables, e.g., household size, urbanization rate and appliance saturation which were determined exogenously and included in the model.

Table 9 shows the breakouts.

Table 9 Technology Variables and Categorizations

End use	Space heating		Air conditioning	Lighting	Cooking and water heating	Appliances		
Category	North	Transition				Clothes Washer	TV	Refrigerator
Technologies	electric heater gas boiler boiler stove district heating heat pump air conditioner		Average	Incandescent Florescent CFL	Electricity Natural gas LPG Coal Coal gas Other	Average	Color TV	Average Reference

The mechanism can be summarized as follows (some subscripts have been omitted for brevity of presentation):

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

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,
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,

Residential equipment are detailed with stock turnover modeling, including information on initial stocks by vintage, energy efficiency by vintage, efficiency degradation profiles, and lifetime or survival profiles. Residential end use energy consumption in base year is based on results of existing research carried out by Energy Research Institute, China, and LBNL led energy consumption survey. Table 10 shows the values for major driver variables that were used to obtain an outcome in line with the base China scenario to 2020.

Table 10 Household Appliance Saturation

	Urban End-use Saturation		Rural End-use Saturation	
	2005	2025	2005	2025
Space Heating				
North	100%	100%	100%	100%
Transition	30%	47%	8%	25%
Refrigerator	91%	100%	20%	94%
Clothes Washer	96%	100%	40%	96%
Water Heater				
Electric	13%	20%	-	-
Natural Gas	21%	42%	-	-
LPG	38%	20%	6%	13%
TV	135%	150%	84%	140%
Air Conditioner	59%	74%	5%	74%

1.3 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.

The key end uses by the subsectors listed above include:

- space heating,
- space conditioning,
- water heating,
- lighting, and
- other uses.

The end uses are further broken out by technologies shown inTable 11.

Table 11 Commercial Building End Uses and Technologies

End use	Space heating	Space cooling	Lighting and other application	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. $E_{RB} = \sum_{k}^{OPTION} \sum_{n}^{OPTION} \sum_{q}^{OPTION} \left[A_{CB,n} \times \left(SH_{CB} + SC_{CB} + W_{CB} + L_{CB} \right) \right]$

where, in addition to the variables listed above:

k = energy type
q = type of end use,
$A_{CB,n}$ = total commercial floor area in commercial building type n in m^2, and
SH_{CB} = space heating energy intensity of energy type k in commercial building type n in kWh/m^2-year,
SC_{CB} = space cooling energy intensity of energy type k in commercial building type n in kWh/m^2-year,
W_{CB} = water heating energy intensity of energy type k in commercial building type n in kWh/m^2-year,
L_{CB} = lighting and other applications energy intensity of energy type k in commercial building type n in MJ/m^2-year, and

All data in base year are derived from Zhou, (2003). From 2000 to 2020, the annual growth rate of total commercial floor area is forecast to be 5%, based on China’s development plan.

For projections of energy intensities and the distribution of prototypical buildings, Japan has been chosen as the reference to estimate future trends, because its high energy efficiency and the similarity in population densities. Basically, the model data were determined by estimating when China will reach the Japanese level for specific end use and technologies.

Commercial building energy use varies by energy intensities in different building types and the total floor area of each. Table 12 shows the energy intensities and the building floor area distributions in prototypical buildings in 2005 and 2025.

Space heating intensity is much higher than that of Japan in 2004. Assuming China will reach the Japanese level in 2040, the unit heating loads will be still be 55% more in 2025 than that of Japan today. The floor area of retail building will grow the fastest, followed by hospital and school, while the share of office building and hotel will decrease.

Table 12 Commercial Building End Uses by Sub-sector

Commercial 2005

		Office	Retail	Hotel	Hospital	School	Other
lighting and other application	kWh/m^2-year	16	34.6	33	19	6	16
water heating	kWh/m^2-year	2	19	66	66	2	2
space heating	kWh/m^2-year	90	70	83	80	70	80
cooling	kWh/m^2-year	43	89	72	52	31	43
floor area distribution		33.6%	14.2%	14.2%	3.7%	16.4%	17.9%

Commercial 2025

		Office	Retail	Hotel	Hospital	School	Other
lighting and other application	kWh/m^2-year	59	85	79	65	13	59
water heating	kWh/m^2-year	2	20	70	70	2	2
space heating	kWh/m^2-year	87	67	170	79	70	77
cooling	kWh/m^2-year	50	97	78	61	35	50
floor area distribution		36.2%	15.3%	15.3%	3.3%	10.6%	19.3%

Lighting: Lighting will be more efficient on average in 2025. The existing proportions of regular and efficiency lighting of 26% and 74% respectively in 2000 will reach 14% and 86% in 2025.

Water heating: The use of boilers for heating water will decrease from 62% in 2005 to 40% in 2025 (Figure 76). Gas use will be extended, and gas boilers will increase its share from 11% to 27% in 2020 and then remain constant through 2025. Small congeneration, which accounts for a 11% share in 2005 will rise to 14% in 2020 and remain constant thereafter. Oil water heaters will retain a 15% share, and electric heaters will grow in share to 4% in 2020 and remain constant. Efficiency of each type of technology will rise through 2020 and then remain constant through 2025 (
Figure 77).

Figure 76 Water Heating Technologies and Fuel Type

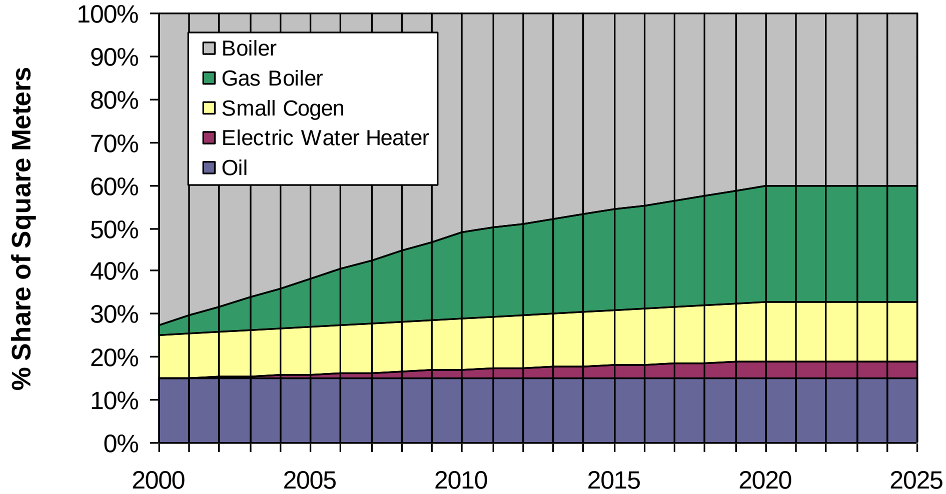
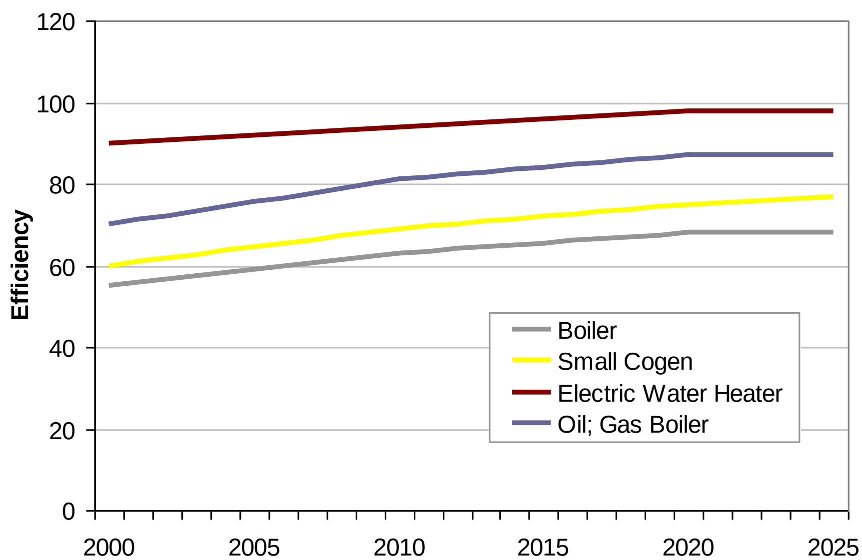


Figure 77 Water Heating Efficiency



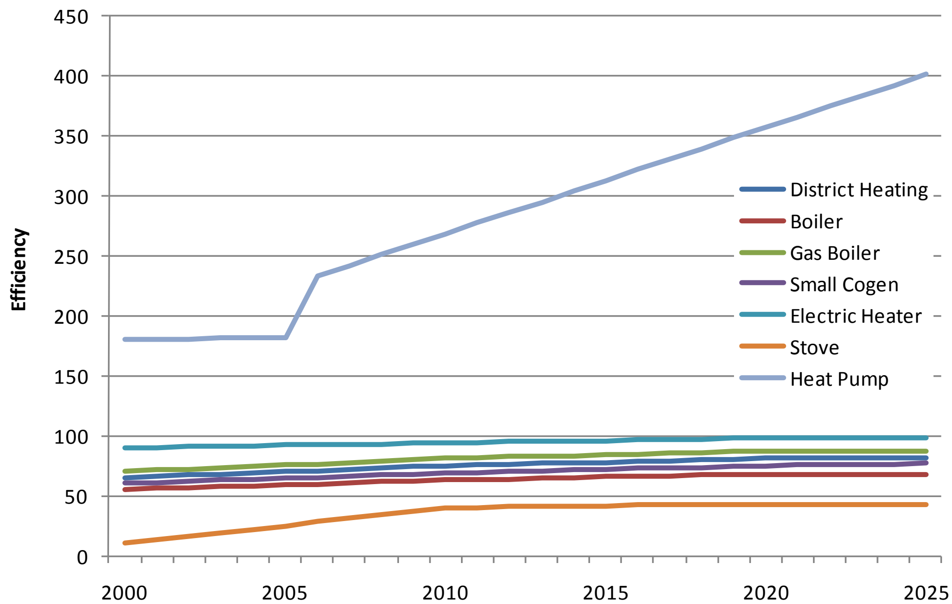
Space heating: Approximately 50% of the building will have space heating in 2025, up from 35% in 2000. Table 13 shows the share of space heating technologies in 2000 and 2020. Although the share varies in different building types, the use of conventional coal boiler will be reduced significantly overall, while more efficient technologies such as gas boilers and heat pumps will grow in share.

Figure 78 shows the efficiency improvement for each technology; the efficiency improvement potential for heat pumps is substantial.

Table 13 Space Heating Technologies by Sub-sector

	Office		Retail		Hotel		Hospital		School		Other	
	2005	2025	2005	2025	2005	2025	2005	2025	2005	2025	2005	2025
District Heating	28%	26%	29%	30%	29%	30%	17%	22%	18%	26%	15%	26%
Boiler	47%	8%	47%	8%	47%	8%	56%	19%	57%	15%	61%	8%
Gas Boiler	11%	40%	11%	40%	11%	40%	12%	35%	9%	35%	11%	40%
Small Cogen	11%	14%	11%	14%	11%	14%	11%	14%	11%	14%	11%	14%
Electric Heater	1%	4%	0%	0%	0%	0%	1%	4%	1%	4%	0%	4%
Stove	0%	0%	0%	0%	0%	0%	2%	0%	3%	0%	0%	0%
Heat Pump	2%	8%	2%	8%	2%	8%	2%	6%	2%	6%	2%	8%

Figure 78 Space Heating Technologies and Efficiency



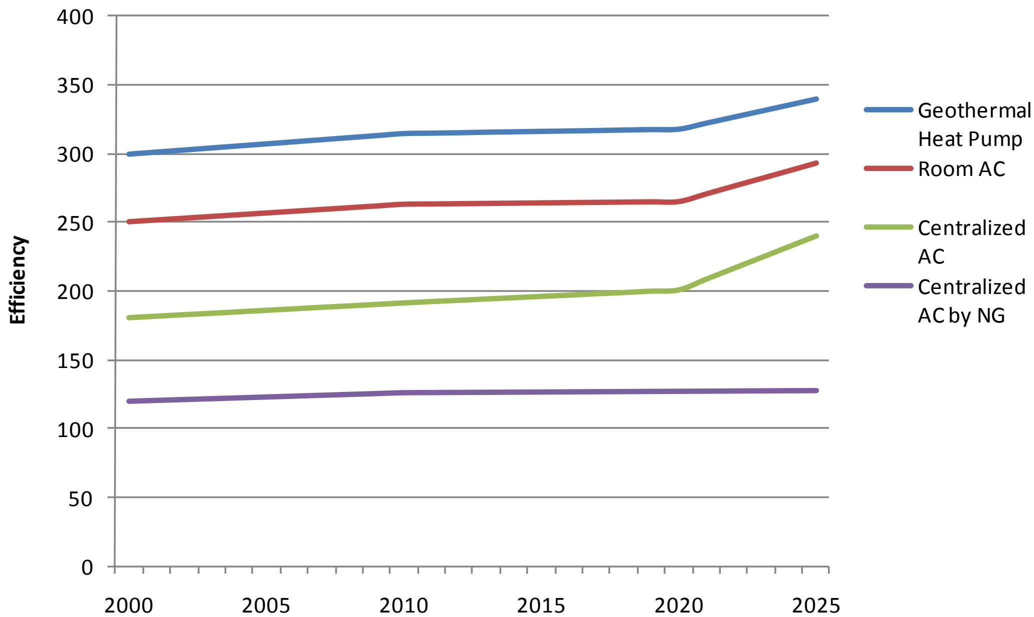
Space cooling: Electric central air conditioners (CAC) and room air conditioners (RAC) are expected to decline slightly in share to 2025, with natural gas and geothermal AC expanding in use (Table 14). The efficiency of space cooling technologies will be improved (Figure 79). Our estimates are based on the qualitative targets laid out by the NDRC[41]. We assume that the technologies will reach the level of Japan today in 2050. The latest data were based on the HVAC efficiency in Japan[42]. Central AC and Room AC efficiency are based on the ECCJ catalog of 2004, from which the most efficient technologies were chosen. Gas AC efficiency (COP 1.3) is based on the most efficient technology in Japan in 2003, developed by Tokyo Gas, Osaka Gas, TOHO Gas, and Yanmar Diesel[43],. Geothermal heat pump efficiency (4.0) is based on the efficient technology level in Japan in 2003.[44]

[41]), China's Sustaibable energy Scenarios in 2020; Nishida (1997)
[42] http://www-atm.jst.go.jp:8080/01050211_1.html
[43] http://www.yanmar.co.jp/aboutus/whats-new/news-release/0103/conts01.htm
[44] http://www.ybm.jp/newtech/chichunetsu/chichunetsu4.htm

Table 14 Space Cooling Technology by Sub-sector

	Office		Retail		Hotel		Hospital		School		Other	
	2005	2025	2005	2025	2005	2025	2005	2025	2005	2025	2005	2025
Centralized AC	62%	58%	62%	58%	62%	58%	63%	57%	63%	58%	62%	58%
Room AC	33%	28%	32%	25%	32%	25%	34%	31%	33%	28%	33%	28%
Geothermal Heat Pump	2%	6%	2%	7%	2%	7%	2%	6%	2%	6%	2%	6%
Centralized AC by NG	4%	8%	4%	10%	4%	10%	2%	6%	2%	8%	4%	8%

Figure 79 Space Cooling Efficiency



1.4 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. It is thus necessary to introduce a breakdown by *mode* of transport (i.e., road, rail, air, water, and pipeline) as well as by *type* of transport (passenger and freight).

It is particularly important to break out by *mode* of transport. For the other transport sub-sectors the class breakdowns could be:

- 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 goods delivered, when detail is available)

For some countries, particularly developing countries, urban and rural transport could exhibit very different energy intensities it may be useful to represent this for some modes, e.g., urban, rural and highway transport. And it then broke out by technology classes (e.g., motorcycles, cars, buses and trucks for the road transport). Further breakouts subdivide it by class and by fuel.

The urban module is divided into cars, taxis, motorcycles and buses. The rural module is divided into cars and motorcycles. The highway module is comprised primarily of buses, which are subdivided into Heavy Duty, Medium Duty, Light Duty and Mini Buses (Table 15).

Table 15 Transportation Modes, Technologies, and Fuels

	Mode		Tech/Type	Type	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
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,diseal, electricity
		local			Steam,diseal, 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

Physical energy intensities used are in terms of energy use per km, per passenger-km, or per ton-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, and
$f_{k,t,m,j}$ = 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 ton-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/(ton-km-year).
k = energy type
t = transport type (passenger, freight)

Turnover data series for rail, water, air and intercity highway can be found in the China Statistical Yearbooks and the Transportation Yearbooks for different years. However, such data do not exist for vehicles intercity or within rural areas. 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. The private vehicle stock number has been often misidentified as the number of personal cars (family car). Our investigation on the definition of this category suggests that this includes private owned cars, mini buses and most taxis. Existing data on car ownership per 100 household in urban and rural, and urban taxi share were used to break the stock number down to each vehicle type. Stock of urban cars in our model is the sum of urban private cars and government vehicles. The total stock of urban buses and trucks were further subdivided into Heavy Duty, Medium Duty, Light Duty and Mini Buses[45].

The total number of civil motor vehicles in year 2020 is based on China's official plan (RNECSPC-Strategy Report), projected to be 110 million vehicles. Historical trends in China were used to extrapolate future demand, and considerations of the limitation on infrastructure were also taken into account, based on historical trend in developed countries with similar population density, such as Japan and Korea).

Table 16 provides a breakout of the vehicle stock.

Table 16 Total Vehicle Stock Projection (millions)

	2005	2015	2025
Cars			
urban	11.2	39.5	96.5
rural	1.1	4.1	5.8
Taxis	0.9	1.9	2.7
Buses	1.3	6.5	9.3
Motorcycles			
urban	28.2	39.7	51.3
rural	47.6	80.8	127

1.5 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 statistical yearbooks. Historic agriculture energy consumption is also available from the Chinese energy statistics.

An LANL report on China's energy forecast to 2015 predicted a 0.94% annual average decline in agricultural energy intensity[46]; however, no reasonable scenario would have a significant impact on the forecast of total energy demand. Based on this, we forecast that intensity will decline by 1% annually due to the efficiency improvement based on historic trend (Figure 80).

[45] The stock breakout into the abovementioned subclasses of buses was made possible using rations obtained from Kebin He, Hong Huo, Qiang Zhang, Dongquan He, Feng An, Michael Wang and Michael P. Walsh, 2005, "Oil consumption and CO_2 emissions in China's road transport: current status, future trends, and policy implications", *Energy Policy* 33 (12): 1499-1507.

[46] E.Iain McCreary, China's Energy A forecast to 2015, LANL, 1996

Figure 80: Agricultural Economic Energy Intensity by Fuel