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China’s Energy and Carbon Emissions Outlook to 2050

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Abstract

As a result of soaring energy demand from a staggering pace of economic expansion and the related growth of energy-intensive industry, China overtook the United States to become the world's largest contributor to CO_2 emissions in 2007. At the same time, China has taken serious actions to reduce its energy and carbon intensity by setting both a short-term energy intensity reduction goal for 2006 to 2010 as well as a long-term carbon intensity reduction goal for 2020. This study presents a China Energy Outlook through 2050 that assesses the role of energy efficiency policies in transitioning China to a lower emission trajectory and meeting its intensity reduction goals.

Over the past few years, LBNL has established and significantly enhanced its China End-Use Energy Model which is based on the diffusion of end-use technologies and other physical drivers of energy demand. This model presents an important new approach for helping understand China's complex and dynamic drivers of energy consumption and implications of energy efficiency policies through scenario analysis. A baseline ("Continued Improvement Scenario") and an alternative energy efficiency scenario ("Accelerated Improvement Scenario") have been developed to assess the impact of actions already taken by the Chinese government as well as planned and potential actions, and to evaluate the potential for China to control energy demand growth and mitigate emissions. In addition, this analysis also evaluated China's long-term domestic energy supply in order to gauge the potential challenge China may face in meeting long-term demand for energy.

It is a common belief that China's CO_2 emissions will continue to grow throughout this century and will dominate global emissions. The findings from this research suggest that this will not necessarily be the case because saturation in ownership of appliances, construction of residential and commercial floor area, roadways, railways, fertilizer use, and urbanization will peak around 2030 with slowing population growth. The baseline and alternative scenarios also demonstrate that China's 2020 goals can be met and underscore the significant role that policy-driven energy efficiency improvements will play in carbon mitigation along with a decarbonized power supply through greater renewable and non-fossil fuel generation.

Executive Summary

In recent years, China has taken serious actions to reduce its energy intensity (energy consumption per unit of gross domestic production) and carbon intensity (CO_2 per unit of GDP). China's 11th Five Year Plan announced in 2005 outlined a goal of reducing energy intensity by 20% from 2006 to 2010. The announcement was followed with extensive programs to support the realization of the goal. China also announced a commitment to reduce its carbon intensity by 40% to 45% below 2005 levels by 2020 in late 2009. In 2011, China announced dual goals of reduction of energy intensity by 16% and carbon intensity by 17% during the 12th Five Year Plan period (2011-2015).

Achieving the 2015 and 2020 goals will require strengthening and expansion of energy efficiency policies in all sectors of the economy including industry, buildings, appliances, equipment, and transport, as well as further expansion of renewable and nuclear power capacity. Achieving this goal will require continuing and strengthening ongoing actions by government and industry beyond efforts initiated during the 11th Five-Year Plan. Given China's crucial role in the expansion of the global economy and because of its high reliance on coal, maximum efforts in improving energy efficiency, reducing energy intensive output of industry and dramatic expansion of carbon emissions control energy technology are needed to address China's energy and climate change issues by 2050.

The research presented in this report aims to develop a China Energy Outlook through 2050 with 2020 and 2030 milestones that can be used to assess the role of energy efficiency, structural change in industry, and new supply options for transitioning China's economy to a lower CO_2 emissions trajectory in the longer term, and to examine the challenge of meeting the shorter term goal in 2020.

In the years since 2005, we have established and significantly enhanced the LBNL China End-Use Energy Model based on the level of diffusion of end use technologies and other drivers of energy demand. The model addresses end-use energy demand characteristics including sectoral patterns of energy consumption, change in subsectoral industrial output, trends in saturation and usage of energy-using equipment, technological change including efficiency improvements, and links between economic growth and energy demand. A baseline (Continued Improvement Scenario or CIS) and an alternative energy efficiency scenario (Accelerated Improvement Scenario or AIS) have been developed to assess the impact of actions already taken by the Chinese government, planned or proposed actions, and actions that may not yet have been considered, in order to evaluate the potential for China to control energy demand growth and mitigate CO_2 emissions. In addition, we have used our judgment about timing and extent of commercialization of carbon capture and sequestration (CCS) to describe our scenario with CCS (CIS and AIS assume no CCS).

This analysis also evaluated China's long-term domestic energy supply in order to gauge the potential challenge China may face in meeting long-term demand. The potential mismatch between supply and demand will undoubtedly raise some very difficult issues. Penetration of each major energy supply option (oil, gas, coal, hydro, nuclear, wind, biomass and solar) were projected out to 2050 using two basic approaches. For non-renewable fossil-fuel energy, derivative logistics curve calculations were used in order to constrain the extraction profile to accord with the total volume of reserves available for extraction. For the renewable energy forms and nuclear energy, projections of installed capacity were collected from a variety of sources, including official government statements (nuclear capacity by 2020);

projections by research groups and in academic journals (wind power and hydropower); and own-estimates (biomass/solar; nuclear power in 2050).

The key results could be summarized as follows:

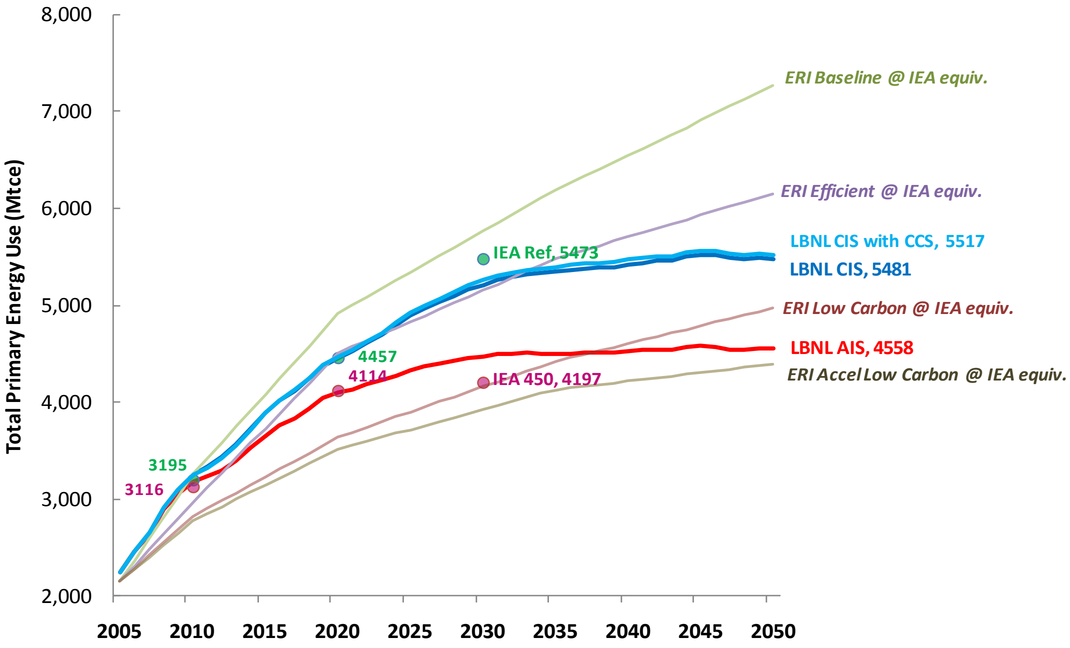
By 2050, primary energy consumption will rise continuously in both scenarios but approach a plateau around 2040 for CIS and AIS (Figure ES-1). Energy demand grows from 2250 Mtce to 5500 Mtce in 2050 under CIS. It is reduced by 900 Mtce to 4600 Mtce in AIS in 2050, a cumulative energy reduction of 26 billion tonnes of coal equivalent from 2005 to 2050. If CCS were implemented under the CIS scenario, with 500 Mt CO_2 captured and sequestered by 2050, total primary energy use would increase by 36 Mtce to 5517 Mtce in 2050 due to CCS energy requirements for carbon separation, pumping and long-term storage, but carbon emissions would decline by 4% in 2050.

CO_2 emissions under both scenarios approach a plateau or peak in 2025 (AIS) and 2030 (CIS). CIS reaches a plateau between 2030 and 2035 with 12 billion tonnes in 2033, while the more aggressive energy efficiency improvement and faster decarbonisation of the power supply under AIS peak between 2025 and 2030 at 9.7 billion tonnes in 2027. CCS at the current level of efficiency and from an integrated system point of view, however, will only have a small net CO_2 mitigation impact of 475 million tonnes in 2050 (see **Error! Reference source not found.**.

China's current per capita GDP and average per capita energy use is still very low compared to developed countries but has the potential to catch up by 2050 (Figure ES-2). Both LBNL and ERI's 2050 scenarios show that China will likely surpass Portugal's current level of per capita GDP, but its GDP will still remain below more developed countries like Singapore, US, and Japan. However, China's projected 2050 pathways are also noteworthy in that their per capita energy use will remain below most other countries with similar GDP levels. Under CIS, China's per capita energy use will be below South Korea and Spain in 2050 while under ERI's base scenario, China will be well below the per capita energy use in Australia and France. These trends underscore the important role China can play in pursuing a more energy efficient pathway of economic development.

From the international perspective, China's future carbon outlook also has important implications as its 2050 GDP levels reach the level of Greece and South Korea in LBNL scenarios and that of the EU in ERI scenarios. However, China's per capita CO_2 emissions are relatively low and remarkable in their relatively "flat" path of development in Figure 39, indicating that per capita CO_2 emissions may not increase significantly despite rising per capita GDP.

As seen in Figure 29, the CIS and AIS results fall within the range of other research published but differ significantly in the shape of their curves. Many analyses project continued exponential growth for China, while our cases show a plateau (AIS) or much slower growth (CIS) in energy demand beginning around 2030 to 2040 time frame because of the saturation effects (appliances, residential and commercial floor area, roadways, railways, fertilizer use, etc.), deceleration of urbanization, low population growth, and change in exports mix to high value added products as examined in this study. Similar deviation can be seen in terms of the CO_2 emission as shown in Figure ES-2. In all three scenarios explored, a peak in CO_2 emission around 2030 can be observed owing to continuous energy efficiency improvement as well as decarbonization in the power sector.



Note: AIS is Accelerated Improvement Scenario, CIS is Continued Improvement Scenario, IEA Equiv. refers to converting ERI's numbers to IEA equivalent given that ERI follows the convention of using power generation equivalent, rather than IEA and LBNL's use of calorific equivalent, to convert primary electricity. This results in a 3.01 lower gross energy content for renewables and biomass.

Figure ES-1: Primary Energy Consumption in Different Scenarios

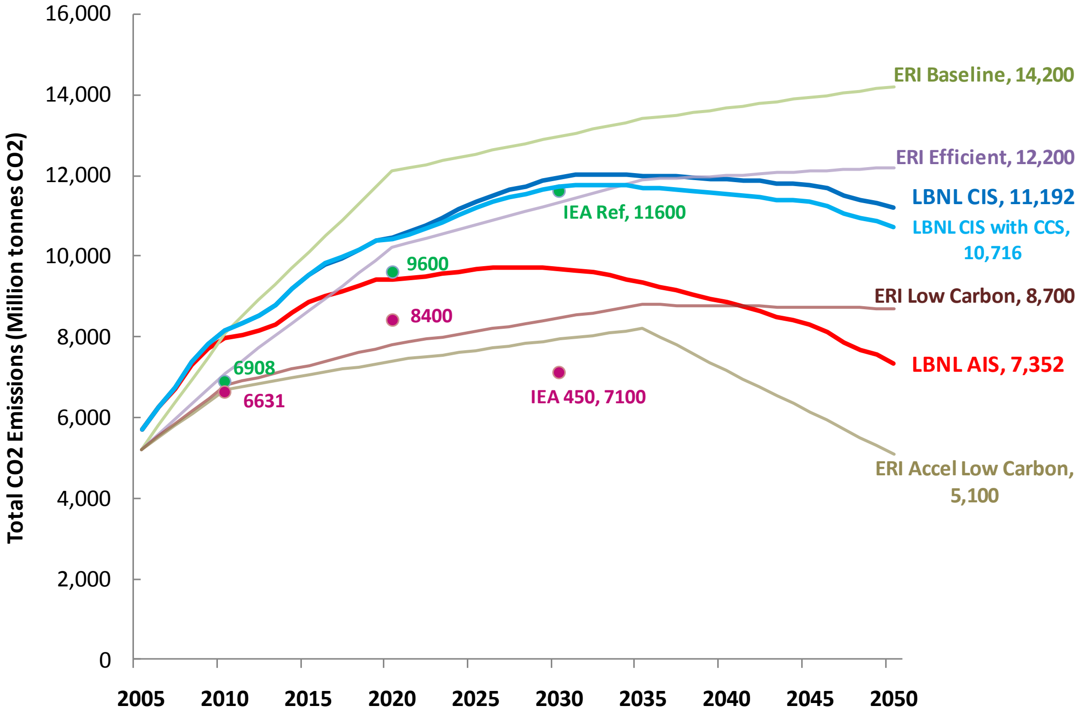
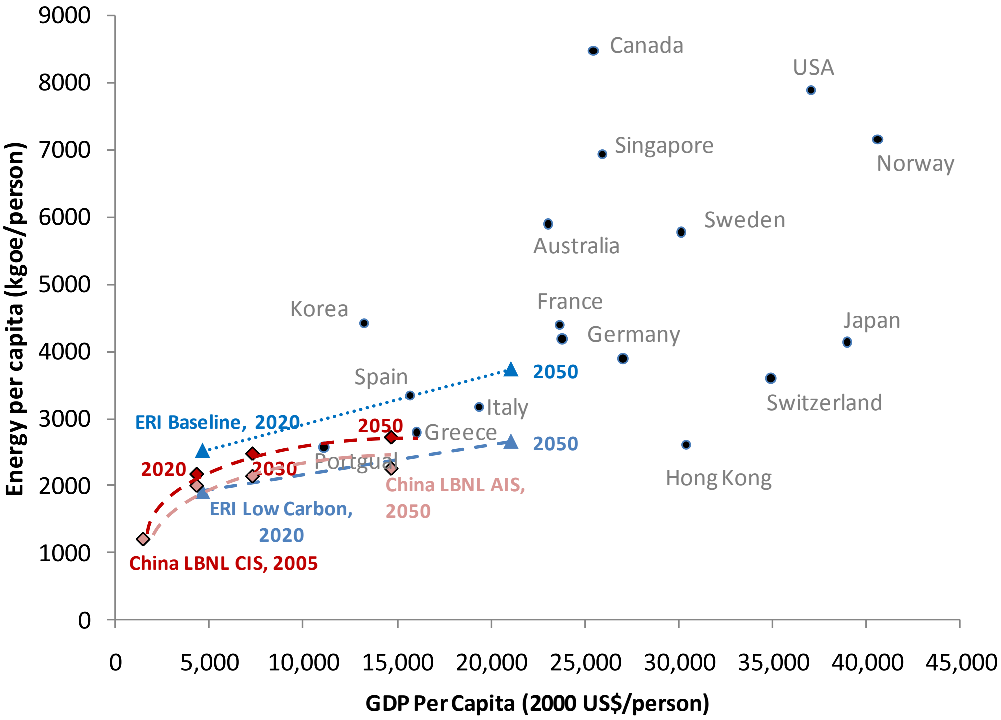


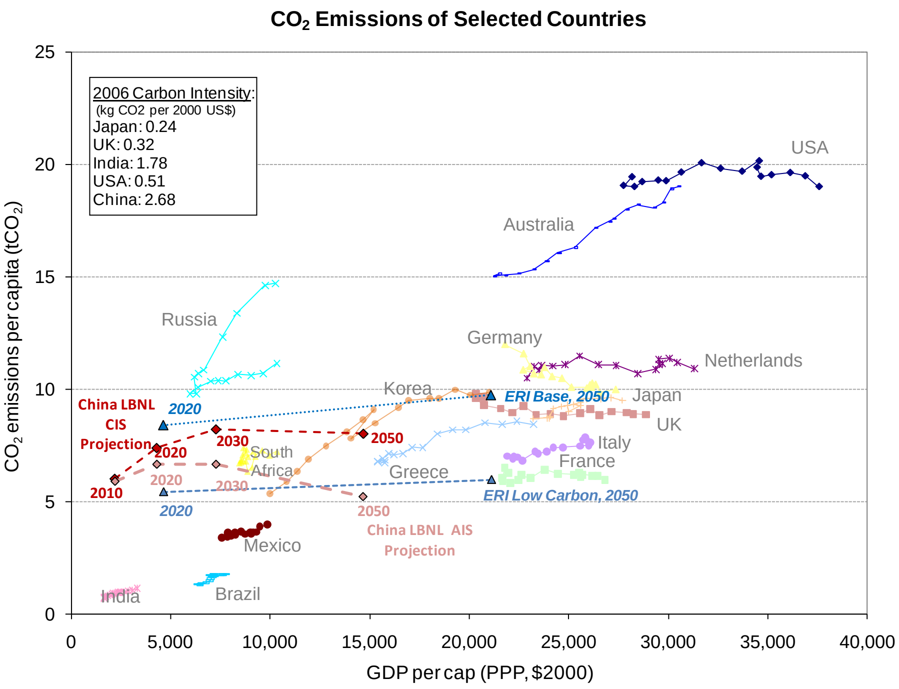
Figure ES-2: Comparison of Carbon Emissions among Scenarios

Sources: Energy Research Institute, 2009; IEA, 2009.



Note: kgce refers to kilograms of standard coal equivalent, the standard energy unit used in China. 1 kgce is equal to 29.27 MJ.

Figure ES-3: International Trends in Energy and GDP per Capita Compared to LBNL and ERI Scenarios to 2050



Note: LBNL projection for GDP per capita in China, market rate is in real US$, while data for other countries are in GDP per capita PPP, 2000 US$.

Sources: Energy Research Institute, 2009; IEA, 2009.

Figure ES-4: International Trends in CO_2 Emissions and GDP per Capita Compared to ERI and LBNL Scenarios to 2050

It needs to be noted that changes in assumptions will lead to significant deviations from CIS projections based on the result from sensitivity analysis presented in Figure ES-5. Among the different sensitivity analysis tested, variables in the industrial sector had the largest impact on total primary energy use, implying that there is a higher level of uncertainty surrounding these variables. For example, a 25% increase in the growth rate of “other industry” GDP, which directly affects steel production, results in an increase of nearly 800 Mtce by 2050 in total primary energy use. Likewise, uncertainties in the production of heavy industrial output and energy intensity of other industry subsector results in changes in total primary energy use in the range of 300 to 700 Mtce in 2050 in our scenarios. As important drivers of energy demand, commercial floorspace and GDP growth rate are also highly sensitive variables that have important impacts on total energy use.

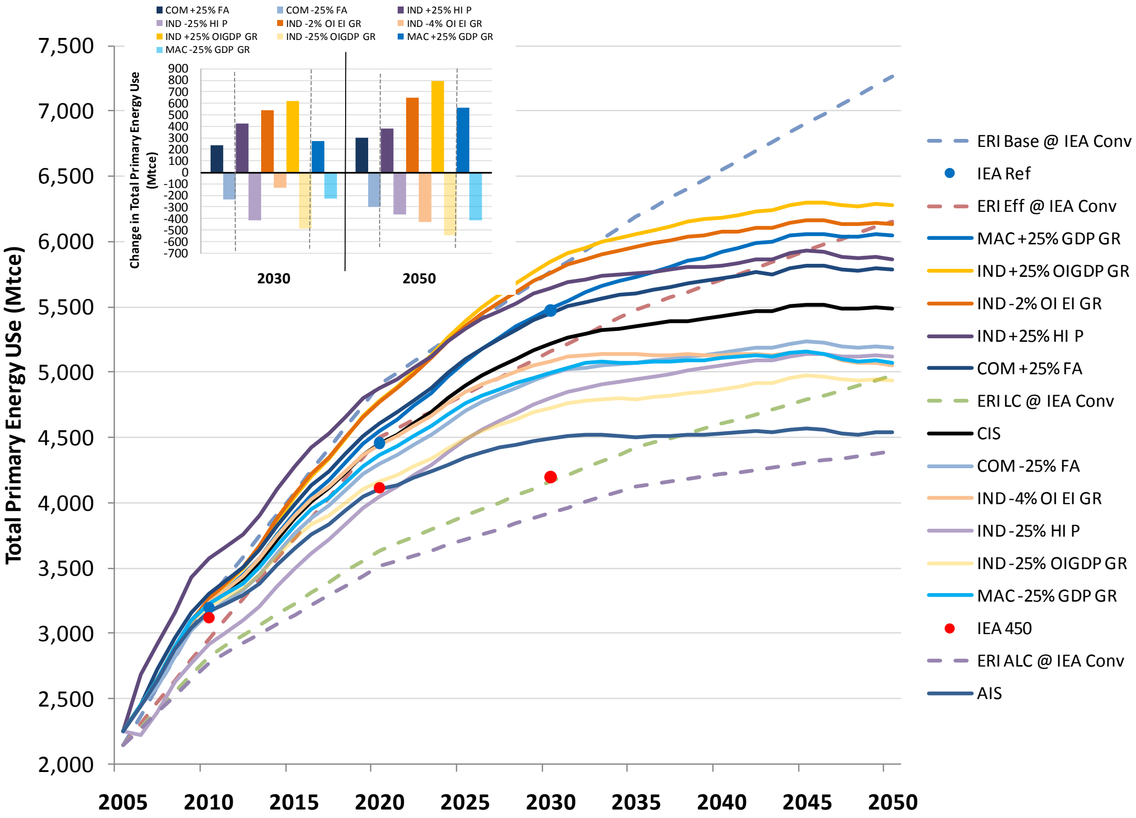


Figure ES-5: Sensitivity Analysis Scenario Results with Greatest Uncertainty[1]

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[1] Abbreviations are included in the section “Uncertainties” in the main report.

Other significant findings are:

Aggregate results

- Future energy demand reduction potential (CIS minus AIS) is greatest in the industry sector in the earlier years and in the buildings sector in the long run.

- The total national CO_2 emissions mitigation potential of moving from a CIS to AIS trajectory of development is 3.8 billion tonnes in 2050 with the power sector having the greatest mitigation potential. In 2050, over 70% of the inter-sector mitigation is from the power sector whereas 12% is from the transport sector.

- Both the CIS and AIS scenarios suggest that the goal of 40% to 45% carbon intensity reduction by 2020 announced in 2009 is possible. It will, however, require strengthening or expansion of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable and nuclear power capacity.

- The share of coal will be reduced from 74% in 2005 to about 47% by 2050 in CIS, and to 30% in AIS. Coal demand in CIS will approach its peak in the late 2020s and reach it in 2031 at 3,000 Mtce. Most of the increase in crude oil demand is driven by a burgeoning transport sector with a growing share of oil demand. While other sectors have declining shares of total oil final demand, the transport sector will reach 66% share of oil demand in 2050 in CIS. This is comparable to the current U.S. transport share of 69%.

- The commercial building sector's emerging role as a major energy consumer is most evident in the rise of final electricity demand, more than offsetting industry's declining share. Under CIS, the commercial sector will be responsible for nearly one-third of all electricity demand. Under AIS, the transport sector has growing share of electricity demand because of more aggressive rail and road electrification.

- Saturation effects are important in this outlook. The saturation of commercial space per employee reduces construction of commercial space. This in turn has a very significant effect on the demand for steel and cement. Similarly, the saturation of fertilizer use per hectare of land results in a flattening of chemical fertilizer production from ammonia. In contrast, expected growth in per-capita consumption of plastic supports strong continued growth in ethylene production. Appliance sales and expansion of urban areas also drive electricity demand.

- Heavy-industrialization-led energy demand growth approach a peak in the short term of 2015 for both CIS and AIS, and industrial energy use will gradually decline as a proportion of the total as transportation and building energy use growth dominate demand through 2050.

Industry

- In spite of the relative decline in energy consumption of the energy-intensive industry sectors, they it still account for 47% of total industry energy consumption in 2050 in CIS, down from 61% in 2005 in CIS scenario. All energy-intensive subsectors decline in energy use over time except the ethylene subsector. Under AIS, the largest subsector potential for energy savings is in iron and steel, followed by non-heavy industry and cement.

Residential Buildings

- Although the ownership of many appliances has reached saturation in urban areas, new sales remain strong with increasing urbanization, with over 470 million additional people expected to become urban residents by 2050. As a result, electricity use from appliances will grow rapidly. Urban fuel consumption from space heating will more than double, due to increases in rural population and heating intensity in both CIS and AIS.

- Rural electricity consumption will continue to grow in spite of the reduction in rural population due to increases in per household use of lighting and appliances. Biomass consumption will decrease considerably, with substitution by commercial fuels.
- Residential primary energy demand will grow rapidly until 2025 or 2030. In CIS, demand rises between 2005 and 2030 at an average annual rate of 2.8%. After 2030, it increases by only 0.6% per year. This slowing of growth is largely due to saturation effects, as the process of urbanization will be largely complete, most households will possess all major appliances by 2030, and efficiency improvements in heat distribution will be largely complete.

Commercial Buildings

- Energy demand in the commercial sector is currently growing rapidly, but there will be a slowing of growth in the medium term, reaching a plateau by about 2030. Total commercial building floorspace may saturate in the short term, but end-use intensity continues to have much room to grow before reaching current levels in industrialized countries. In particular, lighting, office equipment and other plug loads in commercial buildings will grow dramatically through 2030, but level off thereafter in CIS.

Transportation

- Urban private car ownership is expected to increase to over 356 million by 2050, with 30% of these being electric cars under CIS. Increasing this proportion to 70% in the AIS scenario reduces gasoline demand by 82 million tonnes in 2050. This produces the unintended result that China becomes a gasoline exporter, as demand for other oil products is not reduced commensurately. Energy use for freight transport remains important in both scenarios and has a strong impact on the structure of petroleum demand. Although foreign trade becomes less important in 2050 as China relies more on domestic demand, bunker fuel (heavy oil) demand will continue to rise strongly. Increased fuel efficiency of trucks for road freight, higher levels of electrification of the rail system, and more efficient inland and coastal ships moderate diesel demand growth, but diesel remains the largest share of petroleum product demand.

- Power decarbonization has important effects on the CO_2emissions mitigation potential of switching to electric vehicle (EV) technology. Greater transport electricity use under AIS could result in net CO_2 emissions reduction on the order of 5 to 10 Mt CO_2 per year before 2030 and as much as 109 Mt CO_2 by 2050 because AIS power supply is less carbon intensive than CIS power supply. However, in the absence of any decarbonization in the power sector, EVs will increase CO_2 emissions.

Energy Production

- Energy use to produce energy continues to increase from current levels of 150 Mtce to over 360 Mtce in 2030 under CIS. It will increase to 325 Mtce in 2030 and 310 Mtce in 2050 under AIS. This is equivalent to 17% to 19% of total industrial energy use. Energy used in energy extraction and processing in 2050 is led by the petroleum refining and coal mining sectors, together responsible for 70% of fuel use for energy extraction and processing. With the decline in availability of the "easily accessible" coal reserves, energy investment per unit of coal extracted will increase, and with the decline in average quality of crude oil for refining and increasingly stringent product quality specification, unit refinery energy use will rise.

- Decarbonization also plays a significant role in CO2 emission reduction in the power sector, primarily from the increase in nuclear, hydropower and renewable generation.

- One of the largest power sector mitigation potentials is from end-use efficiency improvements that lower final electricity demand and the related CO_2 emissions, which is about half of total CO_2 savings from electricity before 2030 and one-third of total CO_2 savings from electricity by 2050. Another growing source of carbon mitigation potential is the rapid expansion of nuclear generation, which increases from accounting for only 5% of CO_2 savings in 2030 to almost 40% in 2050.

- Of the CO_2 savings from power sector technology and fuel switching, greater shifts in coal generation technology (i.e., greater use of supercritical coal generation) and higher renewable and hydropower capacity each contribute similar magnitude of savings by 2050.

Energy Supply

- In both scenarios, China remains a net importer of oil and natural gas and becomes highly dependent on imports by 2050 (over 97%) based on its remaining proven oil and gas reserve base. Even with substantial expansion of proven reserves, China's import dependency would remain over 75% in 2050.

- China's remaining extractable coal reserves appear to accommodate extraction levels up to over 4 billion tonnes per year, meeting CIS demand, for only for a relatively short period; unless China's reserves turn out to be larger than current estimates, China will be increasingly dependent on coal imports in the long run (after 2050). At lower levels of extraction such as under the AIS scenario, domestic reserves may be sufficient and will last considerably longer.

The model described here represents a comprehensive effort to provide energy efficiency and CO2 emissions reduction scenarios across China's energy system. There are more insights to be gained from further analysis; the modeling framework developed for this study provides a useful framework for continued exploration of issues and sensitivities of results as well as refining input data and assumptions.

Introduction

Rising carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions largely resulting from fossil fuel combustion are contributing to higher global mean temperatures and to climate change. As a consequence of soaring energy demand due to the staggering pace of its economic growth and the related growth of energy-intensive industry, China overtook the United States to become the world's largest contributor to energy-related CO_2 emissions in 2007. Since China is still in the early stage of industrialization and modernization, the process of economic development will continue to drive China's energy demand. Furthermore, China's reliance on fossil fuel is unlikely to change in the long term. In recent years, China has taken serious actions to reduce its energy intensity (energy consumption per unit of gross domestic production) and carbon intensity (CO_2 per unit of GDP). China's 11th Five Year Plan announced in 2005 outlined goal of reducing energy intensity by 20% from 2006 to 2010. The announcement was followed up with extensive programs to support the realization of the goal. And in Nov. 2009, China also announced commitment to reduce its carbon intensity by 40% to 45% percent below 2005 levels by 2020.

Achieving the 2020 goal will require strengthening and expansion of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable and nuclear power capacity. Achieving this goal will require continuing and strengthening ongoing actions by government and industry beyond efforts initiated during the 11th Five-Year Plan. Given China's crucial role in the expansion of the global economy and because of its high reliance on coal, maximum efforts in improving energy efficiency, reducing energy intensive output of industry and dramatic expansion of carbon control energy technology are needed to address China's energy and climate change issues by 2050.

This research aims to develop a China Energy Outlook through 2050, with 2020 and 2030 milestones that can be used to assess the role of energy efficiency, structural change in industry, and new supply options for transitioning China's economy to a lower-GHG trajectory in the longer term, and to examine the challenge of meeting the shorter term goal in 2020.

The past decade has seen the development of various scenarios describing long-term patterns of future GHG emissions. Each new approach adds additional insights to our understanding of aggregate future energy trends. In most of these models, however, a description of sectoral activity variables is missing. Furthermore, end-use sector-level results for buildings, industry, or transportation or analysis of adoption of particular technologies and policies are generally not provided in global energy modeling efforts.

Instead, major analyses of long-term impacts of GHG emissions to date have relied on aggregate scenarios of energy supply and demand. The underlying drivers of all such scenarios are macro socioeconomic variables (GDP, population) combined with storylines describing the context of economic and social development. Unfortunately, these scenarios do not provide more detail than the sector level (i.e., buildings, industry, and transportation). This is to say that the scenarios are developed without reference to the saturation, efficiency, or usage of energy-using devices, e.g., air conditioners. For energy analysts and policymakers this is a serious omission, in some cases calling into question the very meaning of the scenarios. Energy consumption is driven by the diffusion of various types of equipment; the performance, saturation, and utilization of the equipment has a profound effect on energy demand. Policy analysts wishing to assess the impacts of efficiency and industry structure and mitigation policies require more detailed description of drivers and end use breakdown.

In the years since 2005, we have established and significantly enhanced the LBNL China End-Use Energy Model based on the level of diffusion of end use technologies, and other drivers of energy demand. The model addresses end-use energy demand characteristics including sectoral patterns of energy consumption, change in subsectoral industrial output, trends in saturation and usage of energy-using equipment, technological change including efficiency improvements, and links between economic growth and energy demand. A baseline (Continued Improvement Scenario or CIS) and an alternative energy efficiency scenario (Accelerated Improvement Scenario or AIS) have been developed to assess the impact of actions already taken by the Chinese government, planned or proposed actions, and actions that may not yet have been considered, in order to evaluate the potential for China to control energy demand growth and mitigate emissions. In addition, we have used our judgment about timing and extent of commercialization of carbon capture and sequestration (CCS) to describe our scenario with CCS (CIS and AIS assume no CCS).

This analysis also evaluated China's long-term domestic energy supply in order to gauge the potential challenge China may face in meeting long-term demand. The potential mismatch between supply and demand will undoubtedly raise some very difficult issues. Penetration of each major energy supply option (oil, gas, coal, hydro, nuclear, wind, biomass and solar) were projected out to 2050 using two basic approaches. For non-renewable fossil-fuel energy, derivative logistics curve calculations were used in order to constrain the extraction profile to accord with the total volume of reserves available for extraction. For the renewable energy forms and nuclear energy, projections of installed capacity were collected from a variety of sources, including official government statements (nuclear capacity by 2020); projections by research groups and in academic journals (wind power and hydropower); and own-estimates (biomass/solar; nuclear power in 2050).

Drivers of Energy Demand

Scenarios

Neither scenario represents what we believe would actually happen in the long term without policy intervention. We put forth what we believe are distinct alternatives given current trends, macroeconomic considerations, currently available and projected efficiency technologies, and policy choices and degree of successful implementation of the policies. Both scenarios are driven by underlying macroeconomic drivers, which will follow current trends to some extent. However, the model incorporates important non-linear effects, especially saturation effects. The forecast of energy demand underlying both scenarios does not take into consideration resource constraints which, in the case of China are likely to be significant in the long term. Therefore, the model makes no claim as to the actual sustainability of the Chinese energy system.

Continued Improvement Scenario (in energy and carbon intensity)

The Continued Improvement scenario does not assume that current technologies will remain frozen in place, but that the Chinese economy will continue on a path of lowering its energy intensity as a function of GDP. However, efficiency improvements in this scenario are consistent with trends in 'market-based' improvement, achieving levels that are common in industrialized countries.

Accelerated Improvement Scenario (in energy and carbon intensity)

The Accelerated Improvement' scenario assumes a much more aggressive trajectory toward current best practice and implementation of important alternative energy technologies. Efficiency targets are considered at the level of end use technologies, with Chinese sub-sector intensities being lowered by implementation of the best currently available products and processes in the short to medium term, taking into account the time necessary for these technologies to penetrate the stock of energy-consuming equipment.

Continued Improvement with CCS Scenario

A Continued Improvement scenario with CCS was added to explore the energy and carbon implications of installing carbon capture and sequestration (CCS) technology to coal generation under the CIS pathway of power development. The CCS scenario has the same generation capacity as CIS scenario, but assumes that sufficient CCS-enabled coal capacity to capture and sequester 500 million tonnes of CO_2 in 2050 – a level calculated following trend lines in the *2009 World Energy Outlook* 450 ppm scenario. Under this scenario, 90% capture of carbon emissions for pre- and post-combustion technologies are assumed with additional energy requirement of CCS for carbon separation, pumping and long-term storage.

Table 1 Key Assumptions of Two Scenarios

	Continued Improvement	**Accelerated Improvement**
Macroeconomic Parameters		
Population in 2050	1.41 Billion	1.41 Billion
Urbanization Rate in 2050	79 %	79%
GDP Growth		
2010-2020	7.7%	7.7%
2020-2030	5.9%	5.9%
2030-2050	3.4%	3.4%
Residential Buildings		
Appliance Efficiency	Moderate Efficiency Improvement (1/3 improvement relative to AIS level)	Moderate Improvement of new equipment in 2010 – near Best Practice by 2020
Building Shell Improvements: Heating	Moderate Efficiency Improvement (1/3 improvement relative to AIS level)	50% improvement in new buildings by 2010 – 75% improvement in new buildings by 2020.
Building Shell Improvements: Cooling	Moderate Efficiency Improvement (1/3 improvement relative to AIS level)	25% improvement in new buildings by 2010 – 37.5% improvement in new buildings by 2020.
Commercial Buildings		
Heating Efficiency	Moderate Efficiency Improvement by 2020	Current International Best Practice by 2020
Cooling Efficiency	Current International Best Practice by 2050	Current International Best Practice by 2020
Building Shell	50% improvement in fraction of	50% improvement in all new

Improvements: Heating	new buildings growing by 1% per year	buildings by 2010, 75% improvement in all new buildings by 2025
Building Shell Improvements: Cooling	25% improvement in fraction of new buildings growing by 1% per year	25% improvement in all new buildings by 2010, 37.5% improvement in all new buildings by 2025
Lighting and Equipment Efficiency	18 % improvement by 2030	48 % improvement by 2030
Industrial Sector		
Key energy-intensive industries[2]	Most industries meet current world best practice energy intensity around or after 2030	Most industries meet current world best practice energy intensity before 2030
Transport Sector		
Internal Combustion Engine Efficiency Improvements	Moderate efficiency improvements in fuel economy of aircrafts, buses, cars, and trucks through 2050	Significant additional efficiency improvements in fuel economy of buses through 2050
Electric Vehicle Penetration	Electric vehicle penetration to 30% by 2050	Electric vehicle penetration to 70% by 2050
Rail Electrification	Continued rail electrification to 70% by 2050	Accelerated rail electrification to 85% by 2050
Power Sector		
Thermal Efficiency Improvements	Coal heat rate drops from 357 to 290 grams coal equivalent per kilowatt-hour (gce/kWh) in 2050	Coal heat rate drops from 357 to 275 (gce/kWh) in 2050
Renewable Generation Growth	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 535 GW in 2050	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 608 GW in 2050
Nuclear Generation Growth	Installed capacity of nuclear power grows from 7 GW in 2005 to 300 GW in 2050.	Installed capacity of nuclear power grows from 7 GW in 2005 to 550 GW in 2050.
Demand Side Management	Total electricity demand reaches 9100 TWh in 2050	Total electricity demand reaches 7,764 TWh in 2050

Macro Economic Drivers

Key Drivers

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 has and will continue to undergo changes in its physical built environment as a result of rapid urbanization. For example, two more mega-cities with populations of 10 million or more and over fifty second-tier cities with smaller populations are expected through 2030. 290 million new urban residents were added from 1990 to 2007, and 380 million new urban

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[2] See sections on Industry for more details on scenario assumptions.

residents are expected from 2007 to 2030 and another 92 million to 2050. These new urban residents need to be provided with housing, energy, water, transportation, and other energy services. Urbanization and the related demand for infrastructure and commercial, residential energy services will be important driving forces for future energy consumption in China. To account for the potential effects of urbanization as well as inter- and intra-city transport on energy demand in China, we include population growth and urbanization, or share of urban population, as macro-drivers in both scenarios. The urbanization rate is projected to increase to 79% in 2050 from 45% in 2007 (see Figure 1).

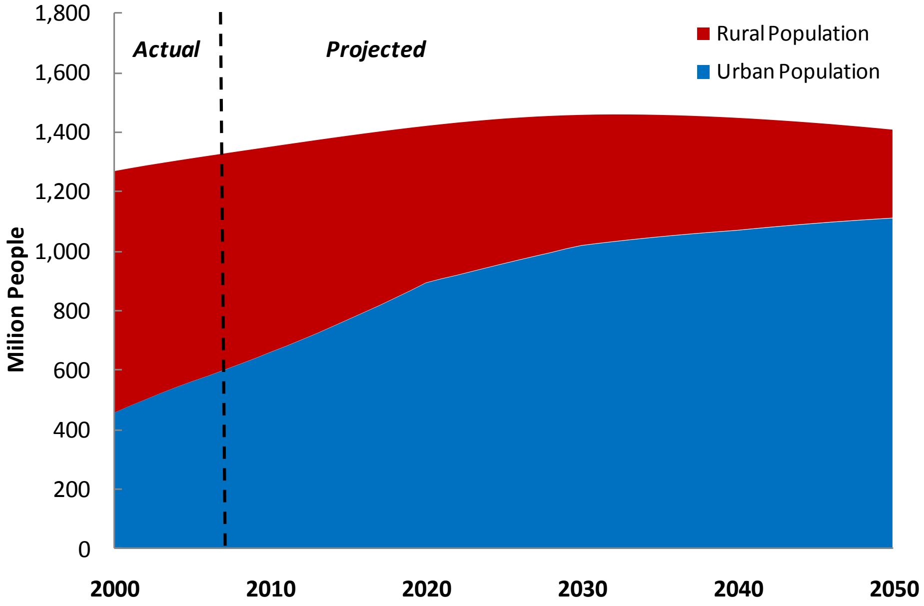


Figure 1 Historical and Projected Population and Urbanization Trends

For all scenarios, macroeconomic parameters such as economic growth, population, and urbanization are assumed to be the same (Table 2). To account for economic growth in China's near future, different rates of GDP growth were assumed for the period between 2010 and 2020, between 2020 and 2030 and between 2030 to 2050 (Table 2). Rapid GDP growth is expected to continue for the next decade, but will gradually slow by 2020 as the Chinese economy matures and shifts away from industrialization.

Table 2 Key Macroeconomic Parameters for All Scenarios

	2005	2050
Population	1.31 Billion	1.41 Billion
Urbanization Rate	43%	79 %
GDP Growth		
2000-2010	9.4%	
2010-2020	7.7%	
2020-2030	5.9%	
2030-2050	3.4%	

Sensitivities

GDP growth rates have significant effects on total primary energy use. In particular, increasing the GDP growth rate by 25% results in a 10% higher total primary energy consumption in 2030 while decreasing urbanization by 12 percentage points to 67% in 2050 only lowers primary energy use by 1.8% (Figure 2).

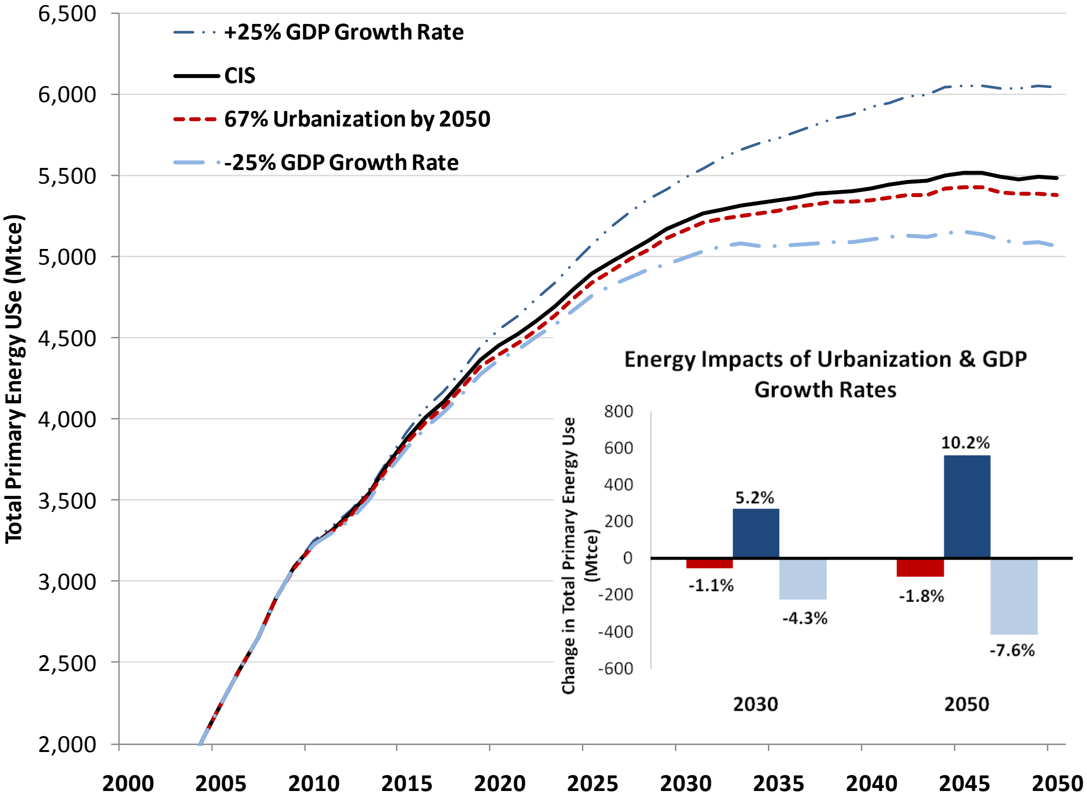


Figure 2 Sensitivity Analysis of Macroeconomic Variables

Drivers of Residential Energy Demand

Key Drivers

There are two main related drivers to growth in the residential buildings sector: urbanization and growth in household incomes. Urban households generally consume more energy than rural ones, especially non-biofuels. Second, incomes are rising for both urban and rural households. The main impacts of household income growth is the increase in the size of housing units, which increases heating and cooling loads and lighting, and the increase in ownership and use of energy-consuming appliances (**Error! Reference source not found.**). Population increase is not a main driver of energy consumption in China per se as population growth has slowed, and total population is expected to peak between 2020 and 2030.

Globally, the size of the household (number of persons per household) tends to decline with increasing income and urbanization of the population. In the case of China, the "One Child Policy" enforced such a decline with average household size in China dropping from 5.2 persons per household in 1981 to 3.16 persons per household in 2008 (Figure 3). This trend is expected to continue, with urban household size decreasing to 2.80 persons/household in 2020, the level of Japanese household size today. Rural household size will remain at around 3.5 persons/household for the next decade or longer.

In developed countries, household floor space per person has been gradually increasing since at least the early 1970s. Similarly, in China, floor space per person increased from 13.7 m^2 in 1990 to 24 m^2 in 2008 in urban areas and from 17.8 m^2 to 32.4 m^2 in rural areas. In 2050, urban and rural residences are assumed to continue to grow in floor space to 46 m^2 per capita. The decline in household size leads to an increase in the total number of households in the region, which, together with the increase in living area, will multiply the contribution of energy demand from households.

As Figure 3 shows, urban appliance ownership exploded in the early 1990s. In forecasting future ownership trends, we use an econometric model correlating historical ownership rates with incomes to predict future trends given an economic growth scenario. The general result is that, while we expect significant growth in ownership, especially in the rural sector, saturation effects will become important in urban households in the near future. Once nearly every household owns a refrigerator, a washing machine, air conditioners and other appliances, per household electricity growth will slow. Some growth is assumed to continue as incomes continue to rise, resulting in increased usage (especially air conditioners), larger refrigerators, more lighting and more devices using standby power. Meanwhile, space heating density and usage also increases with dwelling area and wealth. In addition, the model takes into account prevailing trends in space heating equipment choice, such as an increase in the use of electric heat pumps in the Transition climate zone, and the phase-out of coal boilers.

Significant opportunity exists to reduce energy consumption in households in two main areas: improvement of equipment efficiency and tightening of the thermal shell of residential buildings. Equipment efficiency increases as the stock turns over. Implementation of labeling and minimum efficiency performance standards (MEPS) in China will drive future efficiency. CIS represents a continuation and possible acceleration of the current Chinese appliance standards and labeling program. By 2020, new residential appliances and heating equipment are generally of an efficiency level matching current international best practice. The current schedule of Chinese standards is taken into account explicitly in the construction of efficiency scenarios. For instance, the Chinese government recently implemented newly revised standards for refrigerators. These efficiency gains are modeled in the Continued Improvement Scenario. In the Accelerated Improvement Scenario, we assume that Chinese standards will match international best practice, yielding considerably larger energy saving than in CIS (see Figure 5).

In addition to equipment efficiency, AIS considers improvements to the thermal insulation of residential buildings. These improvements can be achieved through tightening and enforcement of construction codes, or through retrofits of heating controls and improvement of the efficiency of district heating systems. Under AIS, new residential households are assumed to use half as much heating and 75% of the cooling in today's households. In the CIS case, heating improvement of new buildings is 16.7% for heating and 8.3% for cooling.

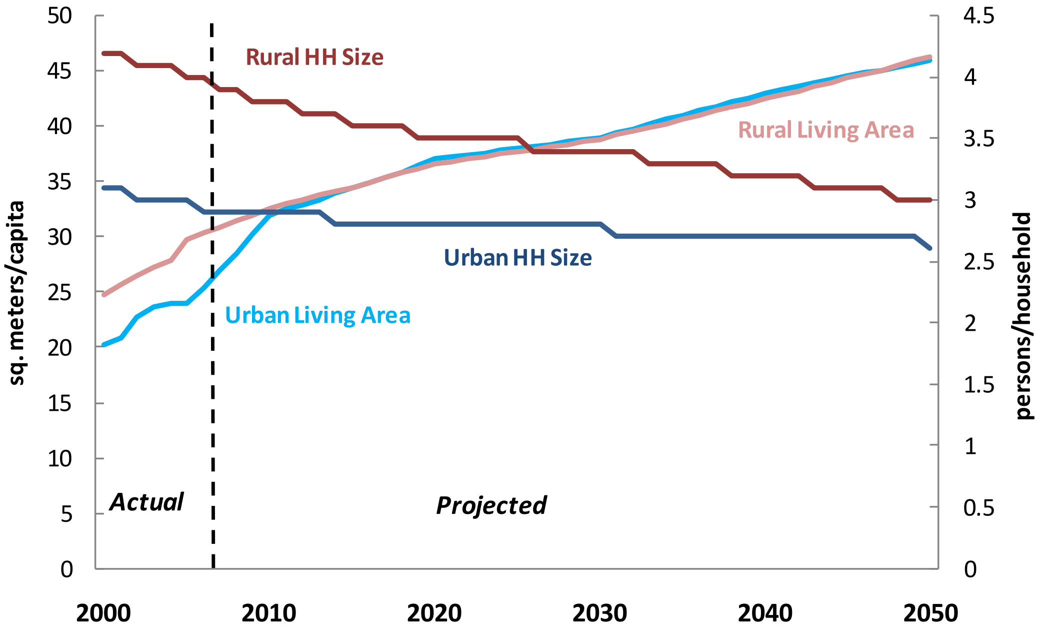
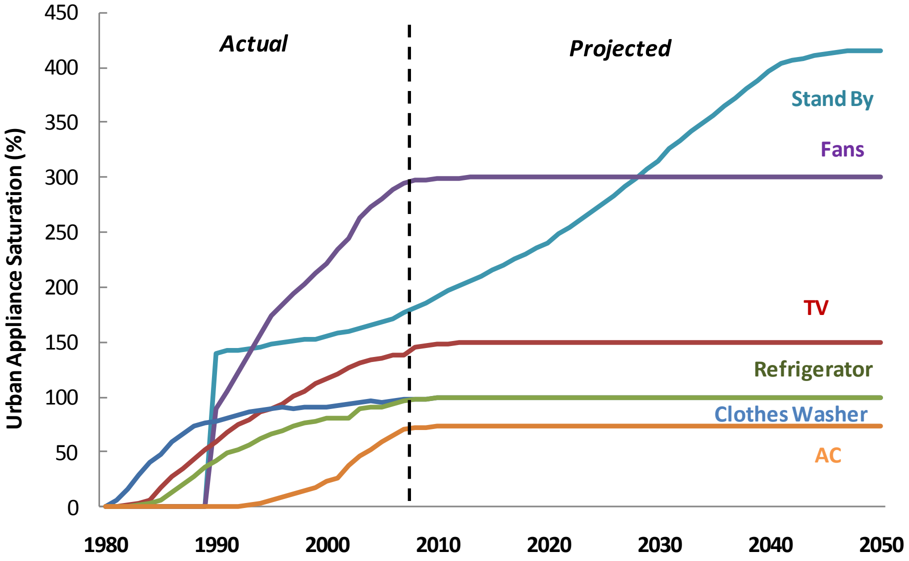
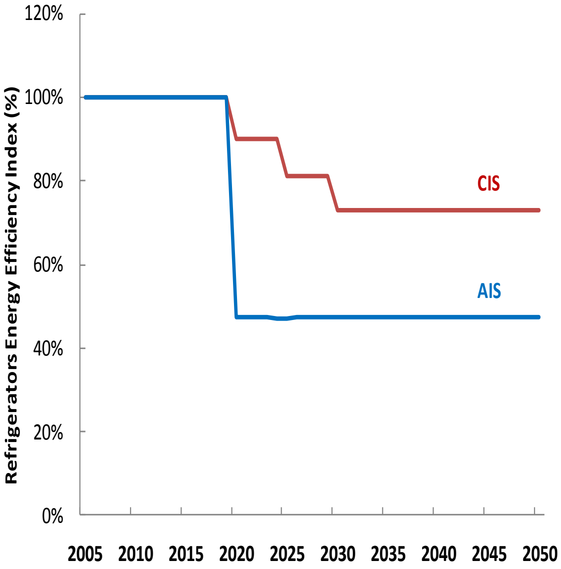


Figure 3 Historical and Projected Residential Living Area and Household Size



Source: Historical data from National Bureau of Statistics, 2009.

Figure 4 Historical and Projected Urban Appliance Penetration Trends



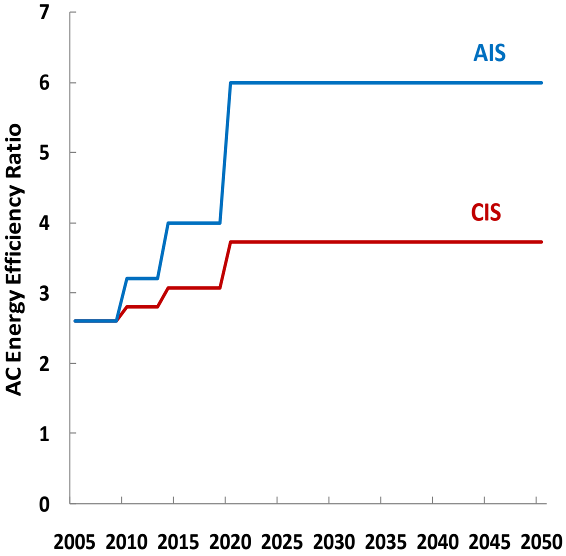


Figure 5 Efficiency Trends for Refrigerators

Figure 6 Efficiency Trends for Air Conditioners

Sensitivities

Uncertainty in the input variables for the residential sector, namely the projected residential floor space, has small impact on total primary energy use resulting in only 2% increase in total primary energy use with 25% more floor space in 2050 (Figure 7). Changing residential floor space primarily affects building materials such as cement, glass, aluminum and steel and thereby affects industrial energy use. Its main impact is on heating and cooling energy. However, we assume that most residents continue to heat or cool space only when occupied.

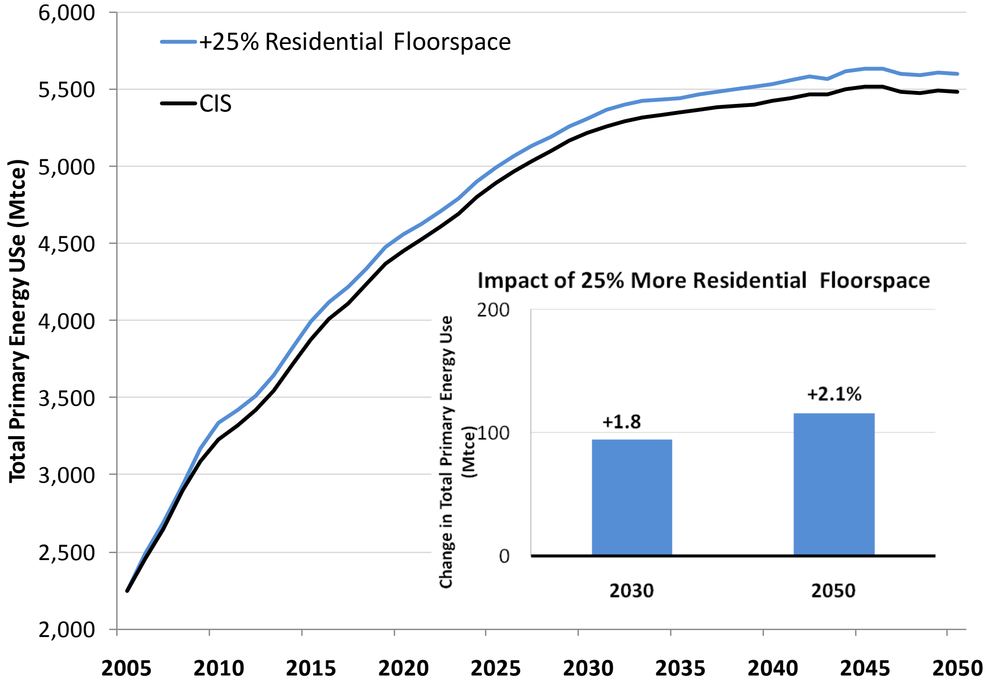


Figure 7 Sensitivity Analysis of Residential Sector Variable

Drivers of Commercial Energy Demand

Key Drivers

Commercial building energy demand is the product of two factors: building area (floor space) and end use intensity (MJ per m^2). Forecasting commercial building floor space demands an understanding of the drivers underlying the recent growth of the sector, and where these trends are likely to be heading. In our analysis, commercial floor space is determined by the total number of service sector employees, and the area of built space per employee. This approach differs from the conventional assumption that commercial floor space grows with GDP, which we consider to be unrealistic. According to national statistics, the fraction of Chinese workers employed in the tertiary sector increased from 27% in 2000 to 32% in 2006, an increase of 19% in just 6 years. When these numbers are corrected to include the number of unregistered workers likely to be working in urban service sector businesses, the current fraction is estimated to be 43%. As a general rule, as economies develop, employment shifts away from agriculture and industry toward the service sector, and this trend is expected to continue in China leading to further increases in commercial building floor space. The potential for growth is not unlimited, however. Chinese population is expected to peak by about 2030. Furthermore, the population is aging, so that the number of employees will peak closer to 2015. By comparing Chinese GDP per capita to that of other countries, we estimate that the tertiary sector share of workers will reach 60% by 2050. Under these assumptions, the total number of tertiary sector employees will increase by only about 33% by 2030 compared to 2005. Floor space per employee has some room to grow: we forecast an increase of about 25% by 2030 and 60% by 2050. Overall commercial floor space may likely only double by 2050, and construction in this sector may already be approaching its peak.

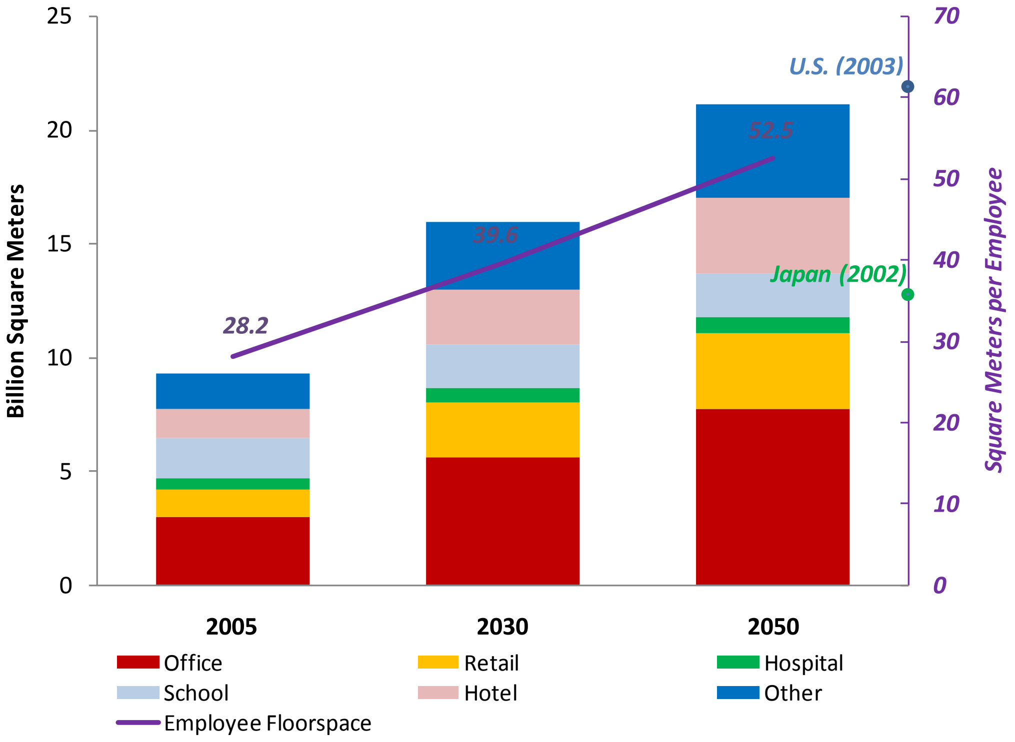
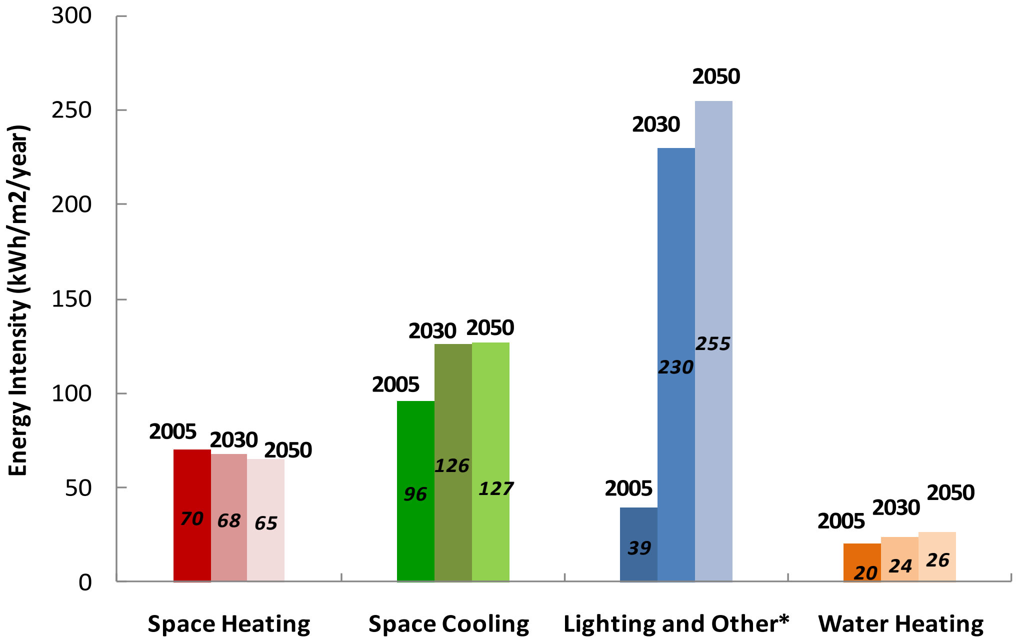


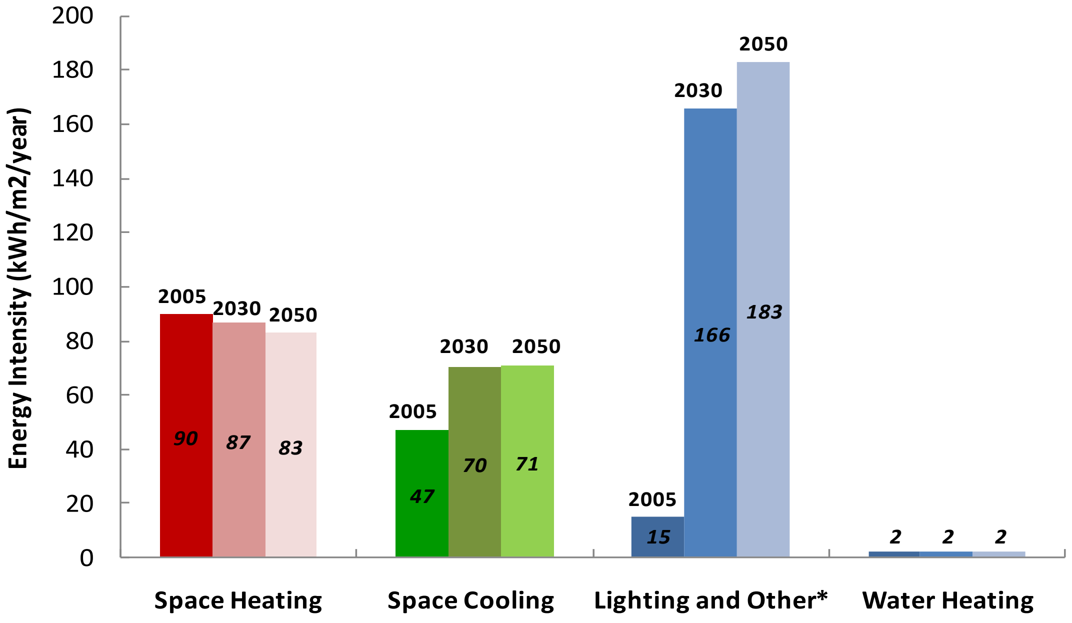
Figure 8 Commercial Floor Space Change

Commercial sector energy demand growth is likely to arise much more from intensity increases than overall floor area growth. Chinese energy use per square meter is still relatively low. Due to the presence of (often unmetered) district heat, space heating intensity in cold climates in China is already comparable to that in Japan. However, space cooling and appliance energy is only a fraction of the Japanese level. We assume that Chinese commercial buildings will reach current Japanese levels of energy intensity for space cooling by 2030, and thereafter grow only moderately. Space heating usage is not expected to increase. In AIS, space heating and cooling achieves current international best practice by 2020, as opposed to only moderate improvements in the CIS. Building shell improvement in AIS applies to all new buildings, where it reduces heating loads by 75% by 2025 and cooling loads by 38% in that year. AIS assumes about 85% penetration of high-efficiency equipment having an energy intensity of 50% of today's level by 2025.



*Other refers to misc. equipment such as computers, printers, audiovisual equipment, elevators, pumps, etc.

Figure 9 Retail Buildings Energy Intensity by End-Use



*Other refers to misc. equipment such as computers, printers, audiovisual equipment, elevators, pumps, etc.

Figure 10 Office Buildings Energy Intensity by End-Use

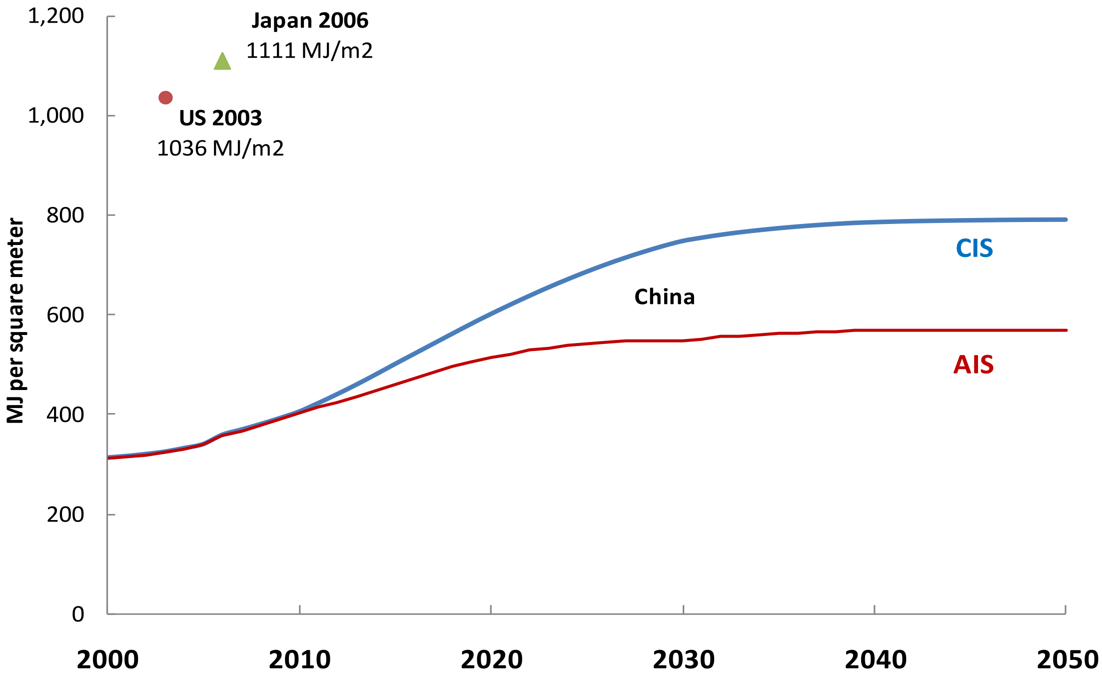


Figure 11 Commercial Floorspace Final Energy Intensity

Sensitivities

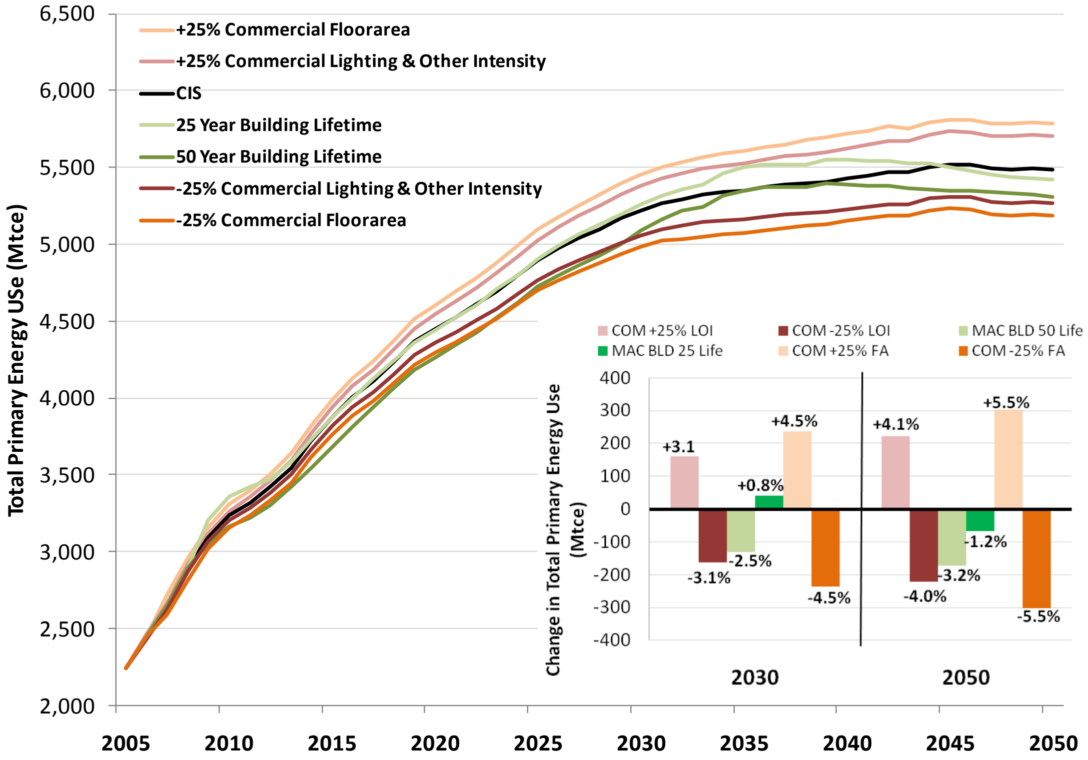


Figure 12 Sensitivity Analysis of Commercial Energy Drivers

Drivers of Industrial Energy Demand

Key Drivers

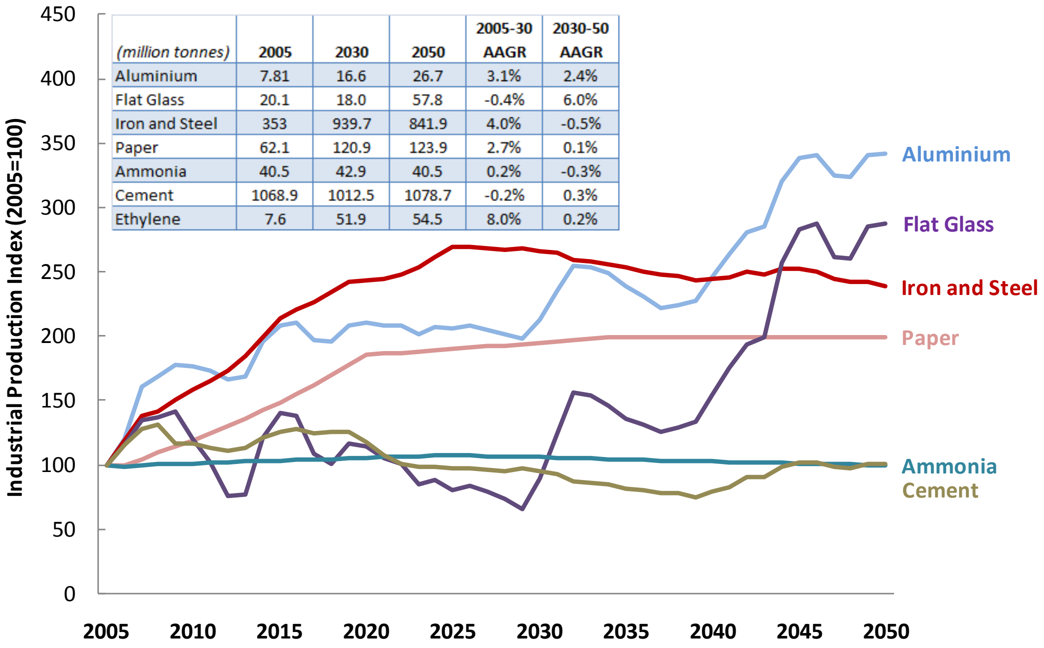
We have analyzed in depth seven energy-intensive industrial sub-sectors including cement, iron and steel, aluminum, ammonia and ethylene. For cement, steel and aluminum, the scenarios were based on floor space construction area and infrastructure construction as a proxy. Ammonia production, in contrast, was modeled as a function of sown area, which is expected to decrease slightly by 2% following current trends, and fertilizer intensity assumed to reach Korea's 2005 level by 2030. Similarly, ethylene production is driven by population growth and rising per capita demand for plastics reaching current Japanese levels by 2030. For each sub-sector, we developed projections of process efficiency requirements and technology shift. We examined the energy requirements to produce and distribute commercial energy.

Overall, the steep rise in output from energy-intensive industrial sectors experienced from 2002 to 2009 is not expected to continue. As shown in Figure 13**,** both scenarios show a leveling of output of cement and some chemicals in the near term. Others such as steel and paper production will increase with an AAGR of ~3% until 2020 and start leveling off or declining, whereas ethylene stands out as an exception because of continuing growth of demand for plastics (reaching Japan's 2007 primary plastics demand per person by 2025). In addition, the surge in growth of ethylene demand assumes that China will be largely self-sufficient in ethylene production—unlike today—and that imports will be no higher than in 2008.

In the case of cement production, future projection is derived based on the amount of cement required to construct China's urban and rural buildings, Class I and II highways and expressways and urban paved areas and new railway track. This methodology takes into account commercial and residential building construction as well as targeted expansion of urban paved areas, highways and rail track. A summary of the drivers and assumptions for cement production in energy use is presented in Table 3**Error! Reference source not found.**. Both scenarios have cement production rising from 1.36 billion tonnes in 2007 to 1.4 billion tonnes in 2009, then declining from 2020 to 2040, after which retirement of existing buildings drive cement production to rise and plateau around 1.1 billion tonnes by 2045.

Table 3 Cement Production and Energy Use Scenario Assumptions

		Continued Improvement Scenario (CIS)	Accelerated Improvement Scenario (AIS)
Production Assumptions	Urbanization	79% in 2050	79% in 2050
	Per-capita building area	24 m2 per capita in 2005; 39 m2 per capita in 2030; and 46 m2 per capita in urban areas in 2050 (ERI assumption)	Same as CIS
	Cement Use in Building Floorspace	3 year rolling average of total new residential and commercial building floorspace	Same as CIS
	Cement Intensity of Buildings	Average cement intensity of 0.22 ton of cement per square meter of floorspace	Same as CIS
	Cement Use in Highway & Paved Area	3 year rolling average of total Expressway, Class I and II highways and paved road area, using projected growing length to 400 vehicles/km by 2050 based on Japan's experience and width of 10.76 m in 2050	Same as CIS
	Cement Intensity of Highways	1 ton of cement per square meter of highway or paved road	Same as CIS
	Cement Use in Railway Track	3 year rolling average of new rail track length based on stated targets of 120,000 km by 2020 and 150,000 km by 2050	Same as CIS
	Cement Intensity of Railway	Average cement intensity of 20,000 ton of cement per kilometer of track	Same as CIS
	Exports of cement	Assume 2007 exports remain constant through 2050.	Same as CIS
Energy Assumptions	Intensity	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. Rotary kilns' final energy intensity reaches 0.099 tce/t cement by 2030 and 0.090 tce/t cement by 2050	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. Rotary kilns' final energy intensity reaches 0.089 tce/t cement by 2030 and 0.075 tce/t cement by 2050.
	Fuels	Steady decline from 2005 coal share of 85% to 70% by 2030 and 58% by 2050	Same as CIS



(million tonnes)	**2005**	**2030**	**2050**	**2005-30 AAGR**	**2030-50 AAGR**
Aluminium	7.81	16.6	26.7	3.1%	2.4%
Flat Glass	20.1	18.0	57.8	-0.4%	6.0%
Iron and Steel	353	939.7	841.9	4.0%	-0.5%
Paper	62.1	120.9	123.9	2.7%	0.1%
Ammonia	40.5	42.9	40.5	0.2%	-0.3%
Cement	1068.9	1012.5	1078.7	-0.2%	0.3%
Ethylene	7.6	51.9	54.5	8.0%	0.2%

Figure 13 Industrial Production Projection and Drivers

Industrial energy requirements can be lowered by new processes and efficiency improvement of processes at the sub-sector level. In addition, fuel switching can multiply the energy savings and emission reductions. The Chinese government plan calls for the industry sector to become more efficient, and targets have been set as expressed in a series of government policies and development goals including the 11th and 12th Five Year Plans, Top-1000 Enterprises Program, and programs to close down inefficient processes and plants. Our baseline assumption has incorporated these existing and planned policies.

Although energy intensity has declined in most industrial sub-sectors over the years, comparison with international levels indicates that much more effort can be made in the future. Figure 14 shows that for the CIS case, the energy intensity in all subsectors will decrease over time with the iron and steel subsector achieving the greatest reductions; the paper subsector shows the second largest energy intensity reduction. The rate of intensity reduction slows down for all subsectors after 2030. Under AIS, more rapid adoption of efficient technologies is expected to lower final energy intensities across the major industrial subsectors more aggressively. This results in a faster annual rate of decline in energy intensity between 2005 and 2030, ranging from intensity reductions of -2.3% per year for iron and steel production to -1.7% per year for ammonia production. The annual rate of decline in energy intensity after 2030 is also faster for all subsectors except paper under AIS.

As shown in Figure 17, vertical shaft kilns, which accounts for about 35% of the total cement production in 2007, will be completely replaced by new suspension preheater precalciner (NSP) kilns, whereas the share of electric arc furnace (EAF)[3] in the iron and steel industry will increase over time as more steel is recycled. Under AIS, the share of EAF production will be further increased with the adoption of an increasingly more efficient technology mix and greater steel recycling rates (Figure 16).

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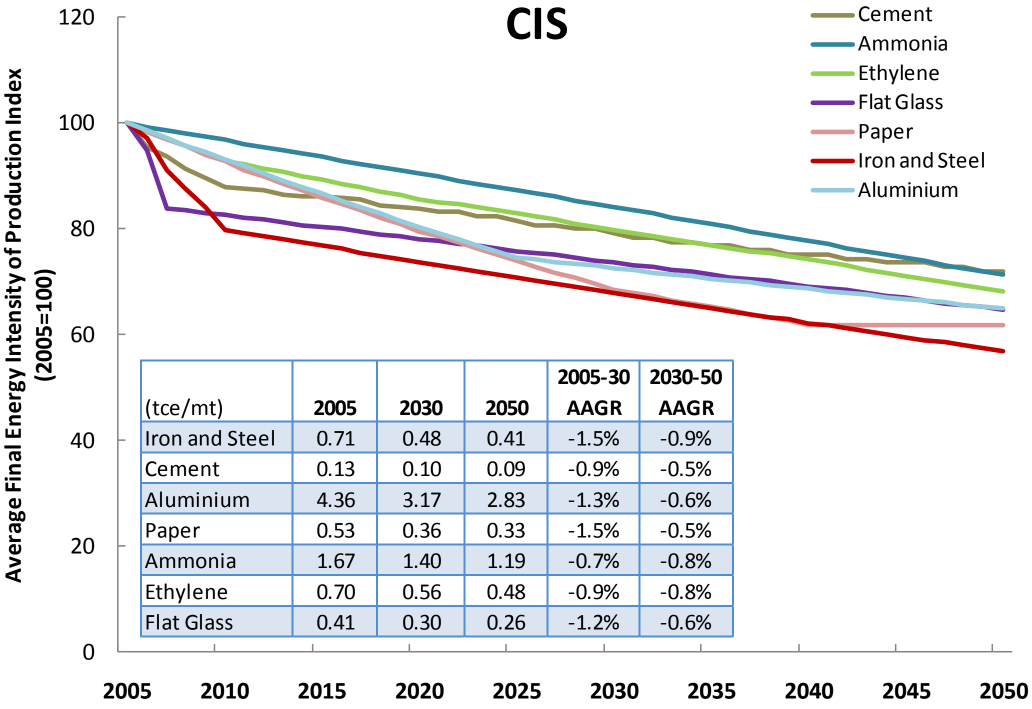
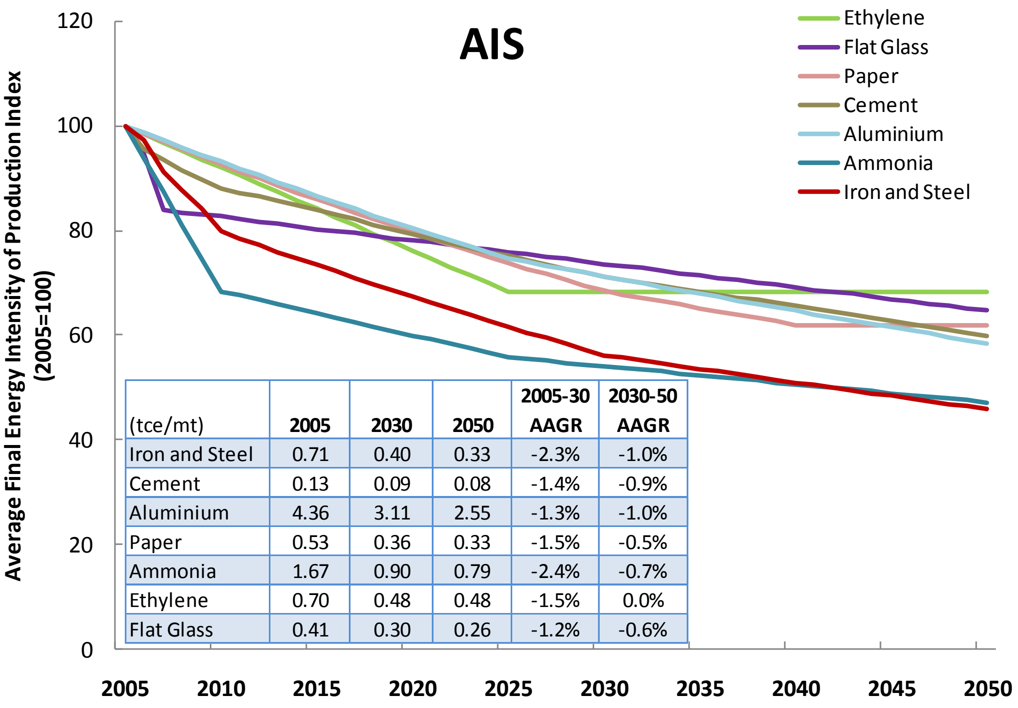
[3] EAFs use steel scrap or sponge iron as raw materials.



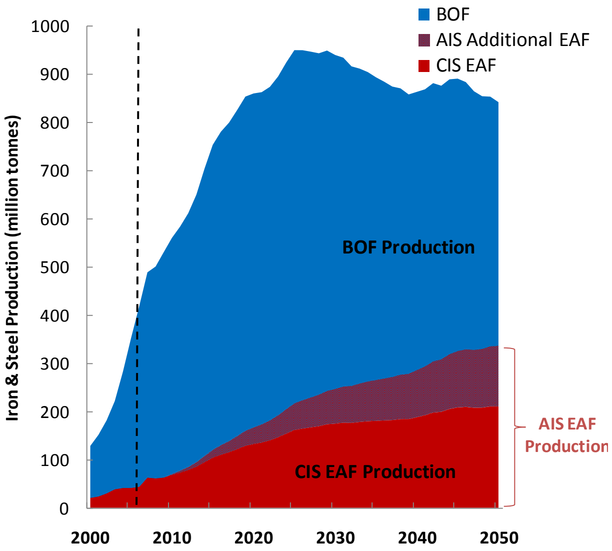
(tce/mt)	2005	2030	2050	2005-30 AAGR	2030-50 AAGR
Iron and Steel	0.71	0.48	0.41	-1.5%	-0.9%
Cement	0.13	0.10	0.09	-0.9%	-0.5%
Aluminium	4.36	3.17	2.83	-1.3%	-0.6%
Paper	0.53	0.36	0.33	-1.5%	-0.5%
Ammonia	1.67	1.40	1.19	-0.7%	-0.8%
Ethylene	0.70	0.56	0.48	-0.9%	-0.8%
Flat Glass	0.41	0.30	0.26	-1.2%	-0.6%

Figure 14 Industrial Production Indexed Final Energy Intensities by Subsector, CIS



(tce/mt)	2005	2030	2050	2005-30 AAGR	2030-50 AAGR
Iron and Steel	0.71	0.40	0.33	-2.3%	-1.0%
Cement	0.13	0.09	0.08	-1.4%	-0.9%
Aluminium	4.36	3.11	2.55	-1.3%	-1.0%
Paper	0.53	0.36	0.33	-1.5%	-0.5%
Ammonia	1.67	0.90	0.79	-2.4%	-0.7%
Ethylene	0.70	0.48	0.48	-1.5%	0.0%
Flat Glass	0.41	0.30	0.26	-1.2%	-0.6%

Figure 15 Industrial Production Indexed Final Energy Intensities by Subsector, AIS



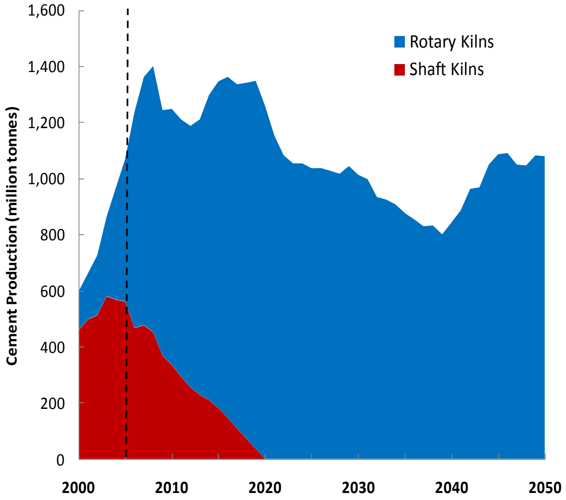


Figure 16 Iron & Steel Production by Technology

Figure 17 Cement Production by Technology

Sensitivities

There is greater uncertainty surrounding energy drivers and key variables in the industrial sector than in other sectors. The greatest uncertainty surrounds variables in the “Other Industry” subsector that includes the chemicals industry, manufacturing and other light industry. For example, a 25% change in “Other Industry” GDP growth rate results in at least 10% higher or lower total primary energy use, or a difference of 500 Mtce. Uncertainties surrounding the projected production of heavy industrial products also have a large impact on total primary energy use.

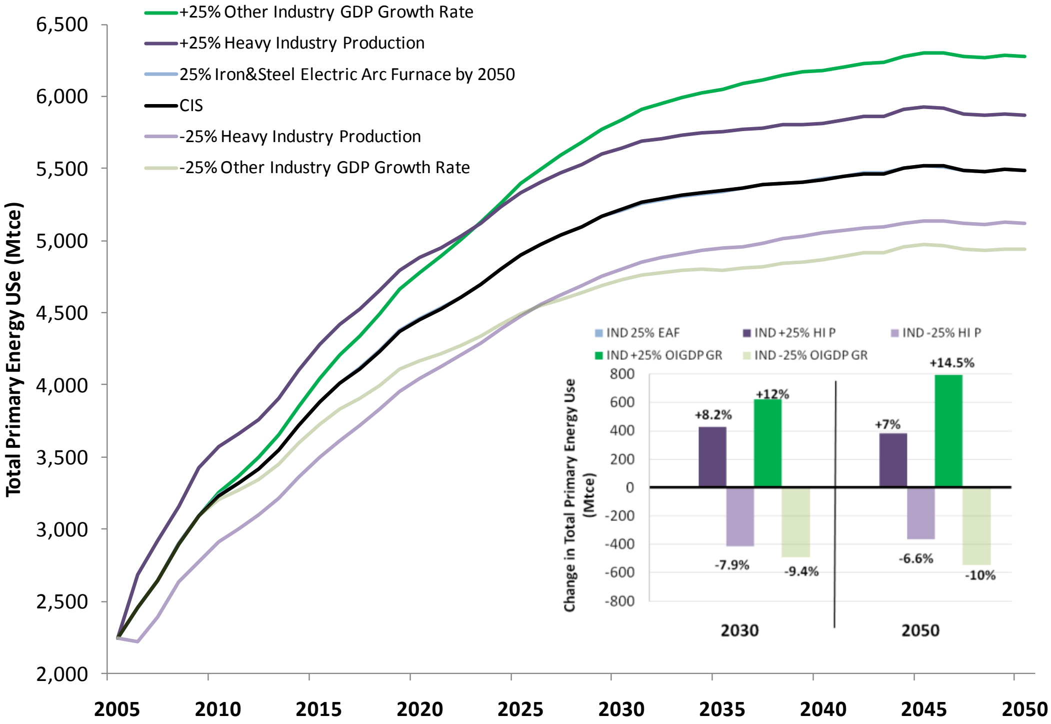


Figure 18 Sensitivity Analysis of Industrial Energy Drivers

Drivers of Transportation Energy Demand

Key Drivers

Transportation demand is driven by demand for freight and passenger transport. Freight transport is calculated as a function of economic activity measured by value-added GDP while passenger transport is based on average vehicle-kilometers traveled by mode (bus, train, and car) moving people. As illustrated in Figure 19, freight transport demand is driven by faster economic growth in the years to 2030 as GDP continues its rapid growth. In later years, road freight growth is slowed to a linear function as the relative importance of foreign trade in GDP is expected to decline. The important roles of both domestic and international freight transport demand is reflected in two major modes of freight transport: water and rail transport. Water transport includes growing international ocean transport as well as domestic coastal and inland transport while demand for road freight transport reflects primarily high demand for domestic freight transport with doubling freight intensity for rail transport.

For passenger transport, growing vehicle-kilometers traveled in different modes is driven by population growth and growing demand for personal transport with rising income levels. Air transport activity is driven by demand for both domestic and international travel, which grows with GDP per capita (Figure 20). Passenger rail transport activity will rise with growth of high-speed rail and increased use of rail for short distance domestic travel. Road transport is the largest mode of passenger travel, which is driven primarily by the burgeoning ownership of private cars that follows rising per capita income (Figure 22). Personal car ownership is forecast on a per-household basis by relating current car ownership rates around the world to household income, with a slight adjustment for the fact that current Chinese personal car ownership is low even compared to countries of similar income. By 2050, personal car ownership reaches 0.68 per household, which while extremely high compared to current values, is still below current levels in the United States and Europe. The high population density in cities in China, like that of New York City, means that cars are generally driven less. Nonetheless, road transport grows rapidly (Figure 20). As personal income and private car ownership rises, motorcycle and taxi passenger transport plateaus and water passenger transport declines modestly after 2020.

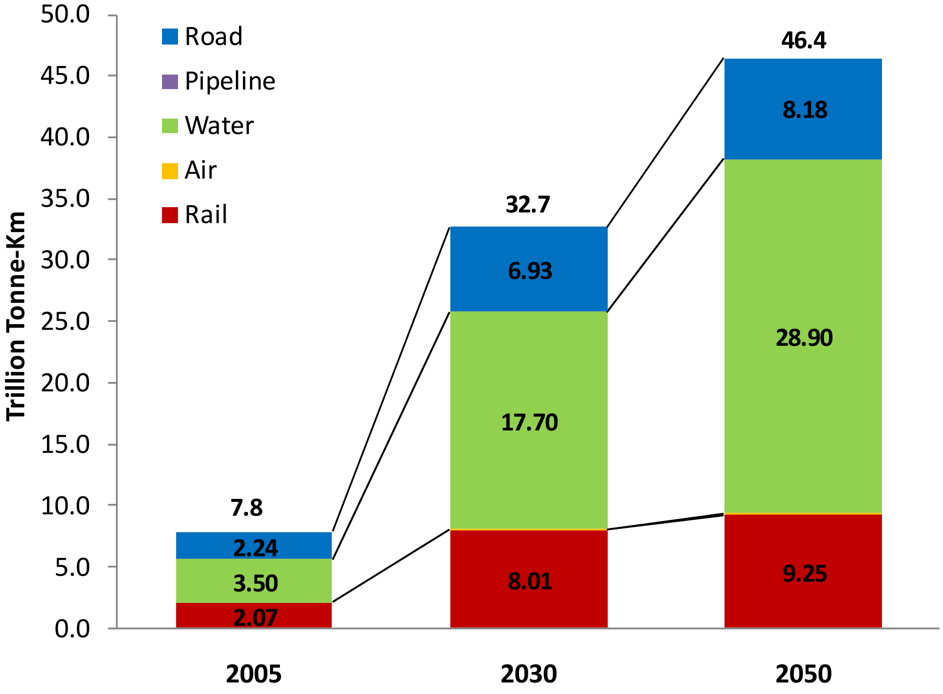


Figure 19 Freight Transport by Mode

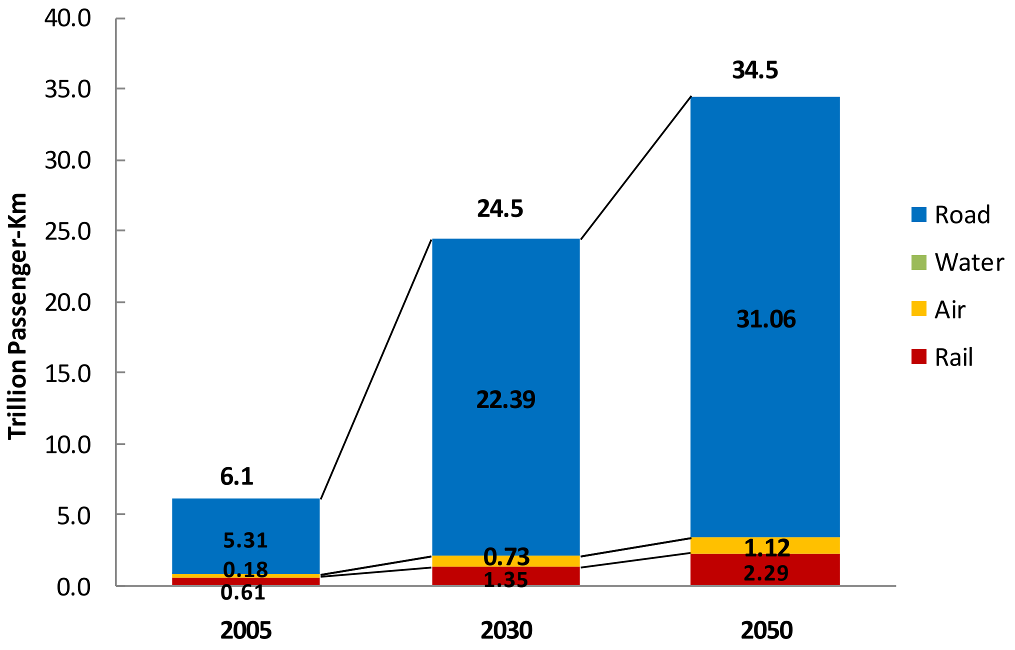


Figure 20 Passenger Transport Activity by Mode

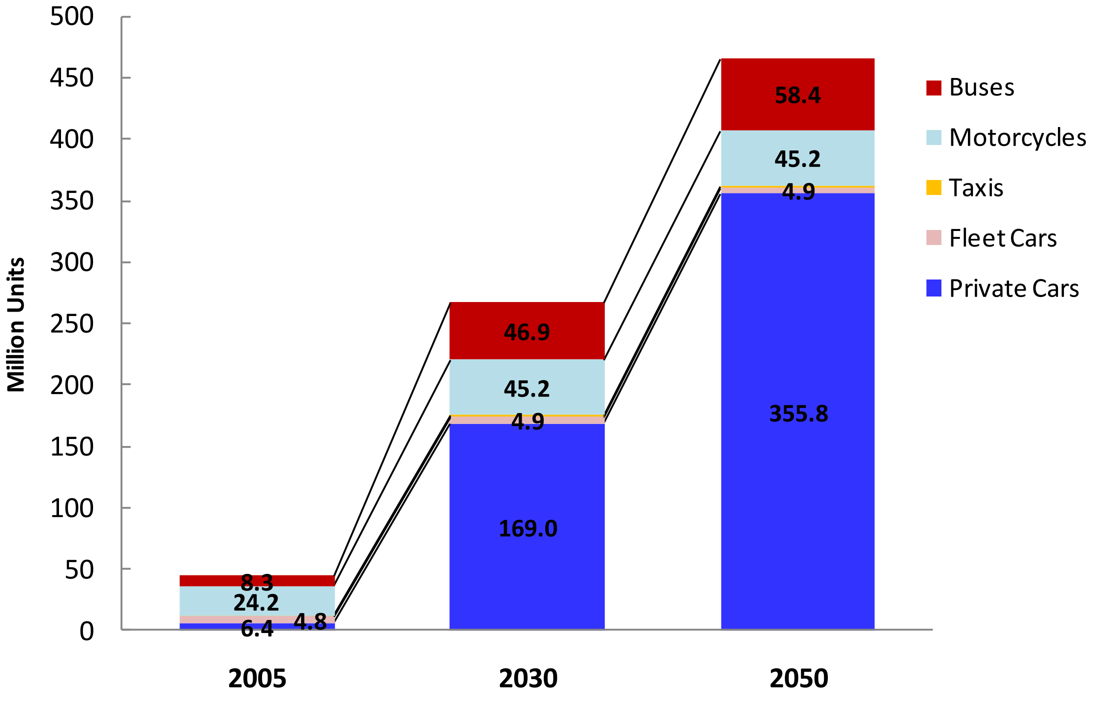
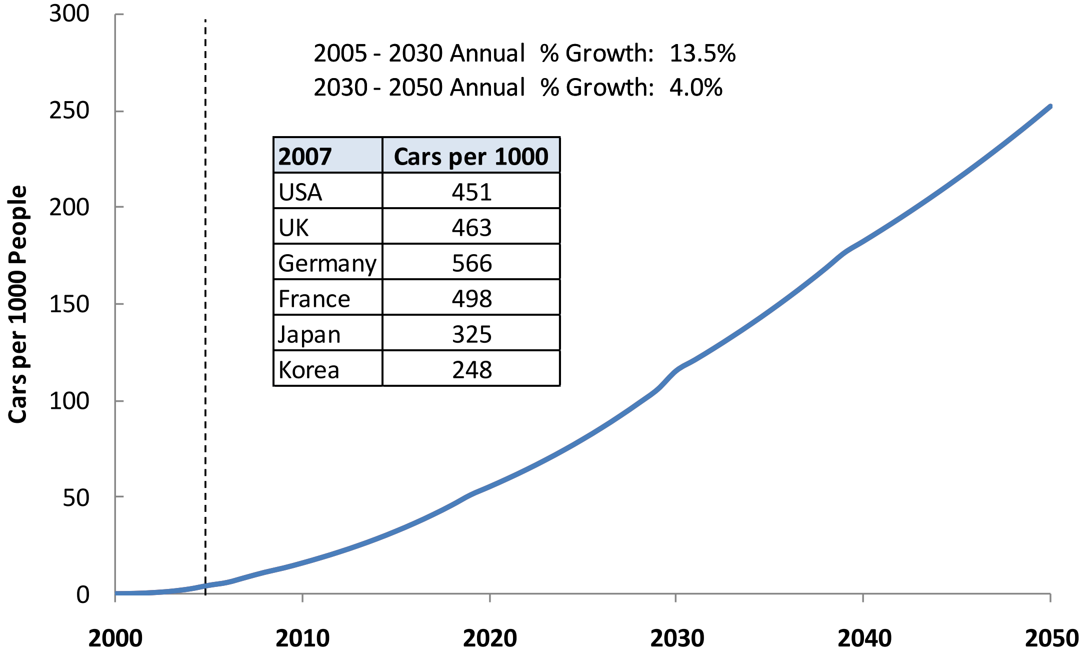


Figure 21 Passenger Road Transport Stock



2007	Cars per 1000
USA	451
UK	463
Germany	566
France	498
Japan	325
Korea	248

Source: World Bank, 2010

Figure 22 China Car Ownership Trends, 2000 - 2050

Besides transport activity, other factors that directly affect transport energy demand include declining energy intensity for road and air transport as well as greater electrification in rail and private car transport. In both the CIS and AIS cases, the energy efficiency performance of internal combustion engines (ICE) is expected to improve through 2050, particularly for road and air transport. For road transport, lower energy intensity per vehicle-kilometer is expected with growing saturation of hybrid vehicles and stricter fuel economy standards, with the most recent standards and current international best practice informing potential efficiency gains for China to 2050 in both scenarios. In AIS, there is more significant and additional efficiency improvement in light-duty vehicles and mini buses. Electric vehicles in AIS achieve 70% market share by 2050 compared to 30% in CIS is seen in Figure 23. Rail electrification affecting both passenger and freight transport is similarly much faster in AIS (85% by 2050) compared to 70% in CIS. Therefore, the major drivers in reducing transport energy intensity include technological improvements in conventional ICE, saturation of electric vehicles and rail electrification at differing speeds between the two scenarios.

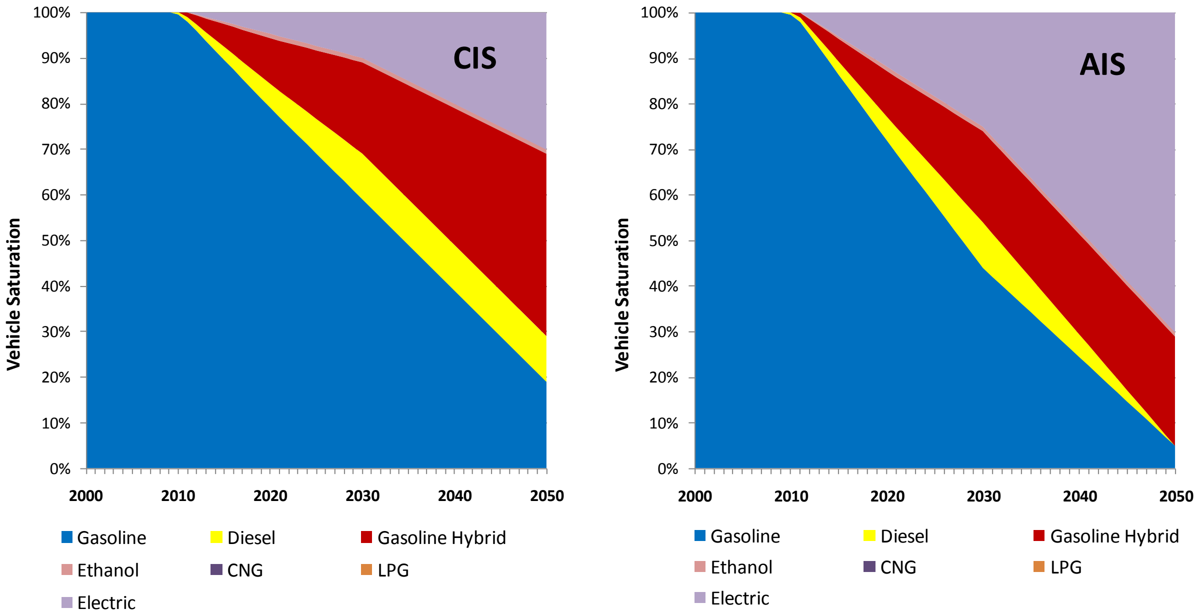


Figure 23 Car Saturation by Fuel Type, CIS and AIS Scenarios

Sensitivities

Uncertainties in the transport sector drivers, including both passenger and freight stock and activity, have much smaller impact on total primary energy use than other sectors. Specifically, increasing car ownership to 90% of US levels by 2050 -- or the equivalent of a 250 million increase in private car stock by 2050 -- increase total primary energy use by 100 Mtce, less than 2% of the total (Figure 24). Lowering the penetration of electric vehicles by five percentage points has barely visible impact on total primary energy, with only 7 Mtce increase by 2050. Similarly, lowering ocean freight activity – the largest subsector of freight activity – by 25% decreases total primary energy use by less than 1%.

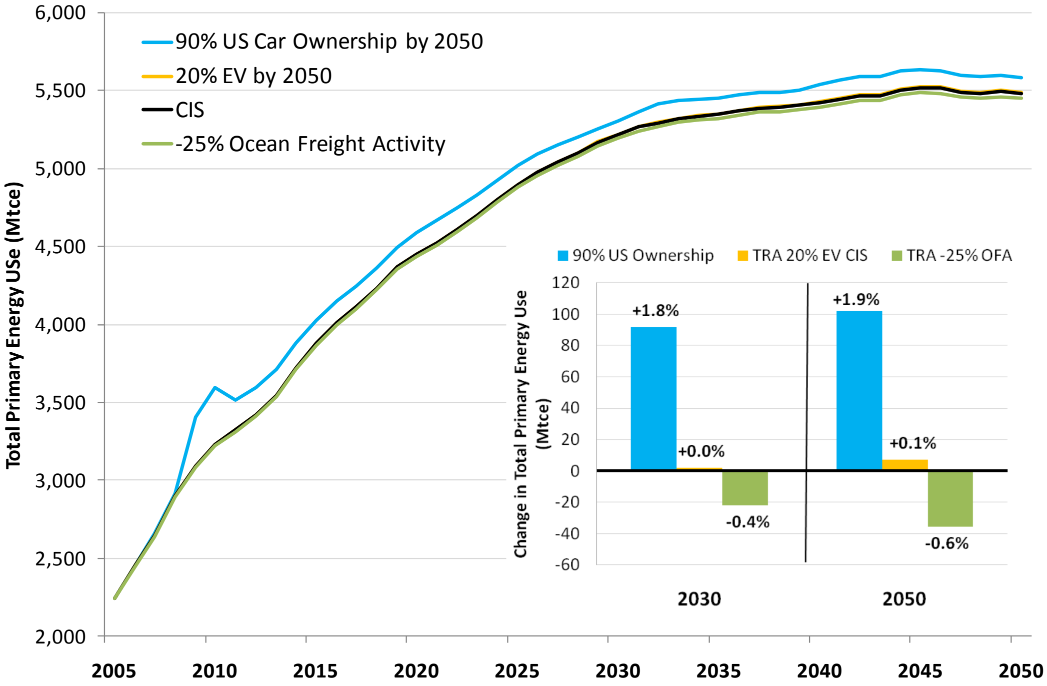


Figure 24 Sensitivity Analysis of Key Transport Energy Drivers

Drivers of Transformation Sector

This analysis examines the potential growth of low-carbon electricity generation through fuel switching and efficiency improvements. In all three scenarios, the capacity growth of low-carbon fuels and renewable is modeled first. Coal is used to close the gap between electricity demand and non-fossil electricity supply.

Fossil Fuel Power Generation

The AIS scenario includes maximum growth of non-coal electricity generation capacity. Non-coal capacity reaches 1200 GW in 2050 under CIS and 1600 GW by 2050 under AIS. Coal capacity is calculated as the amount required filling the gap between total demand and generation by non-coal fuels. Aside from fuel switching, the AIS case also examines the implications of more efficient coal-fired electricity generation.

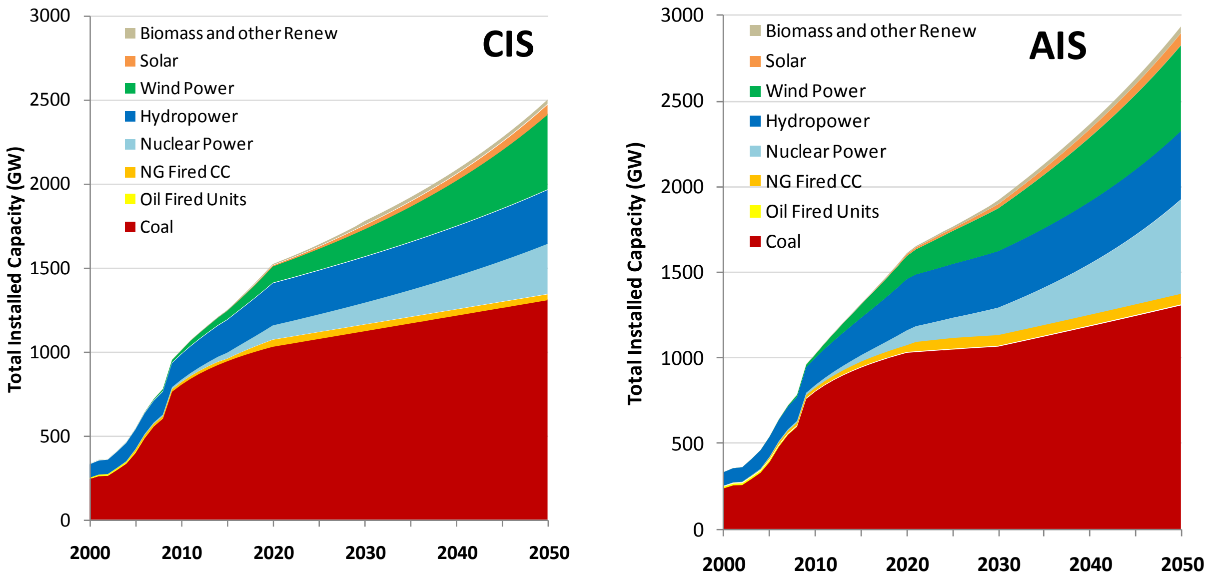


Figure 25 Power Generation Capacity by Fuel Source, CIS and AIS Scenarios

In addition, a CCS case was added to explore the energy and CO_2 implications assuming sufficient CCS-enabled coal capacity to capture and sequester 500 million tonnes of CO_2per year in 2050 – a level calculated following trend lines in the International Energy Agency (IEA)'s *2009 World Energy Outlook* 450 ppm scenario (IEA, 2009).. Under this scenario, 90% capture of carbon emissions for pre- and post-combustion technologies is assumed with an additional energy requirement of CCS for carbon separation, pumping and long-term storage.

The efficiency of coal-fired electricity is calculated as a weighted average of the range of combustion technology shares. Whereas the share of ultra super critical coal generation reaches 50% in 2030 and 75% in 2050 in the CIS scenario, it climbs to 60% and 95% in the AIS scenario as a result of the shutdown of small inefficient plants (Figure 26). This technological shift results in the scenario fleet efficiency levels shown in Figure 27.

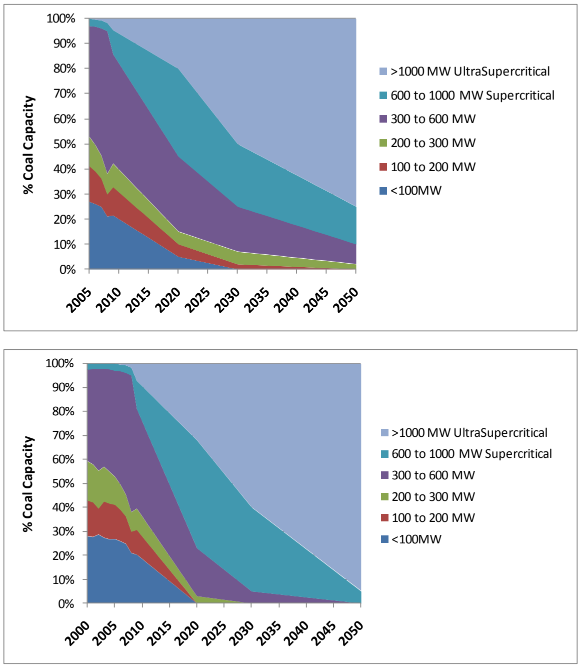


Figure 26 Size Distribution of Coal-Fired Power Plants (CIS top, AIS bottom)

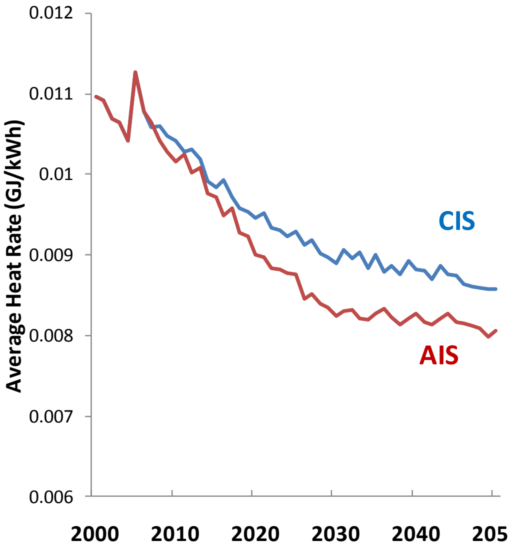


Figure 27 Heat Rates of Coal-Fired Power Plant

Power generation capacity factors are held constant with the exception of natural gas, wind power, and hydropower. The natural gas capacity factor is expected to fall to 35% as these plants are expected to be used exclusively for peak generation while the wind capacity factor is expected to increase to a maximum of 30% over time. In the case of hydropower, the capacity factor increases from 38% to 45% based on projections from ERI (ERI, 2009). For the other generation technologies of nuclear, biomass, solar and coal, the capacity factors are expected to remain constant at 88%, 25%, 19% and 90%, respectively.

Non-Fossil Fuels and Renewables

For the renewable energy forms and nuclear, the constraint on production is assumed to be the construction of new generation capacity. To develop supply curves, projections of installed capacity were collected from a variety of sources, including official government statements (nuclear capacity by 2020); projections by research groups and in academic journals (wind power and hydropower); and own-estimates (biomass/solar; nuclear power in 2050).

In the case of hydro, the projection to 2020 draws on the NDRC's *Medium- and Long-Term Plan for Renewable Energy* (NDRC, 2007) that calls for 300 GW of hydropower by 2020, including pumped storage and small hydro. In the AIS, this hydropower capacity target is reached and overall capacity continues to grow until 2050, reaching 400 GW—the maximum economically feasible exploitable capacity (reference). In the CIS case, total hydropower capacity reaches 250 GW in 2020 and 320 GW in 2050.

Wind capacity projections draw upon the *China Wind Power Report* (Li et al., 2007). Total wind capacity grows from 1.3 GW in 2005 to 100 GW in 2020 and 450 GW in 2050 for CIS; to 150 GW in 2020 and 500 GW in 2050 for AIS.

China currently has about 1 GW of “other” renewable power generation, including biomass-to-power, tidal energy, and geothermal energy. Biomass and solar power capacity were both modeled for this analysis.

China’s nuclear capacity in 2020 is based on China’s recently announced but unofficial capacity target of 86 GW by 2020 (Zheng and Mao, 2009).

These growth rates for non-fossil based electricity generation are remarkable and exceed 10% on annual average basis for solar, wind and nuclear capacity (Table 4). In the CIS case, total installed solar capacity in China in 2020 reaches over 25% of current global installed capacity and wind capacity reaches over 60% of current global capacity.

At these capacities, renewables do not exceed the proportion that has been demonstrated elsewhere (Germany, Denmark) to be fully integratable into the grid. Moreover, China is increasingly focused on integration; its “Strong and Smart” grid program is primarily designed to support renewable integration, with less focus on demand side management.

Table 4 Key Assumptions of Power Sector Scenarios

	Key Focus	2050 Primary Energy	2050 CO_2 Emissions	2005 Installed Capacity	2020 Installed Capacity	2050 Installed Capacity	2005 - 2050 AAGR
CIS	Continuing efficiency improvements and fuel shifting	2278 Mtce	3484 Mt CO_2	Solar: 0.07 GW Wind: 1.26 GW Nuke: 6.9 GW Hydro: 116.5 GW	Solar: 6 GW Wind: 100 GW Nuke: 86 GW Hydro: 250 GW	Solar: 60 GW Wind: 450 GW Nuke: 300 GW Hydro: 320 GW	Solar: 16% Wind: 14% Nuke: 9% Hydro: 2%
AIS	High efficiency and renewable eletricity generation	1723 Mtce	628 Mt CO_2	Same as CIS	Solar: 10 GW Wind: 135 GW Nuke: 86 GW Hydro: 300 GW	Solar: 70 GW Wind: 500 GW Nuke: 550 GW Hydro: 400 GW	Solar: 17% Wind: 14% Nuke: 10% Hydro: 3%
CCS	Capture and sequestration of 500 Mt CO_2 emissions by 2050	2311 Mtce	3008 Mt CO_2	Same as CIS	Solar: 6 GW Wind: 100 GW Nuke: 86 GW Hydro: 250 GW	Solar: 60 GW Wind: 450 GW Nuke: 300 GW Hydro: 320 GW	Solar: 16% Wind: 14% Nuke: 9% Hydro: 2%

Sensitivities

In this study, sensitivity analyses of varying penetration of carbon neutral electricity generation were conducted based on the CIS pathway of demand rather than on AIS in order to separate the effects of CCS from accelerated efficiency improvements. With all else equal, the impact of CCS on primary energy demand and emissions reduction can be identified by comparing the CIS scenario with CCS scenarios. The CCS base scenario featured 87 GW of capacity equivalent to 4% of total power capacity by 2050; the CCS low case dropped to 1% of total capacity (24 GW) and the CCS high case rose to 107 GW of capacity. In 2050, the reduction of CCS capacity caused a 321 Mt CO_2 emissions increase while the increased CCS sensitivity case resulted in a 295 Mt reduction of CO_2 emissions. The renewable energy base case assumes 535 GW of renewable capacity in 2050, comprising 21% of total capacity. The low case drops to 11% and the high case increases to 23%. With the low case featuring a larger change from the base than the high case, the low renewable energy sensitivity cases result in over 400 Mt change in CO_2 emissions. This suggests that switching to renewable fuels has a larger impact on emissions than CCS, though this effect also results from the larger base penetration of renewable electricity generation. Figure 28 illustrates the results of the electricity scenario sensitivity analysis.

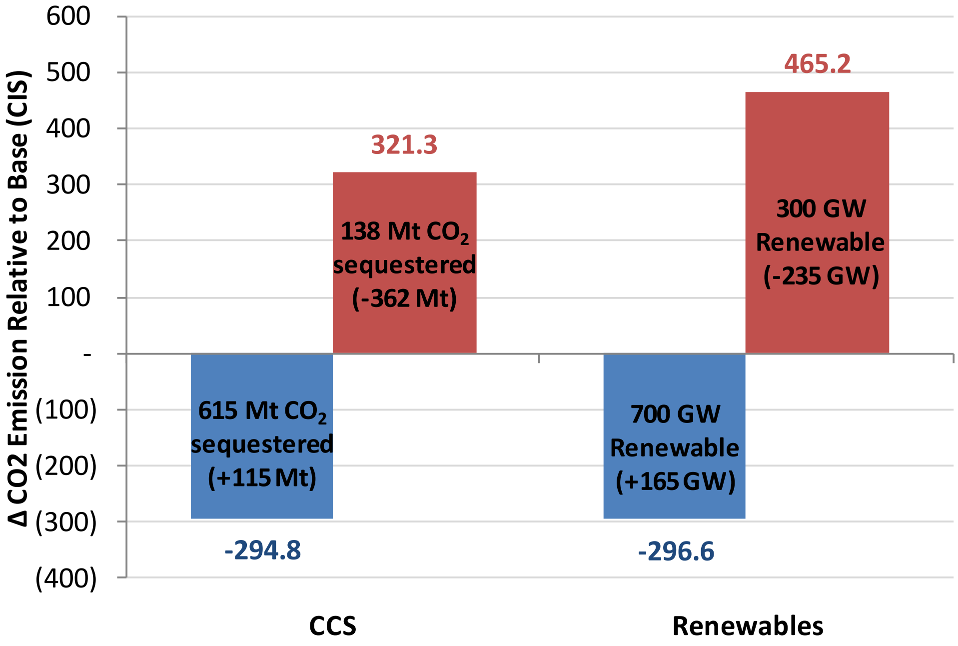


Figure 28 China Power Sector Sensitivity Analysis Scenarios in 2050

Drivers of Energy Extraction

In addition to different scenario assumptions about the transformation sector, the model also included assumptions about the energy intensiveness of energy extraction, processing and transformation. As China is a major energy producer as well as consumer, part of the country's total energy demand is used to extract primary fossil fuels such as coal, natural gas and oil and to operate processing and conversion plants producing derived products such as electricity, coke, and petroleum products. While technological improvements can raise the efficiency of resource extraction over time, there is also a corresponding decline in resource quality over time. This may result from factors such as deeper coal mines, lower coal quality, and secondary recovery in the oil and gas sectors, which subsequently raises the total required energy investment into these sectors. Similarly, although technology in the energy processing sectors may also improve in efficiency, more stringent standards for product quality (such as lower sulfur content in oil products) requires more intensive processing overall, increasing total energy consumption. In this model, energy extraction was examined using assumptions for the Energy Return on Energy Investment (EROEI) ratio, or the quotient of usable acquired energy from coal, oil and natural gas over energy expended, for coal mining and oil and natural gas extraction[4]. Additional assumptions about conversion and processing efficiency levels for coke, oil refining and electricity generation were also included for both scenarios.

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[4] Energy return on energy investment ($\frac{Energy\ output}{Energy\ input}$) is typically calculated to include the indirect inputs on the energy input side as well (e.g. embodied energy of machinery). In this study, only direct energy inputs are considered.

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. In other words, more energy will be required as an input to coal extraction as the easiest reserves are exhausted and new and less accessible reserves are exploited. Because this study considers only the direct energy inputs to energy extraction, the inverse of energy intensiveness is equal to EROEI, and this figure for coal mining, based on trends in other mature coal producing nations such as the US and the UK, will decline from 27.67 in 2005 to 20 in 2025 and further decrease to 10 in 2050. The total final energy consumed in coal mining can be calculated by dividing total coal production by EROEI.

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. 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 and 0.25 tce in 2050. At the same time, the EROEI for oil and natural gas extraction declines from 9.54 in 2007 to 8 in 2025 and to 4 in 2050, as has been observed in other mature oil and gas producing countries such as the US.

Coking

From 2000 to 2005, the energy input to producing coke dropped dramatically from 0.17 to 0.145 tce per tonne of coke. After 2005, the energy intensity of coking will continue to decrease but at a much slower speed for both the CIS and AIS Scenarios**.**

Oil Refining

Oil refining is also expected to experience declining energy efficiency. Currently, China's measure of oil refining efficiency is a weighted index that calculates an "adjusted volume" of total processing capacity based on the type of secondary processing equipment installed. By this measure, refining efficiency has continued to increase. However, in this study, efficiency is considered without volumetric adjustment by comparing crude oil throughput to energy inputs. From this angle, it is expected that China will experience the same trend in total energy use as was seen in Japan in the last few decades, where unit refinery fuel use increase by 34% from 1990 to 2007 (Japan Petroleum Energy Center, 2008). 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 CIS and AIS scenarios are assumed to have decreasing efficiency (higher energy intensity) in oil refining unit process at rates similar that what Japan has experienced.

Aggregated National Results

Energy Consumption

For the CIS, the analysis shows that China' energy consumption would double from 2005 to 2050, with an annual growth rate (AGR) of 3.4% from 2005 to 2030, and 0.3% from 2030 to 2050. The primary energy consumption will rise to 5,481 Mtce under the assumption of continued government policies fostering technology advancement, restructuring the economy, along with the adoption of sustainable development measures (Figure 33). Both CIS and AIS show a plateau in energy demand around 2040; however, such achievement would require aggressive policy measures to support industrial reform and energy efficiency improvement, more stringent appliance standards and building codes, electrification of the transportation system, and the further improvement in the supply of electricity. If realized, the energy demand for AIS could be reduced by 923 Mtce to 4558 Mtce, a reduction of 17% from CIS levels in 2050, or cumulative energy reduction of nearly 26 billion tonnes of coal equivalent from 2005 to 2050. As illustrated in the Figure 30, under both scenarios, the total primary energy consumption will largely be supplied by coal: from 73% in 2005 to 47% in 2050 in CIS and 30% in AIS.

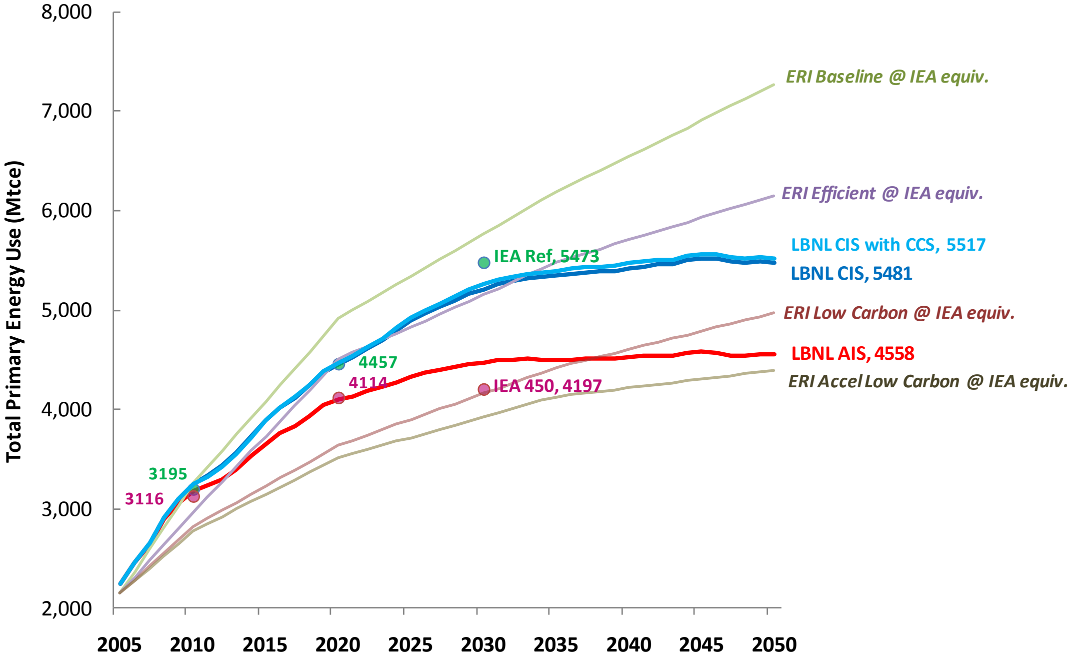

Figure 29 Primary Energy Consumption in Different Scenarios

Note: AIS is Accelerated Improvement Scenario, CIS is Continued Improvement Scenario, IEA Equiv. refers to converting ERI's numbers to IEA equivalent given that ERI follows the convention of using power generation equivalent, rather than IEA and LBNL's use of calorific equivalent, to convert primary electricity. This results in a 3.01 lower gross energy content for renewables and biomass.

As seen in Figure 29, the CIS and AIS results fall within the range of other scenarios published by Energy Research Institute (ERI) as well as the IEA (ERI, 2009; IEA, 2009) . Both CIS and AIS are very close to IEA's 2020 results for its reference scenario and its alternative, low carbon, 450 parts per million (ppm) stablization scenario.. After 2020, CIS diverges from IEA's reference case and is lower in total energy use by 2030 because it is not a business as usual scenario, but rather reflects continuation of current and planned portfolio of programs. Similarly, the aggressive additional efficiency improvements and decarbonization encompassed by AIS results in a lower total primary energy use in 2030 than IEA's 450 ppm stabilization scenario. By 2050, AIS's total primary energy use is slightly higher than ERI's accelerated low carbon scenario but below its low carbon scenario when the same conversion factors are used for expressing non-fossil fuel electricity in primary energy terms.[5] Likewise, both the CIS and CIS with CCS scenarios are consistent with ERI's Efficient Scenario until 2030, but diverge and fall below the ERI Efficient Scenario by 2050. The AIS shows very different growth pattern but nonetheless comparable with the ERI's Low Carbon scenario, although the energy consumption in 2050 in AIS is lower. We have not evaluated a business-as-usual scenario (BAU) largely because it is not likely to happen, thus a comparison to ERI Baseline Scenario was not possible.

The share of coal will be reduced from 74% in 2005 to about 47% by 2050 in CIS, and could be further reduced to 30% in AIS. Instead, more energy demand will be met by primary electricity generated by renewable and nuclear sources, which could reach 32% with further decarbonisation in the power sector under the AIS. Petroleum energy use will grow both in absolute terms and the relative share to overall energy consumption, attributing to the increase in vehicle ownership as well as the freight turnover in transportation sector (Figure 30).

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. Existing studies have demonstrated that the share of industry sector against the total has increased, and at the same time, the energy intensive industry subsectors such as cement, steel and chemicals have grown much faster than other subsectors, which resulted in the overall energy intensity gain in the whole economy between 2002 and 2005. Even after the Chinese government made significant effort toward the goal of reducing energy intensity per GDP by 20% from 2006 to 2010, the trend toward increasing energy-intensity industry has not been reversed. However, among the drivers of the energy growth--aside from urbanization and its concomitant expansion of residential construction--commercial construction, fertilizer use, and appliance ownership also affect 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 has already attained 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 industry energy consumption that are used to make building materials or appliances will likely to reach a plateau around 2010. Future energy growth will be driven mostly by the transportation and residential building sectors, and the shift in sectoral energy consumption is in line with global social and economic development trends. Unlike past trends in China, Figure 31 also demonstrates that the buildings sector could account for the largest portion of future reduction in energy demand. As most of the industry outputs peak and industrial energy consumption reaches a plateau, there are many drivers in the building sector such as rising number of housing units, per capita floor area, urbanization increase, and demand in more energy services, pursuit of more comfort level will all contribute the energy demand growth, providing more potential in reduction.

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[5] ERI results are converted to IEA equivalent given that ERI follows the convention of using power generation equivalent, rather than IEA and LBNL's use of calorific equivalent, to convert primary electricity. This results in a 3.01 lower gross energy content for renewables and biomass.

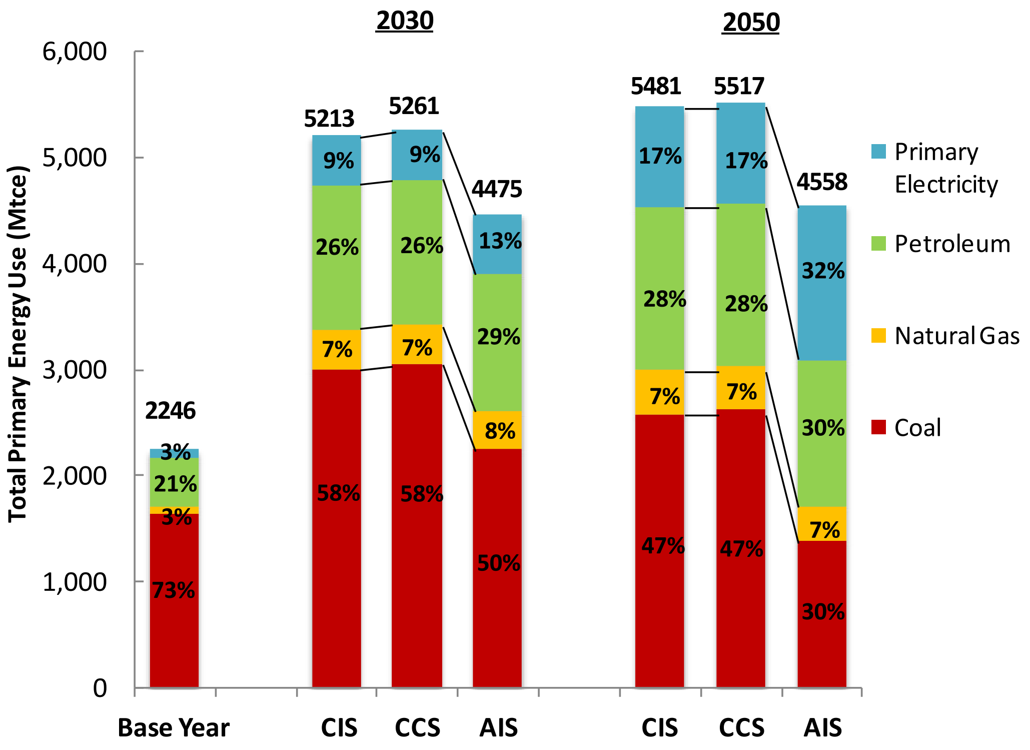


Figure 30 Total Primary Energy Use by Fuel

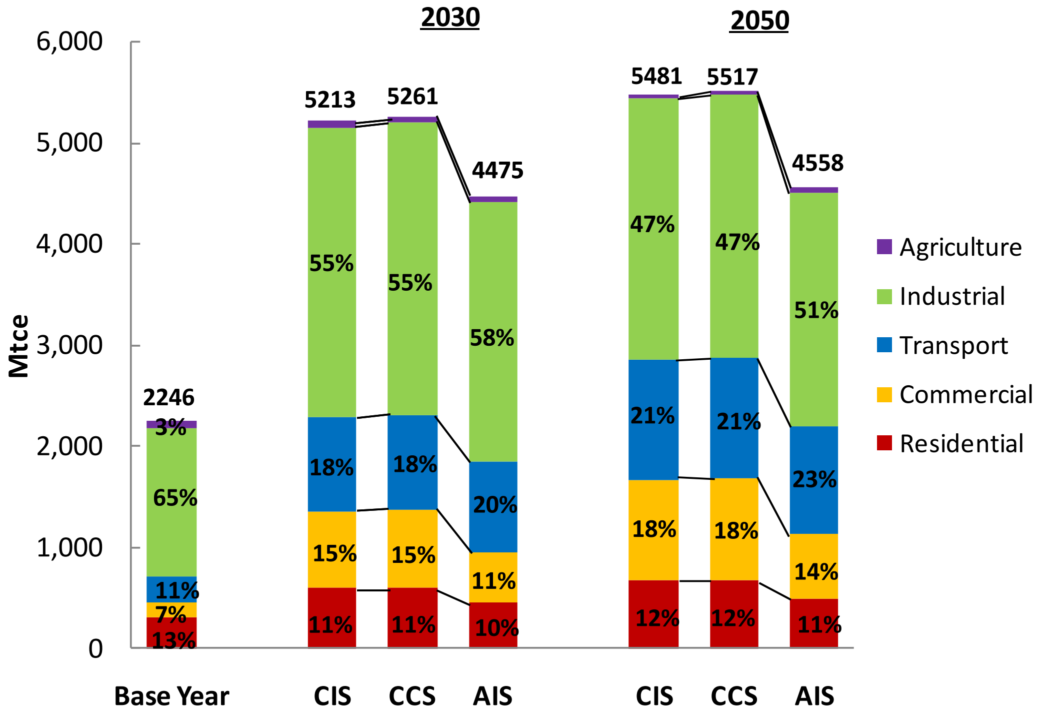
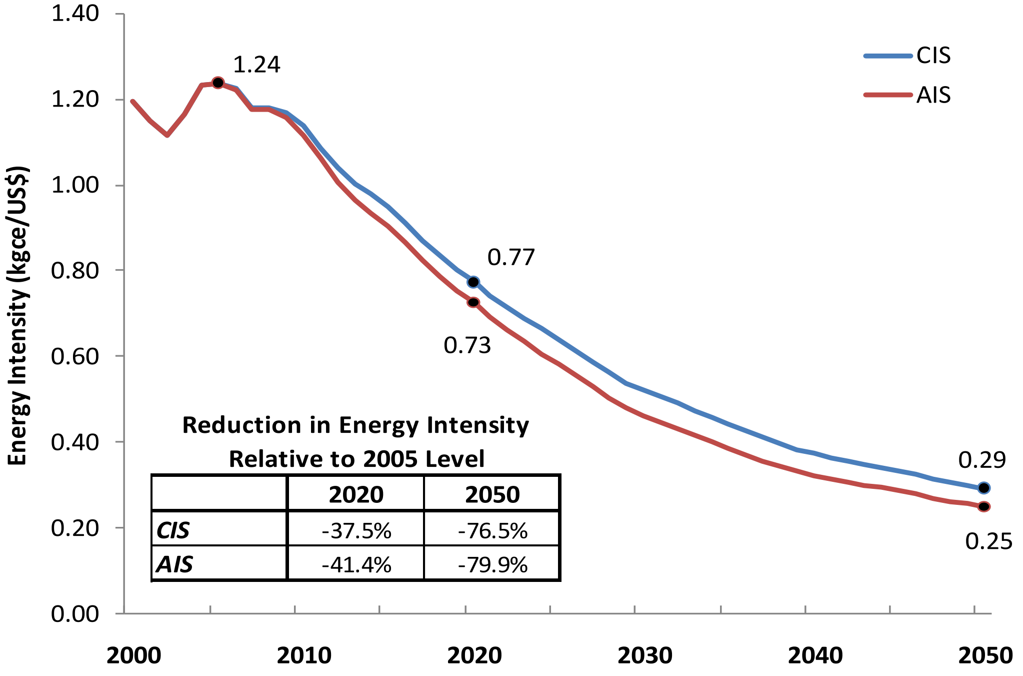


Figure 31 Total Primary Energy Use by Sector

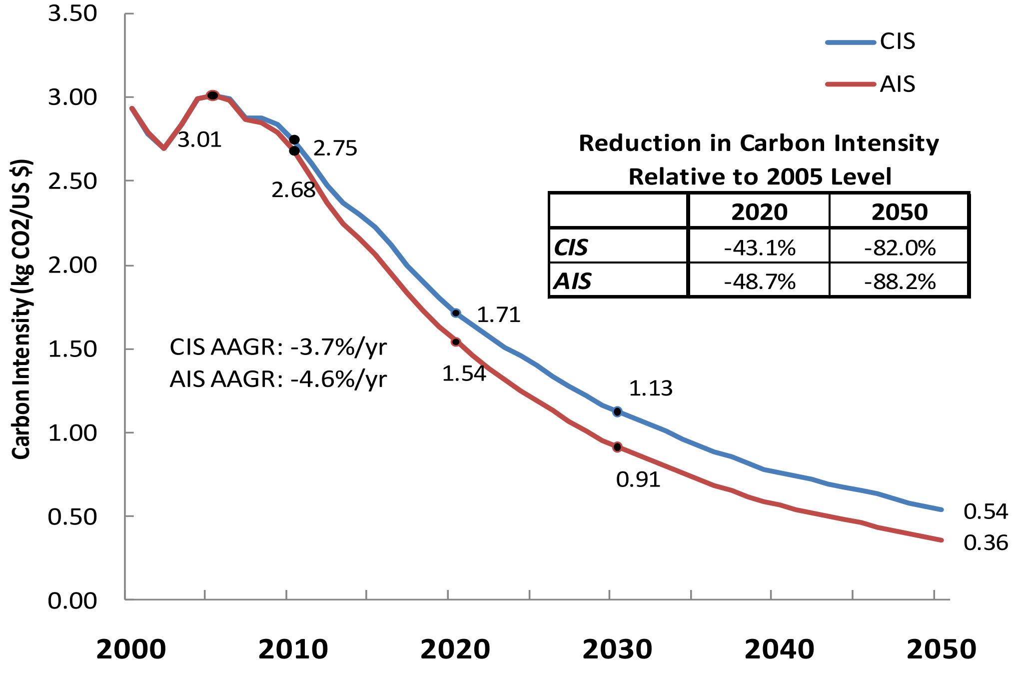
Overall, the growth of annual energy demand in China could range from 3.4% to 2.8% between 2005 and 2030, and 0.3 to 0.1% between 2030 and 2050, while GDP experiences an average growth rate of 7.1% from 2005 to 2030, and 3.4% from 2030 to 2050. This implies a very large reduction in energy consumption elasticity of GDP even in the less aggressive CIS scenario, with over 76% reduction relative to 2005 levels by 2050 (Figure 32). The energy elasticity is in both CIS and AIS notably lower than that of any prior historical period in China.



Reduction in Energy Intensity Relative to 2005 Level

	2020	**2050**
CIS	-37.5%	-76.5%
AIS	-41.4%	-79.9%

Figure 32 Energy Intensity Reduction by Scenario, 2000 - 2050

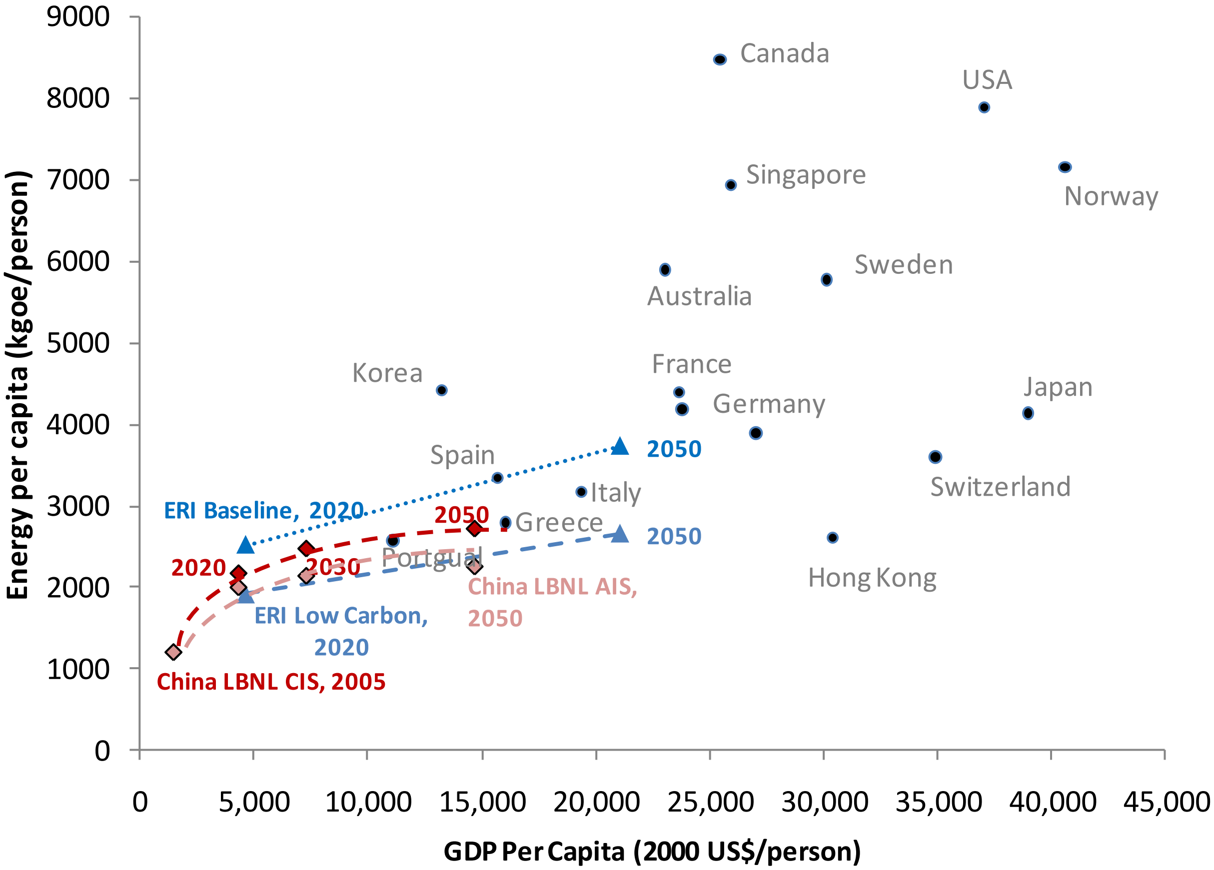


Reduction in Carbon Intensity Relative to 2005 Level

	2020	**2050**
CIS	-43.1%	-82.0%
AIS	-48.7%	-88.2%

Figure 33 Carbon Intensity Reductions by Scenario, 2000 - 2050

Figure 34 illustrates that China's current per capita GDP and average per capita energy use is still very low compared to developed countries but has the potential to catch up by 2050. Both LBNL and ERI's 2050 scenarios show that China will likely surpass Portugal's current level of per capita GDP, but its GDP will still remain below more developed countries like Singapore, US, and Japan. However, China's projected 2050 pathways are also noteworthy in that their per capita energy use will remain below most other countries with similar GDP levels. Under CIS, China's per capita energy use will be below South Korea and Spain in 2050 while under ERI's base scenario, China will be well below the per capita energy use in Australia and France.. These trends underscore the important role China can play in pursuing a more energy efficient pathway of economic development.



Note: China LBNL projection for GDP per capita, market rate is in real US$, while historical international data are in GDP per capita PPP, 2000 US$.

Sources: International data for 1990 to 2006 from IEA.

Figure 34 International trends in Energy and GDP Per Capita, with China 2050 Scenarios

Carbon Emissions

Figure 35 illustrates that carbon emissions could reach a peak in the late 2020s to early 2030s in both scenarios, at 12 billion tonnes for CIS in 2033 and 9.7 billion tonnes for AIS in 2027. The contribution of the more accelerated improvement in carbon emission reduction could lead to a cumulative reduction of 86.5 billion tonnes of CO_2 from 2005 to 2050, predominately attributable to the decreased use of coal and electricity in demand sectors, and the decarbonization of the power sector. Under AIS, annual emissions in 2050 alone could be reduced to around 7 billion tonnes from 11 billion tonnes of CO_2.

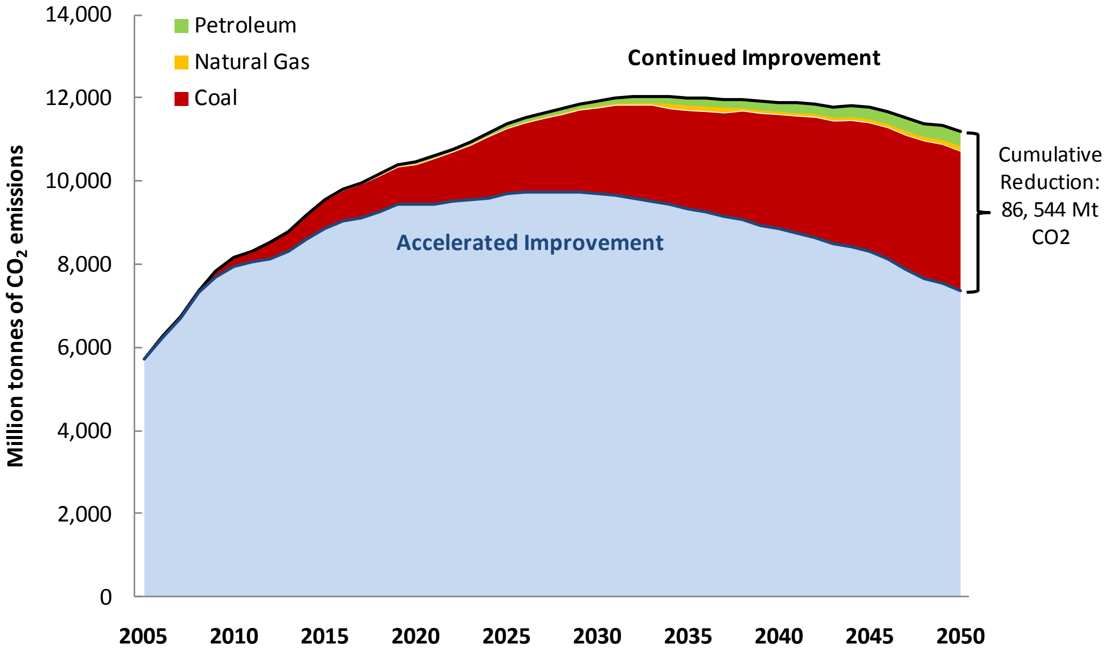


Figure 35 Carbon Emissions Outlook for Two Scenarios by Fuel

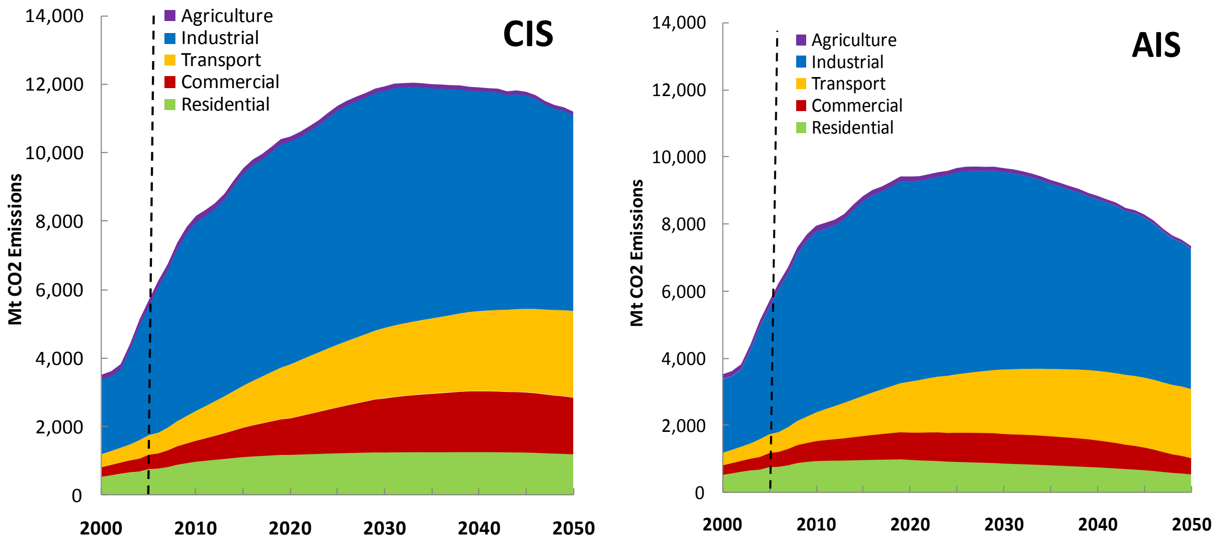


Figure 36 Carbon Emissions Outlook for CIS and AIS Scenarios

Among sectors, the single largest emission reduction potential between the CIS and AIS can be seen in the commercial and residential buildings sector, followed by the industry sector, as illustrated in Figure 37. The industrial sector shows early achievement in emission reduction, but in the long-run, more reduction could be achieved through more aggressive policies, measures and technology improvement in building sector and lead to more than half of the emissions reduction over the 45 year period.

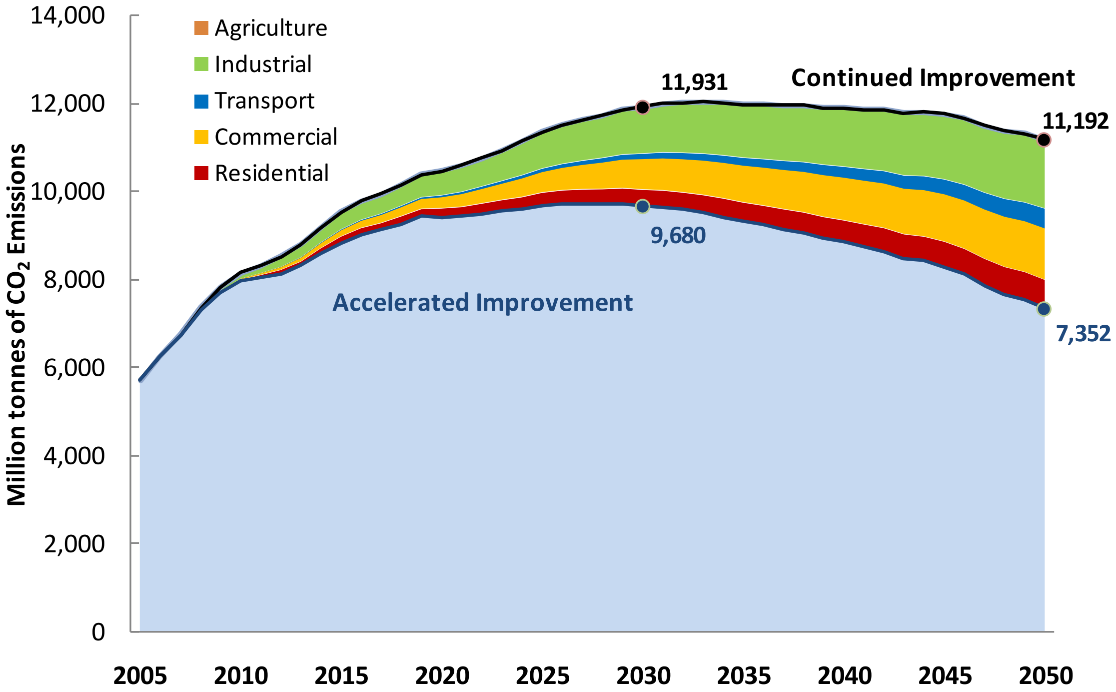


Figure 37 Carbon Emissions Difference between Two Scenarios by Sector

Both the CIS and AIS carbon outlooks fall within the range of ERI's carbon emission scenarios. The AIS outlook falls between ERI's low carbon and accelerated low carbon scenario while the CIS scenario is just below the efficient scenario. ERI's accelerated low carbon scenario has noticeably lower CO_2 emissions than AIS because it includes aggressive CCS assumptions after 2030, which was not considered under AIS. Interestingly, the CIS with CCS scenario has only slightly lower emissions than the CIS scenario, suggesting a small net mitigation impact of only 475 million tonnes of CO_2 in 2050, or 4.5% less than the total emissions. Moreover, as with ERI's low carbon and accelerated low carbon scenarios, CIS and AIS both peak in emissions in the 2030s. Likewise, all three LBNL scenarios are also very close in scale to IEA emissions outlook to 2030, although CIS is slightly below IEA's reference scenario (IEA, 2010). As with ERI's accelerated low carbon scenario, IEA's 450 scenario is noticeably lower than AIS because it includes aggressive CCS implementation.

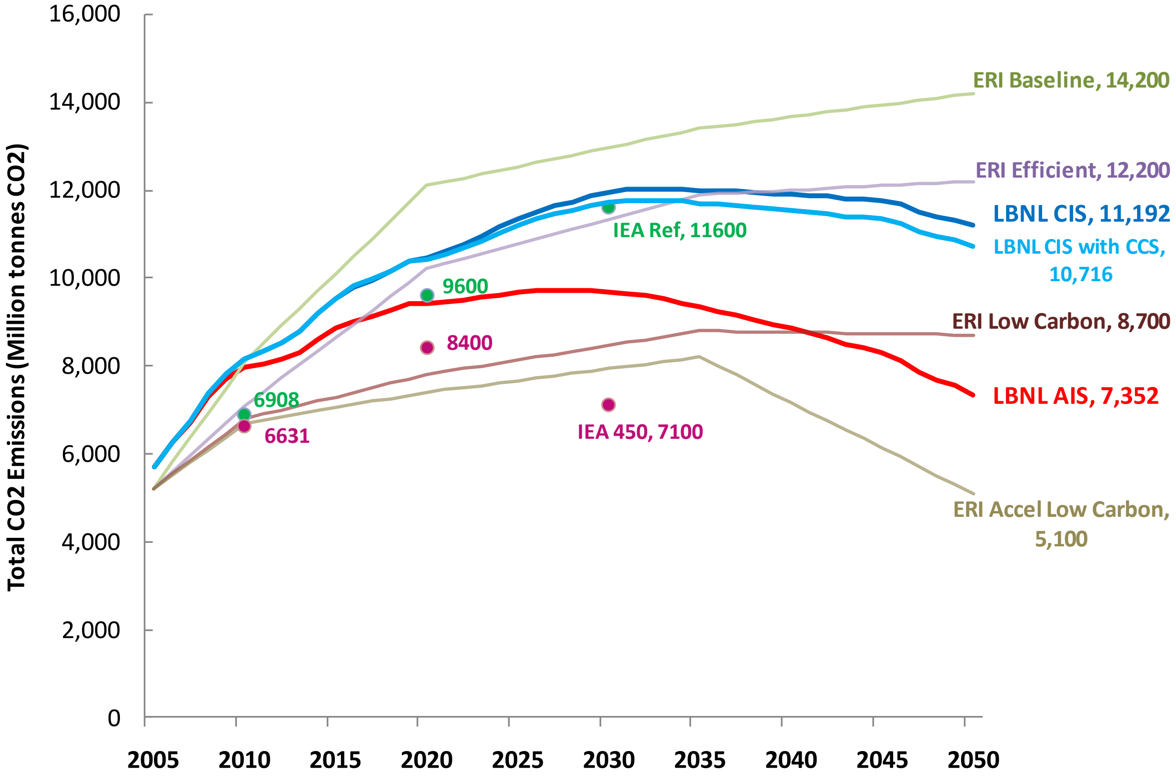


Figure 38 Comparison of Carbon Emissions between Scenarios

In many respects, China's 40%-45% carbon intensity goal outlined in the Copenhagen Accord continues China's new energy development pathway that began in 2006. Considering that the 20% energy intensity goal between 2006 and 2010 will likely be reached,[6] the remaining portion of the carbon intensity goal must be achieved over the next 10 years. Both the CIS and AIS scenario demonstrates that with continuous improvement such reduction rate is possible and by 2050, the reduction could be as much as 80% in the CIS scenario (Figure 32). However, such reduction will require strengthening or expansion of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable and nuclear power capacity. Thus achievement of the carbon intensity goal will require continuing and strengthening ongoing actions by government and industry beyond efforts initiated during the 11th Five-Year Plan.

From the international perspective, China's future carbon outlook also has important implications as its 2050 GDP levels reach the level of Greece and South Korea in LBNL scenarios and that of the EU in ERI scenarios. However, China's per capita CO_2 emissions are relatively low and remarkable in their relatively "flat" path of development in Figure 39, indicating that per capita CO_2 emissions may not increase significantly despite rising per capita GDP.

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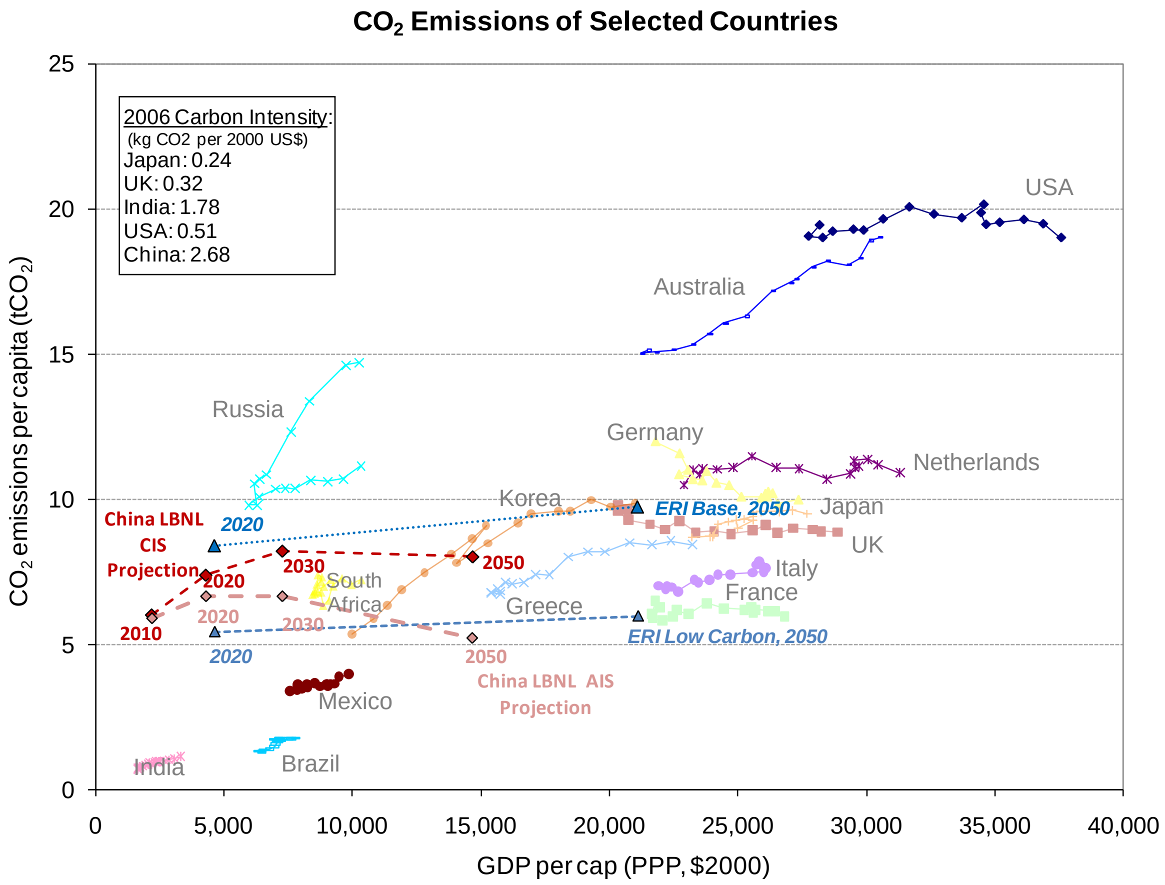
[6] In late February of 2011, Premier Wen Jiabao announced that China achieved a 19.1% drop in energy per unit of GDP between 2006 an 2010 (Li, 2011). .



Note: China LBNL projection for GDP per capita, market rate is in real US$, while historical international data are in GDP per capita PPP, 2000 US$.
Source: International data for 1990 to 2006 from IEA.

Figure 39 International trends in CO_2 emissions and GDP per capita, with China 2050 Scenarios

Coal

As seen by the shifting end-uses of coal demand, the sharp decline in coal use is actually the result of fuel switching in the power sector with aggressive deployment of more renewable and non-fossil fuel energy. Specifically, the transformation sector is responsible for the vast majority of coal end-uses in both scenarios through 2050 (Figure 40). Of the transformation end-uses, coal demand for generation flattens and declines as a share of total coal demand under accelerated decarbonization in AIS. Specifically, under AIS, the share of coal used for power generation dramatically declines from 43% in 2030 to 16% in 2050 as a result of fuel switching to nuclear, hydropower and renewable. In contrast, the industrial end-use demand remains relatively flat as a share or in absolute numbers under both scenarios. Under CIS, coal demand would peak at 3017 Mtce in 2031 and could reach the peak earlier and at lower amount of 2417 Mtce in 2019 under AIS.

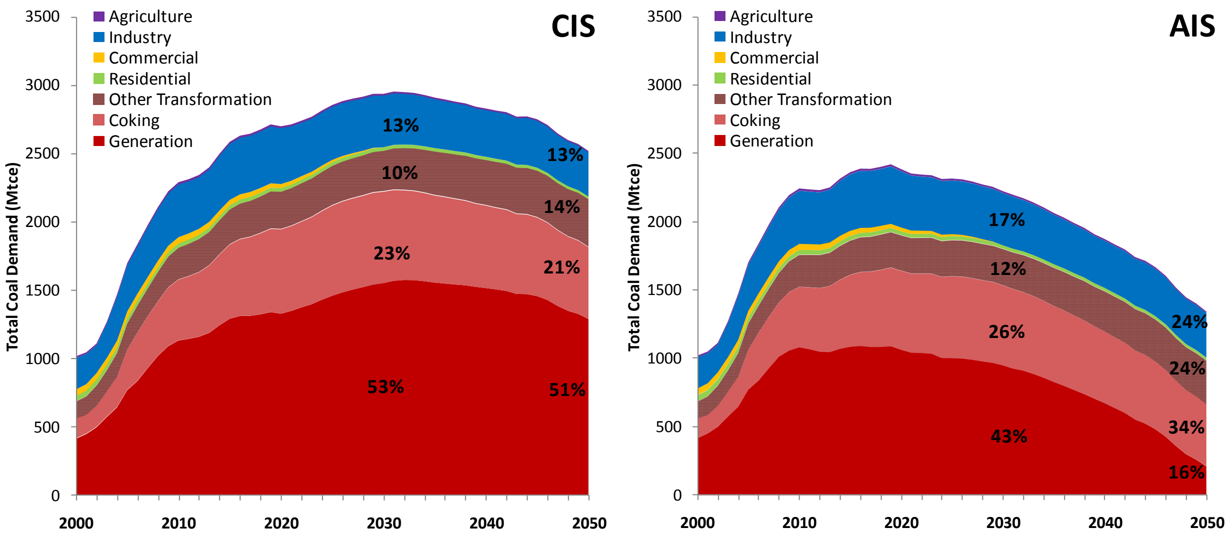


Figure 40 CIS and AIS Coal Demand by End-Use, 2000 - 2050

Oil

In terms of the rising share of petroleum in total primary energy use, most of the increase in crude oil demand is driven by a burgeoning transport sector that is increasing its share of total oil use. While the other sectors all have declining shares of total oil final demand, the transport sector will grow from 55% of the total to in 2005 to 66% in 2050 under CIS and to a slightly lower 62% under AIS with greater transport electrification and efficiency improvements (Figure 41). By 2050, the Chinese transport sector's share of national oil demand will be comparable to the current U.S. transport share of 69%.

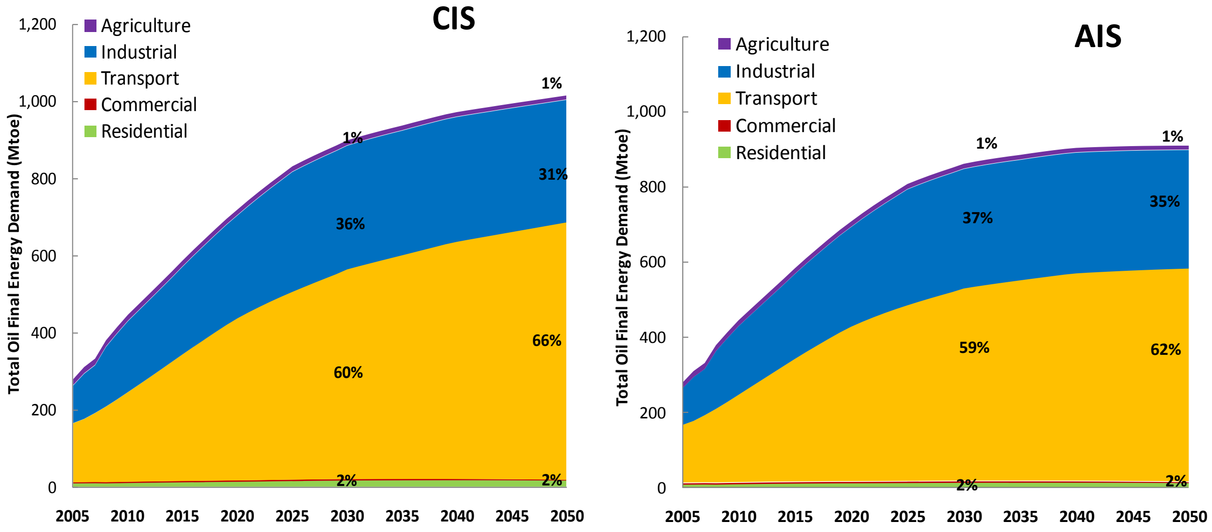


Figure 41 CIS and AIS Oil Final Demand by Sector, 2005 - 2050

Electricity

The commercial sector's emerging role as a major energy consumer is most evident in the rise of final electricity demand, where industry's declining share in electricity demand is more than offset by the commercial sector's expanding share (Figure 42). In fact, under CIS, the commercial sector will be responsible for nearly one-third of all electricity demand despite continued efficiency improvements in heating and cooling, equipment and lighting. The transport sector under AIS also has growing share of electricity demand because of more aggressive rail and road electrification.

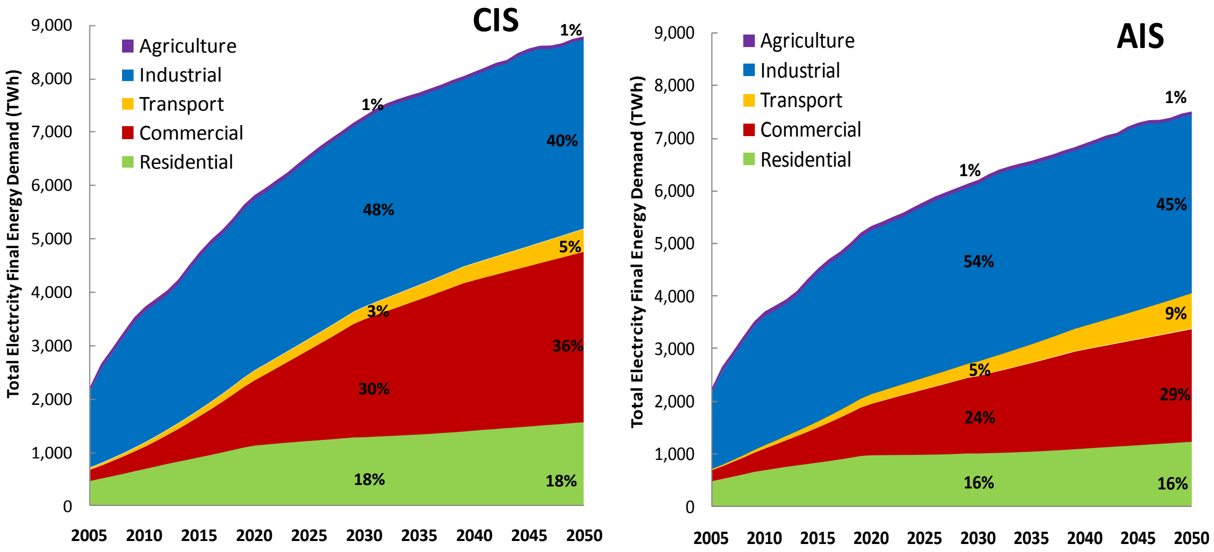


Figure 42 CIS and AIS Electricity Final Demand by Sector, 2005-2050

Sectoral Results

Residential Buildings

As Figure 43 and Figure 44 show, residential primary energy demand continues to grow rapidly,, but this growth will slow by 2030. In CIS, demand rises between 2005 and 2030 at a rate of 2.8% per year, but increases by only 0.6% per year thereafter. This slowing of growth is largely due to saturation effects, as the process of urbanization will be largely complete and most households will possess all major appliances by 2030.

The main effect of the AIS pathway is to cap the long-term energy demand plateau at a significantly lower level, about 23% lower than in CIS in 2030. Further growth in AIS is nearly zero, so that by 2050 energy demand is 27% below CIS. Effects of this magnitude in any sector are significant, and show that policy actions taken now to cap energy intensity in non-industrial sectors can contribute greatly to China's ability to cap energy demand. In this scenario, the contribution of intensity reduction is magnified by the decarbonization of the power sector.

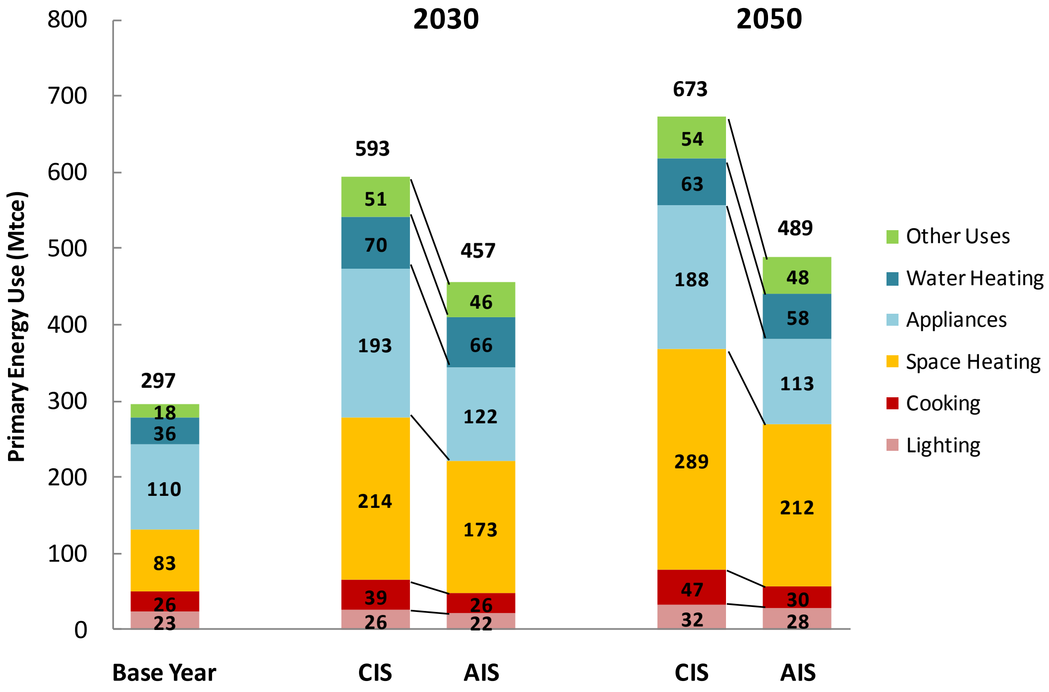


Figure 43 Residential Primary Energy Consumption by End-Use

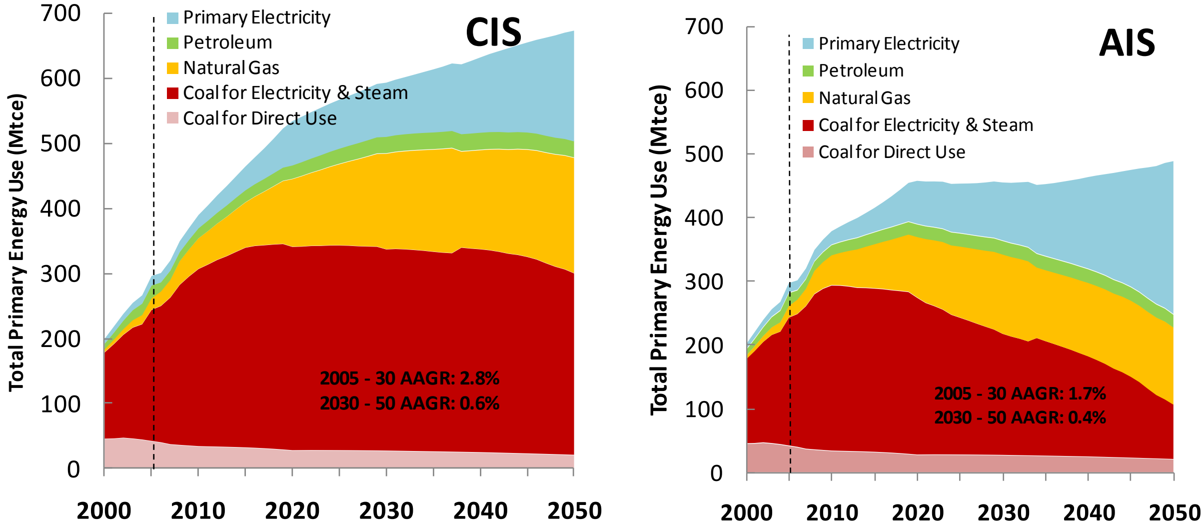


Figure 44 Residential Primary Energy Consumption by Fuel, CIS and AIS

Energy demand in residential buildings has been rising very fast in recent years. The forecast for further energy consumption growth in this sector, and the difference between alternative scenarios is based on the degree to which energy consumption levels off, when, and at what level. In both CIS and AIS, household energy consumption will continue to rise over the next few years. Energy demand growth is expected across end uses, especially for appliances (including air conditioning), and for space heating. Appliance consumption grows most rapidly, but plateaus by about 2030, in both urban and rural areas.

In absolute terms, urban appliance consumption energy demand is about four times as high in 2030 as in 2005 to reach over 200 Mtce. In rural areas, appliance energy consumption increases by a factor of 10, also reaching nearly 200 Mtce. Space heating grows more gradually than appliances before 2020. Thereafter, demand growth for space heating is slower, but this growth continues through 2050. In AIS, residential energy demand plateaus by 2020, and stays level through about 2040, at which point increased space heating demand causes total demand to rise again, in spite of efficiency improvements. This earlier plateau in the AIS leads to significantly lower demand considered over the length of the forecast. Figure 45 shows that savings opportunity in the residential sector are distributed across end uses, with appliances and space heating showing the largest savings.

These results show that, in the residential sector, even as energy demand grows with GDP (since appliance ownership in the model is directly related to household income), it is growing more slowly and, in the long term becomes even more decoupled. The AIS demonstrates the potential for household energy consumption in China to become completely decoupled from economic growth in the long term.

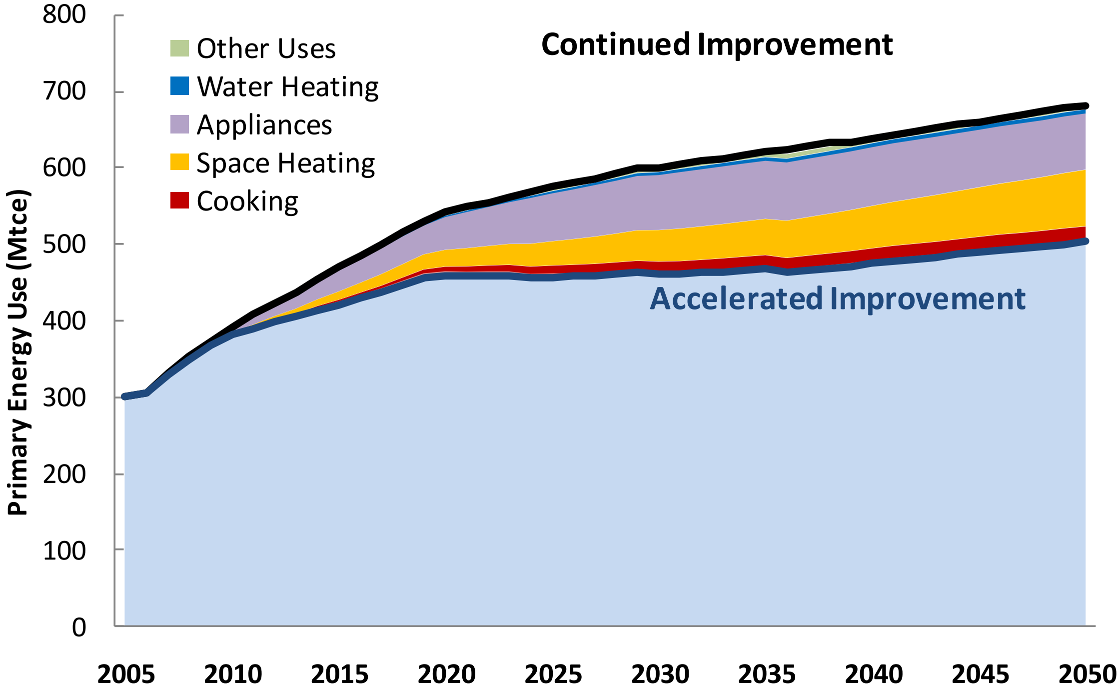
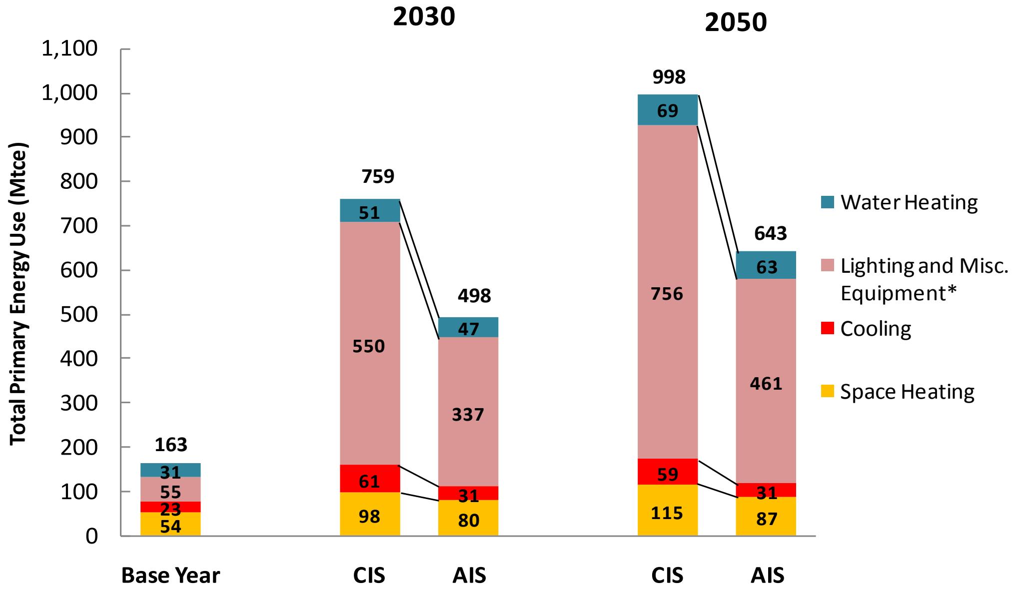


Figure 45 Residential Primary Energy Use and Potential Reductions by End-Use

Commercial Buildings

While building energy demand in the commercial sector is driven by different variables than that of the residential sector, the patterns expected over the medium and long term are similar. Specifically, energy demand in this sector is currently still growing rapidly, but there will be a slowing of growth in the medium term, reaching a plateau by about 2030. Total commercial building floor space may saturate in the short term, but end uses of energy have much room to grow before reaching current levels in industrialized countries. In particular, lighting, office equipment and other end uses in these buildings are expected to grow dramatically through 2030, but then level off.

The main dynamic of energy consumption in commercial sector buildings revealed by this study is that energy growth will be largely dominated by intensity increases, rather than overall increases in commercial floor area. As noted above, increases in commercial building space will be limited by the number of workers available to this sector in China's future – while the economic activity in this sector will continue to gain in significance, growth in the physical infrastructure will by no means keep up with growth in value added GDP. The first main implication of this to contributed to the future ongoing decoupling of energy demand with economic growth.



*Note: Misc. equipment includes various types of office equipment, elevator, pumps, etc.

Figure 46 Commercial Primary Energy Consumption by End-Use

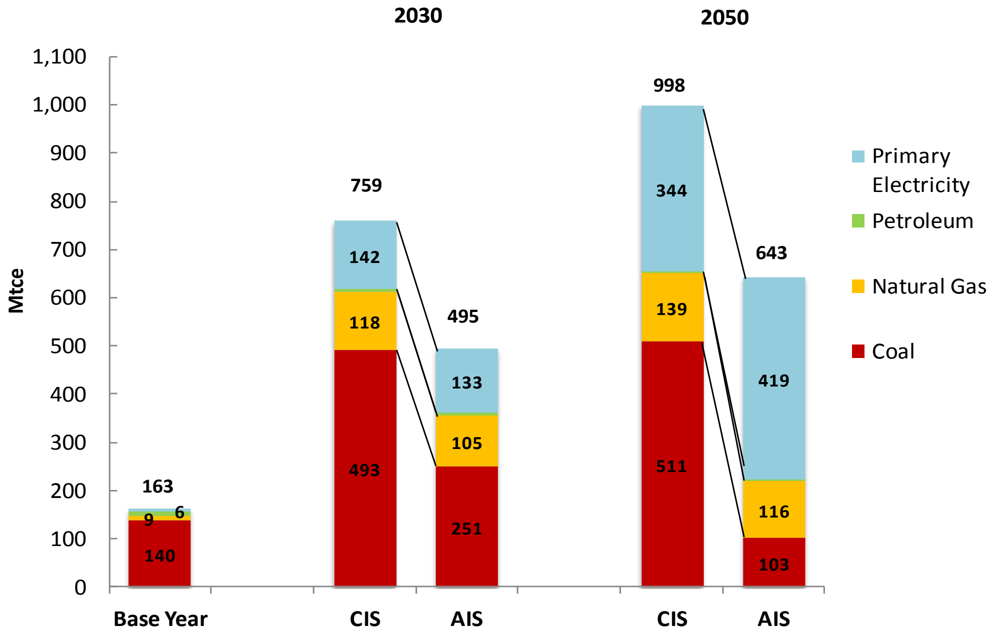


Figure 47 Commercial Primary Energy Use by Fuel

Industry

Within industry, the energy consumption of the seven sectors[7] singled out in China's long-term development plan for substantial energy efficiency improvements will gradually decline relative to other sectors, though still account for 47% of total energy consumption in 2050, down from 61% in 2005 in CIS. In the case of the iron and steel and cement industries in particular, China's expected transition from rapid industrialization and infrastructure development to more intensive growth and expansion in the services sector after 2010 underlies the slowdown and eventual decline in total iron and steel output and in the growth of the cement industry (Figure 49). Among the sectors in "Other Industry", steady increases in energy consumption growth are expected from the refining sector, the coal mining and extraction sector, and the oil and gas exploration and production sector. China's refining sector, already challenged by the requirements to produce cleaner fuels in the face of a rising proportion of high-sulfur crude oil in the processing mix, will need to add substantial numbers of energy-intensive secondary processing units such as hydrotreaters at existing refineries. Similarly, both the coal and oil and gas industries face higher energy consumption driven both by an expansion in the scale of activity and in rising unit energy costs of extraction as the resource base is drawn down.

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 2030. The model results for projected CIS and AIS industrial energy use reflect key differences in only efficiency improvements, with a 290 Mtce reduction in energy use under AIS in 2030, and 274 Mtce in 2050, as seen in Figure 48.

The more efficient AIS development trajectory has differing impacts on energy reduction in each of the seven industrial sub-sectors. Between 2005 and 2030, the iron and steel and cement sub-sectors comprise the largest energy reduction potential under both CIS and AIS scenario when compared to other sub-sectors. However from 2030 to 2050, the largest energy use reduction potential in the AIS scenario is in the aluminum sector, followed by the steel sector. As the sub-sector with relatively low production and net imports, ethylene has negative energy use reduction.

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[7] The seven industrial subsectors analyzed in depth in this study include iron and steel, cement, aluminum, paper, ammonia, ethylene and glass industries.

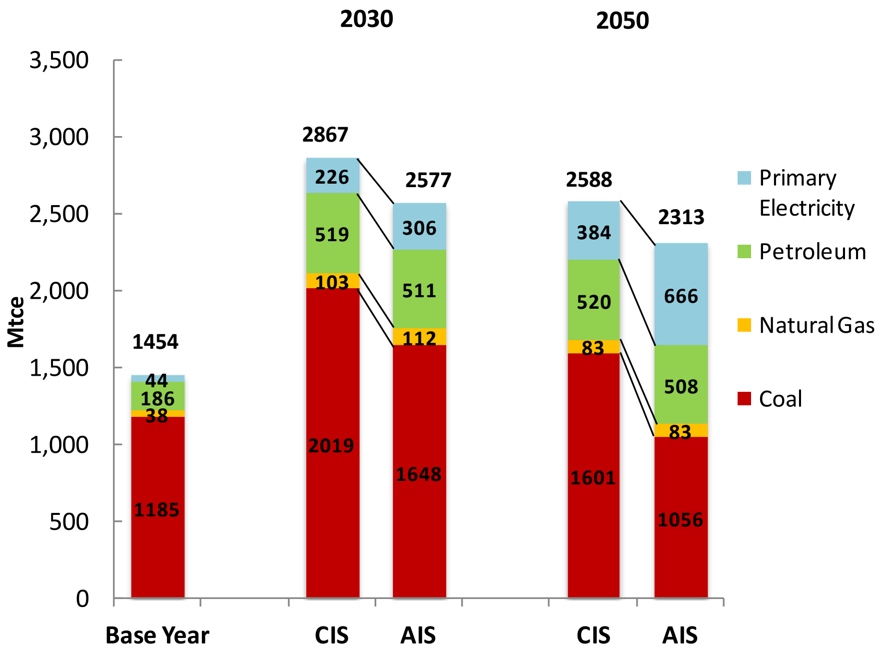
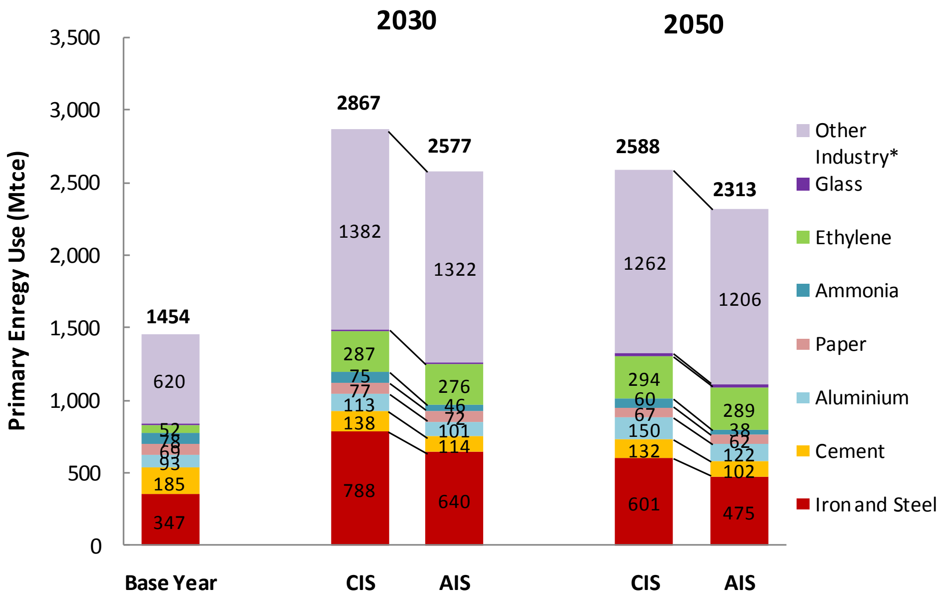


Figure 48 Industrial Primary Energy Use by Fuel



*Primarily manufacturing but includes some extractive sectors

Figure 49 Industrial Primary Energy Use by Subsector

Possibly even more important, however, are the implications of these trends for the industrial sectors. This effect is considerable. Energy demand in China is currently dominated by a few energy-intensive sectors, particular by the main construction inputs – cement and iron and steel. The recent explosion of construction in China has had a driving role in these industries, and therefore Chinese energy demand as a whole. The slowing of this construction boom will therefore have a major impact as seen by the peaking of industrial primary energy use around 2030. Under AIS, the largest subsector potential for energy savings is in the iron and steel subsector, followed by other (non-heavy) industry and cement subsectors.

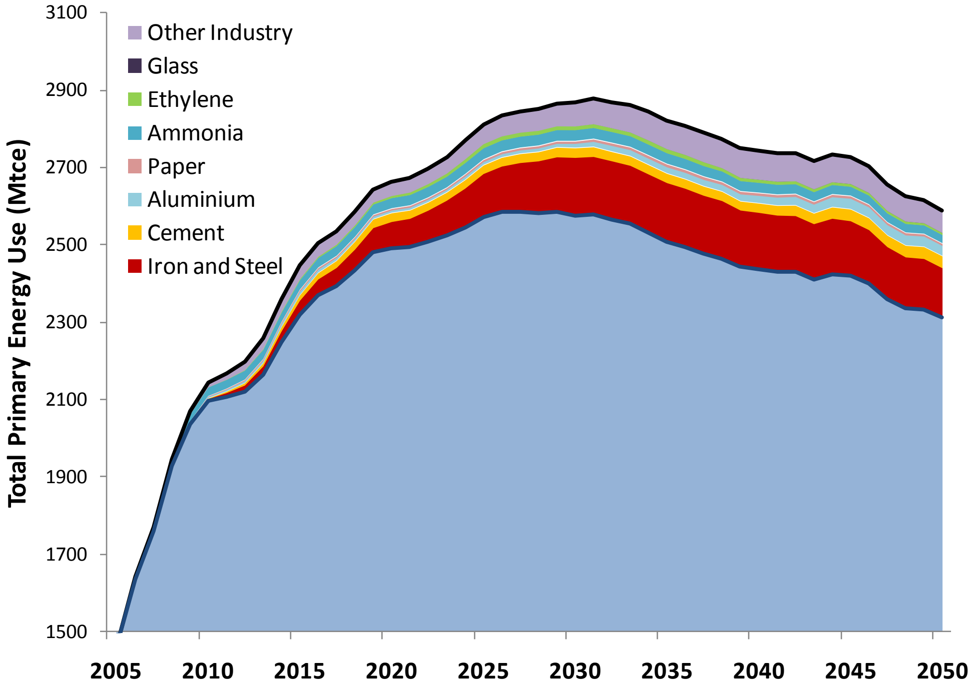


Figure 50 Industrial Energy Savings Potential by Subsector

Transportation

In primary energy terms, the impact of improved efficiency in motor vehicles and accelerated electrification of passenger cars and the national rail system lowers total transportation energy use in 2050 by 107 Mtce compared to CIS. This is particularly evident in the reduction of petroleum use by nearly 146 Mtce, offset by increased use of electricity (Figure 51). This is evident as well in examining energy use by transportation mode for both passengers and freight, where consumption for passenger road transport declines by about 110 Mtce owing to the higher penetration of electric vehicles (Figure 52). Because electrification of vehicles is primarily applicable to passenger cars and not to long-distance or heavy-duty truck or bus transport, it is assumed in both scenarios that internal combustion engines will remain predominant, yet improved in efficiency over this period. Similarly, efficiency gains in both water and air transport remain the same in both scenarios as well.

The fuel mix for transportation shifts between the two scenarios. China primarily relies on diesel for transportation (truck, train, inland waterways), and this reliance remains in both scenarios as the potential for fuel-shifting is less than in the case of gasoline. Gasoline consumption begins to decline absolutely after about 2030 in the AIS scenario as growing use of electric vehicles displaces it (Figure 53, Figure 54). Demand for heavy oil for ship bunkers continues to rise, reflecting expectations of continued growth (albeit at lower rates) of China’s international trade.

Figure 51 Transport Primary Energy Consumption by Fuel

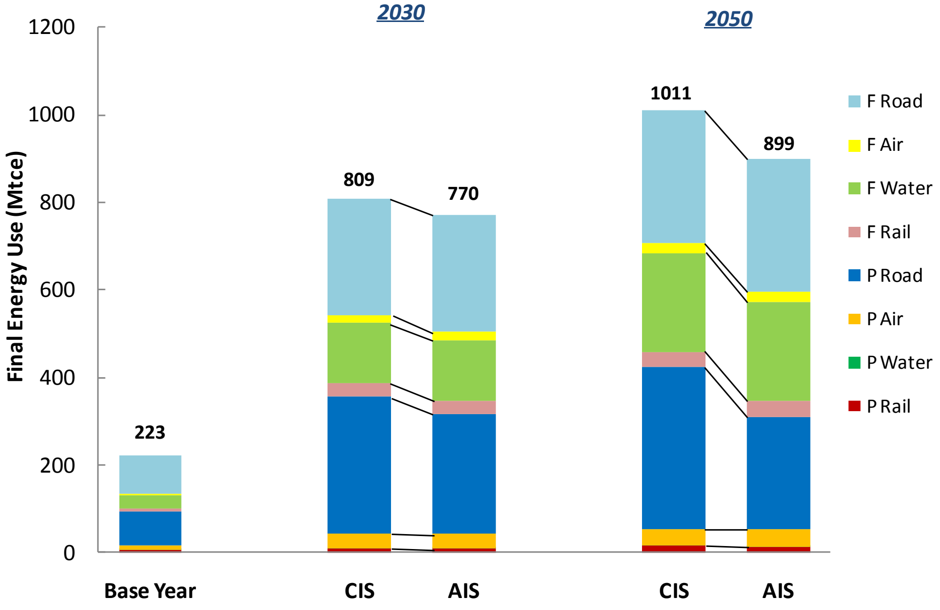


Figure 52 Transport Final Energy Consumption by Mode

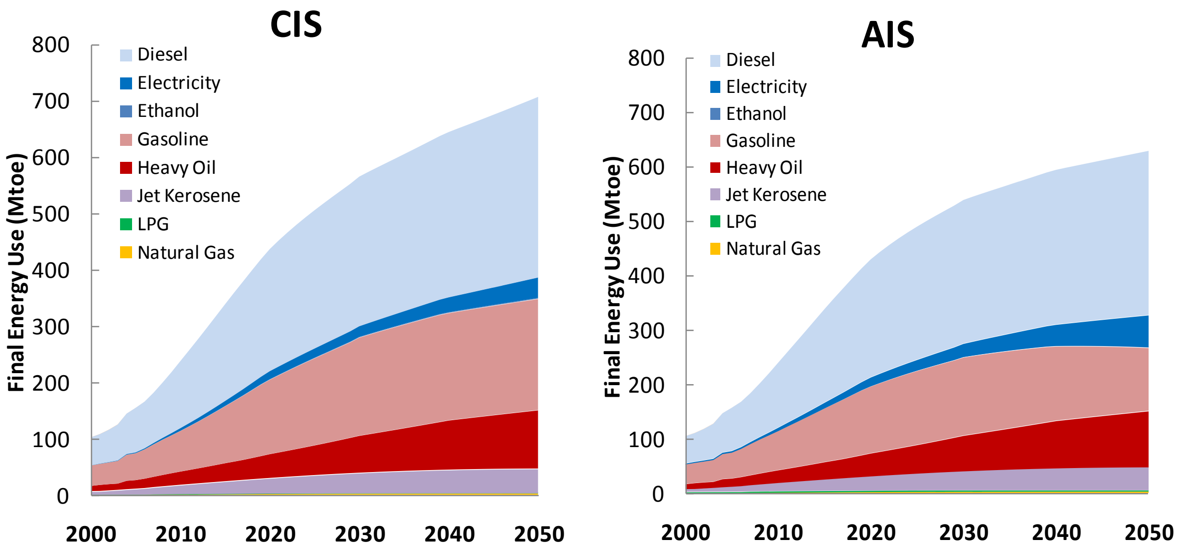


Figure 53 Transport Energy Consumption by Final Fuel, CIS and AIS Scenarios

In total, oil demand decreases by 144 million ton of oil equivalent (Mtoe) in 2050 in the AIS scenario compared to CIS. This is predominately due to the displacement of gasoline, but additional volumes of diesel are saved through increased rail electrification. LPG savings result from improvements in cooking and water heating equipment in the residential and commercial sectors, and saving of refinery gas are due to the reduced need for refinery processing of crude oil (Figure 54). In terms of refinery processing capacity and crude oil demand (including domestically produced and imported crude oil), it is assumed effective refinery capacity will be 95% of aggregate domestic demand. Because of the demand mix, this results in large volumes of both refined product imports and exports.

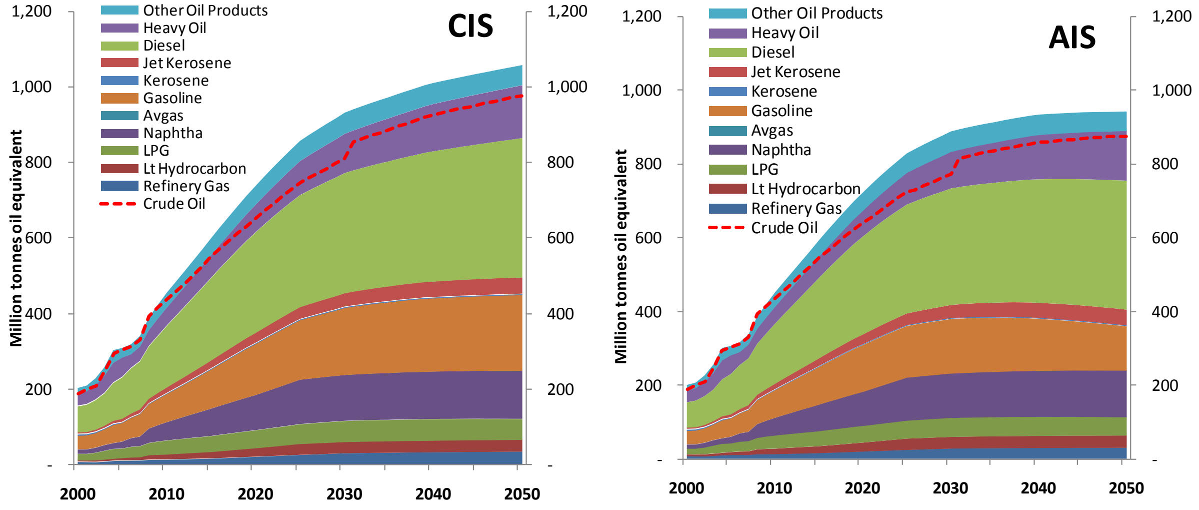


Figure 54 Total Domestic Demand for Petroleum Products, CIS and AIS Scenarios

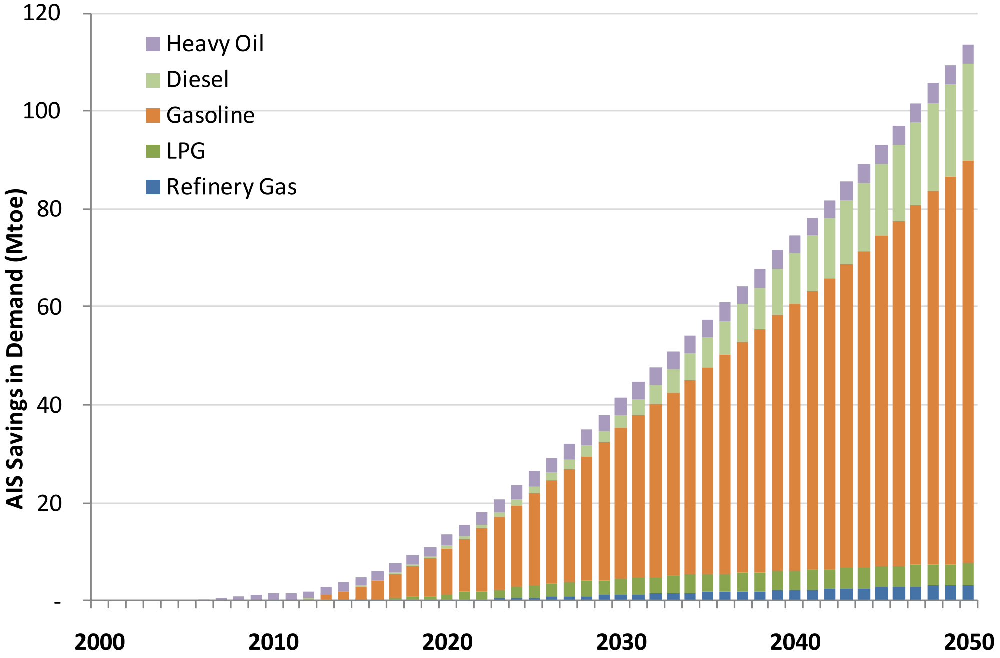


Figure 55 Petroleum Savings in the AIS Scenario

The demand pattern for oil as seen earlier in Figure 54 is fairly well balanced with refinery product output given the slate of crude and types of technologies in use in China's refineries. However, demand trends to 2050 result in significant imbalances between what is demanded and what can be produced from refineries, even considering potential shifts in the output slate as the demand slate changes. Because refineries operate as a coproduction process, attempts to balance domestic production of one product with demand will most likely result in imbalances in other product types. Indeed, in both scenarios, China becomes more dependent on a mix of product exports and imports to balance production and demand (Figure 56). In the CIS scenario, a strong focus on diesel maximization in refineries combined with improvements in diesel vehicle efficiency and continued electrification of the rail system results in a diesel surplus, while growing imports are needed to satisfy demand for naphtha, gasoline, jet kerosene and heavy oil (bunker fuel). LPG, for the most part, remains in balance. In the AIS scenario, however, after a short period of gasoline deficit owing to rapid increase in car ownership, aggressive displacement by electricity results in a gasoline surplus. The remaining products remain in deficit. Although this imbalance can be somewhat mitigated through further investment in refinery technology, the imbalance shows that policies focused on a single fuel (e.g. gasoline in personal cars) can have unintended consequences for both the refining sector and foreign trade.

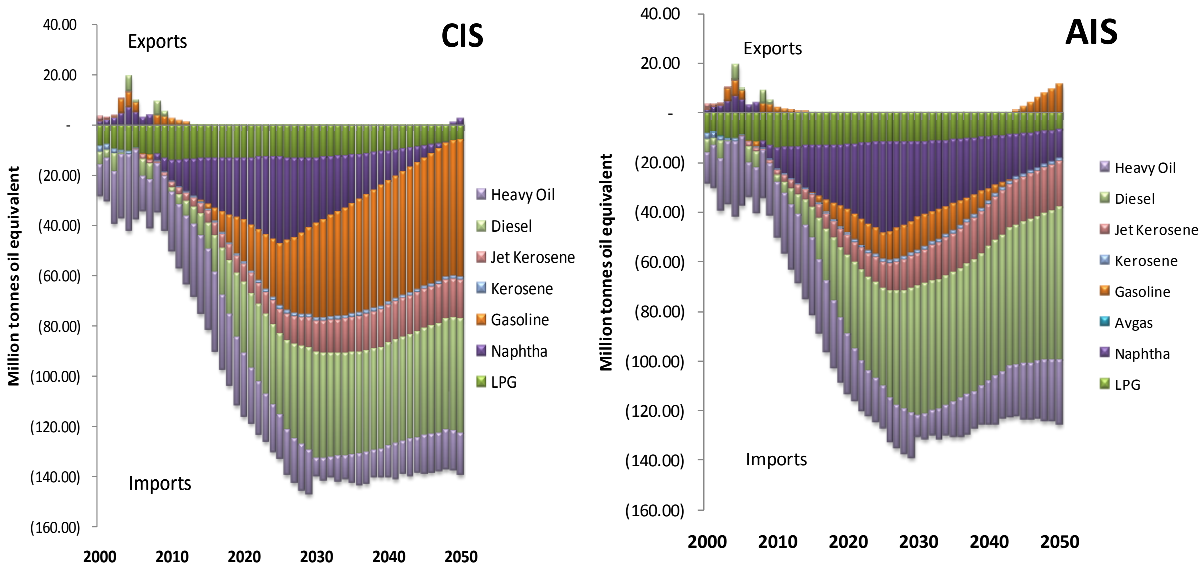


Figure 56 Major Oil Product Imports and Exports

The lower transport final energy demand in AIS can mostly be attributed to savings from more aggressive fuel economy improvements in light-duty bus fleet and greater EV penetration, with rail electrification having a diminutive effect (Figure 57). In particular, additional fuel economy improvements in buses and fuel switching in cars under AIS had the greatest gasoline final demand savings with 117 Mtce in 2050, followed by diesel savings from rail fuel switching at 26 Mtce in 2050. However, diesel energy savings are offset by an increase in electricity demand for rail, with 24 more Mtce needed to power 15% larger share of electrified rail n 2050.

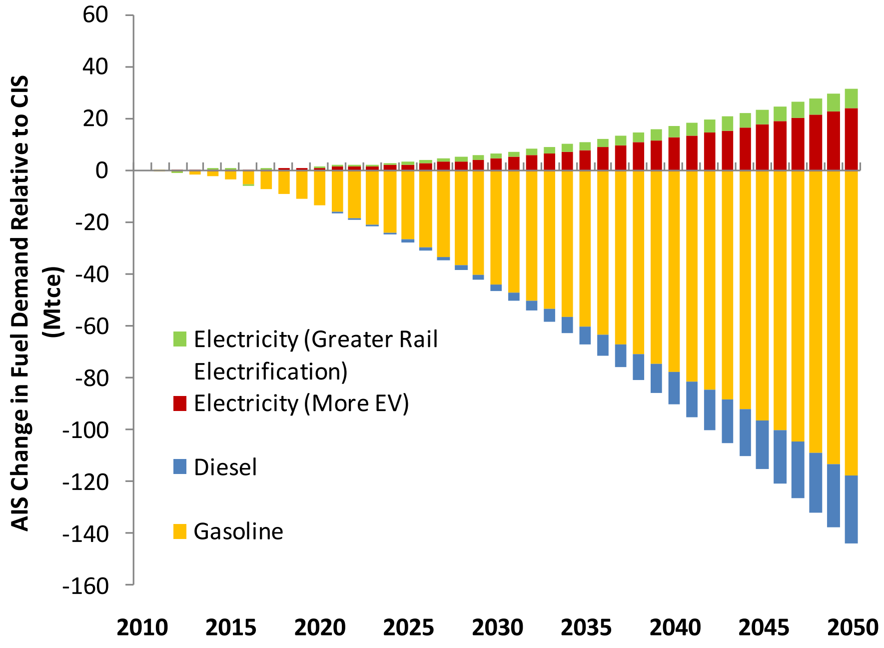


Figure 57 AIS Change in Transport Final Energy Demand Relative to CIS

As with the change in transport fuel consumption between CIS and AIS, the majority of transport CO_2 emissions reductions will also be from lower gasoline use resulting from fuel economy improvements and EV technology switch (Figure 58). Moreover, with electrification playing an important role in both CIS and AIS, the transport CO_2 emissions outlook will also be interlinked with decarbonization of the power supply. This is most evident in net AIS CO_2 emissions reduction compared to CIS despite increased electricity demand from electrified rail and cars. In fact, greater transport electricity use under AIS actually results in net CO_2 reduction on the order of 5 to 10 Mt CO_2 per year before 2030 and as much as 109 Mt CO_2 by 2050 because AIS power supply is less carbon intensive than CIS power supply.

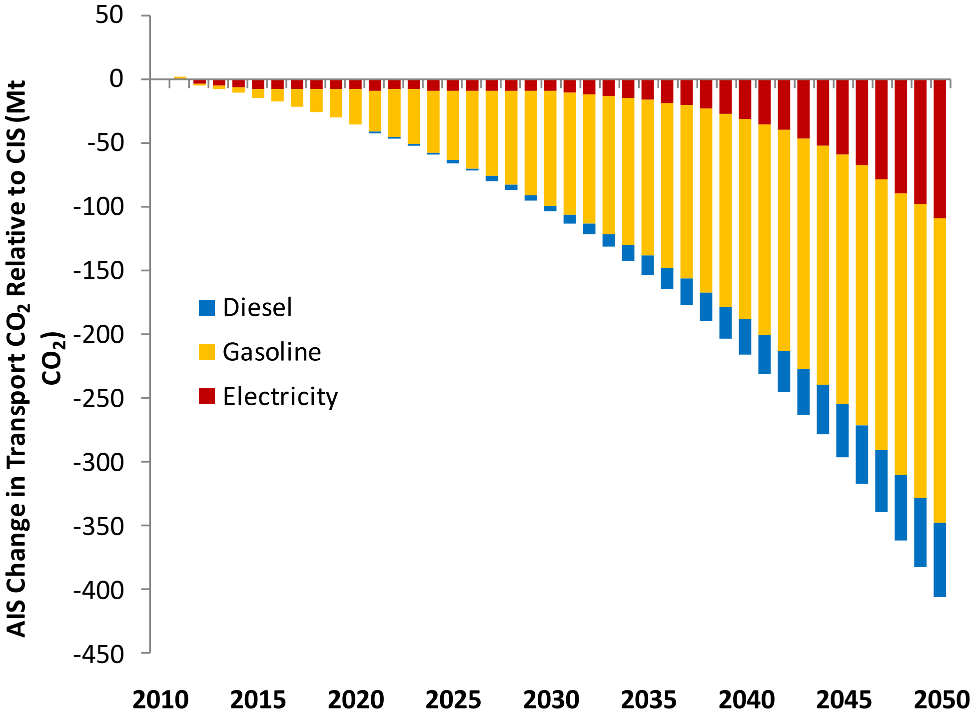


Figure 58 Transport CO_2 Emission Reduction under AIS by Fuel Source

The important impact of decarbonization on transport electrification is illustrated more clearly in the case of CO_2 reduction from EV technology switch. In AIS, the CO_2 reduction from a larger EV fleet share relative to CIS in 2050 actually results from two compounding effects: a cleaner power supply and gasoline demand reduction with the technology switch. The effect of EV technology switch in the absence of decarbonization can be captured by comparing the CO_2 reduction from lower gasoline demand with the additional CO_2 from greater electricity demand at a frozen power fuel mix at the 2005 base level. Although there is a net reduction in CO_2 emissions with AIS EV fleet shares through 2030, the more aggressive deployment of EV after 2030 in the absence of any decarbonization in the power sector will result in rising CO_2 emissions on the order of 54 Mt more CO_2 emissions in 2050 than CIS from EV electricity demand.

In contrast, relative to CIS, the additional CO_2 reduction due to faster EV technology switch in AIS can be captured by holding the fuel mix constant at CIS levels and looking at the net CO_2 impact of AIS EV shares at CIS fuel mix. This net CO_2 reduction is similar in magnitude to the reduction at a frozen fuel mix prior to 2030 but results in much greater CO_2 reduction from 2030 to 2050 as EV deployment accelerates.

Finally, accelerated power decarbonization in AIS contributes to additional CO_2 emission reduction of 60 Mt CO_2 in 2050 because a TWh under AIS has a lower emissions factor than a TWh under CIS.

Therefore, depending on the baseline for comparison, power decarbonization has important effects on the carbon mitigation potential of switching to EV technology. Relative to a frozen power mix, the impact of aggressive decarbonization under AIS is significant, with the potential to reduce 149 Mt CO_2 in 2050 and cumulative reduction of 1.4 billon tonnes of CO_2 (i.e., the EV change in CO_2 due to decarbonized power supply and additional change in CO_2 due to fuel switching sections in Figure 59). Relative to expected decarbonization following a continued path of efficiency improvement and planned renewable deployment under CIS, there is a smaller but still notable carbon impact of accelerated decarbonization in AIS on EV deployment (i.e., only the EV change in CO_2 due to decarbonized power supply section in Figure 59). This impact amounts to annual savings of 60 Mt CO_2 in 2050 or cumulative savings of 575 Mt CO_2 under AIS.

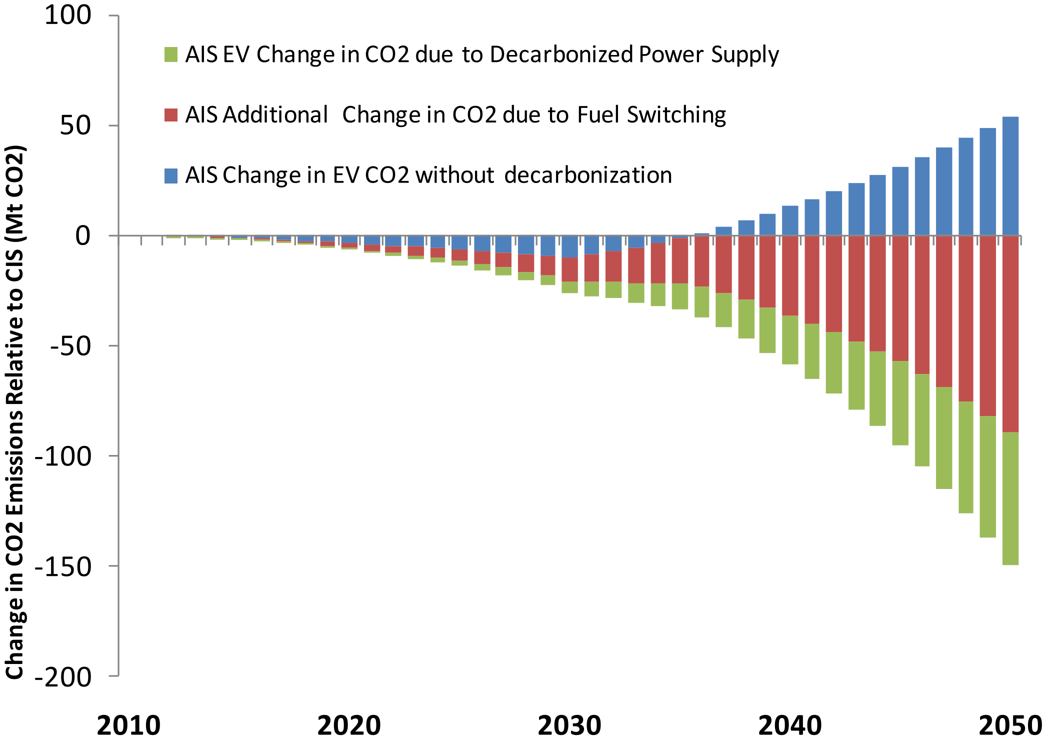


Figure 59 AIS EV Change in CO2 Emissions Relative to CIS

Power Generation

The electricity sector accounts for a large growing share of China's energy use and related CO_2 emissions. On the demand side, AIS results in 15% lower total electricity generation in 2050 than CIS. On the supply side, efficiency improvements and fuel substitution brings the 2050 coal share of total electricity generation from 49% in CIS to 10% in AIS.

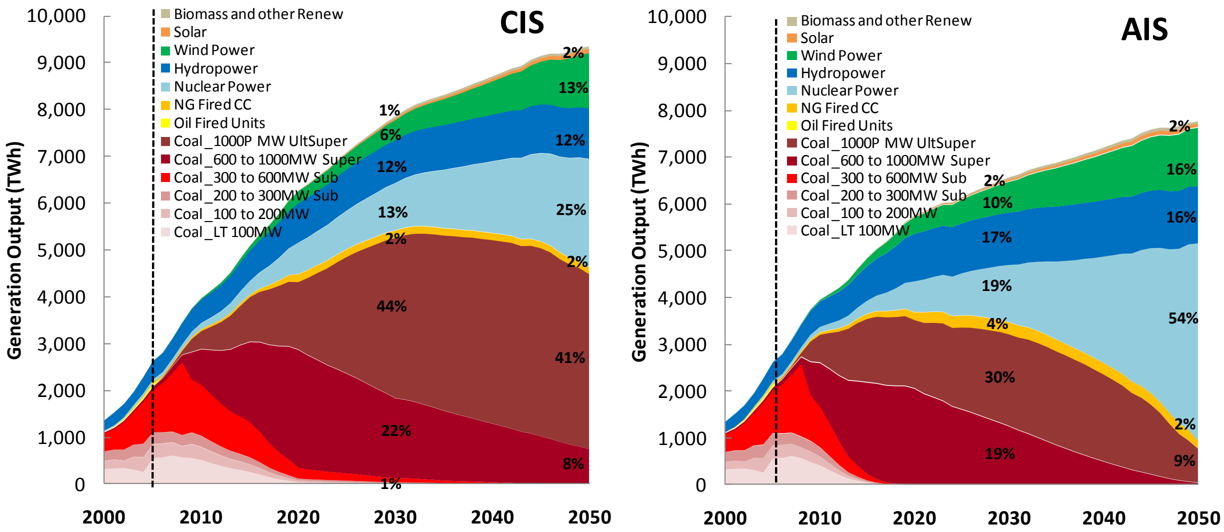


Figure 60 Electricity Generation by Fuel, CIS and AIS Scenarios

Decarbonization also plays a significant role in CO_2 emission reduction in the power sector and substantially outweighs the potential impact of carbon capture and sequestration (CCS). Besides the CIS and AIS scenarios of power sector development, an additional scenario was added to represent the implementation of CCS to capture 500 Mt CO_2 by 2050 under the CIS pathway of efficiency improvement and fuel shifting. Of the three scenarios, the AIS scenario requires the least primary energy and produces significantly lower energy-related power sector CO_2 emissions than either the CIS or the CCS scenario. In fact, AIS power sector emissions peak just below 3 billion tonnes in 2019 and begin declining rapidly thereafter to 0.6 billion tonnes in 2050. The CCS base scenario results in 476 million tonnes less emissions in 2050 than the CIS scenario with a 1.4% increase in the total primary energy requirement for carbon capture, pumping and sequestration.

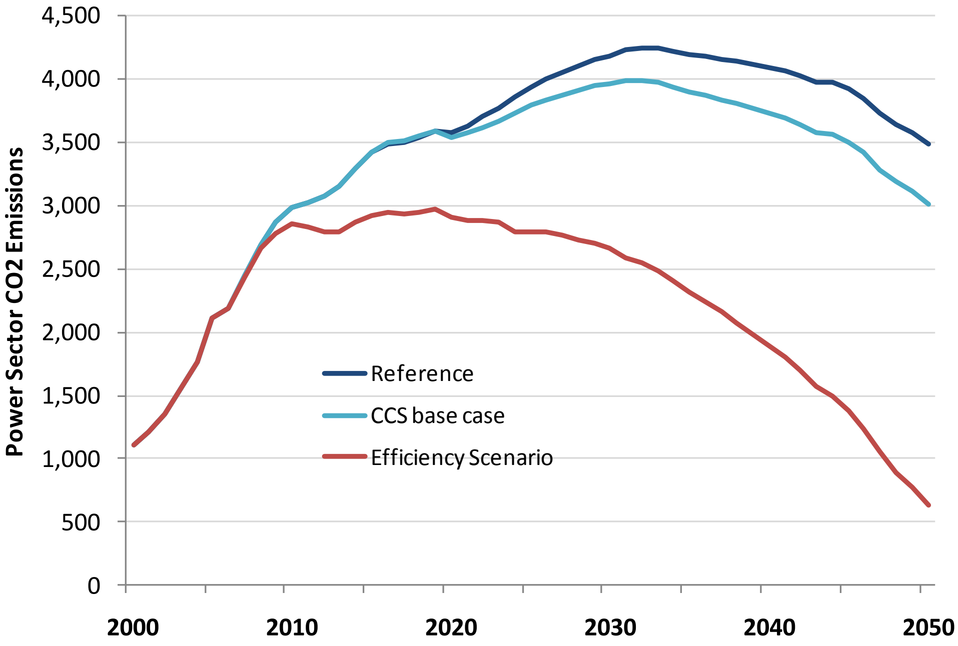


Figure 61 Power Sector CO_2 Emissions under Three Scenarios

The total national CO_2 emissions mitigation potential of moving from a CIS to AIS trajectory of development is 3.8 billion tonnes in 2050 with the power sector having the greatest mitigation potential. In 2050, over 70% of the inter-sector mitigation is from the power sector whereas 12% is from the transport sector.

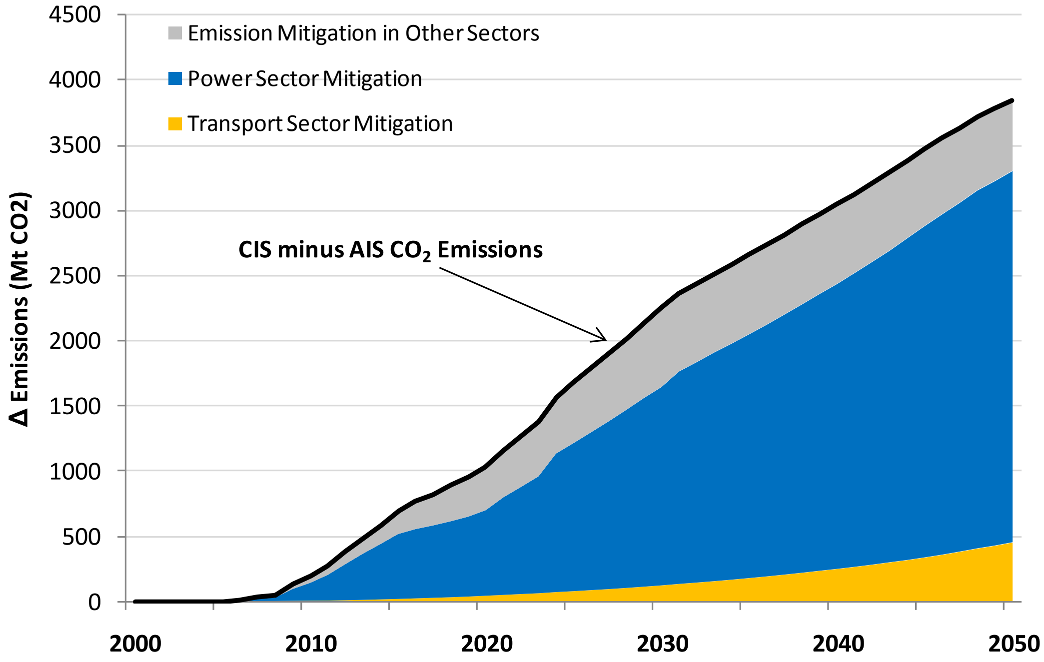


Figure 62 CO_2 Emission Mitigation under AIS by Source

Within the power sector, the greatest AIS-CIS inter-scenario CO_2 emissions mitigation potential is from direct electricity demand reduction as a result of more aggressive end-use efficiency improvements in industrial, residential, commercial, and transport sectors under AIS. Figure 63 illustrates five wedges that lead to power sector emissions reductions of almost 3.5 billion tonnes of CO_2 per year by 2030, where the solid wedges represent CO_2 savings from various power sector changes and the stripped wedge represents CO_2 savings from electricity demand reduction. One of the largest power sector mitigation potential is from end-use efficiency improvements that lower final electricity demand and the related CO_2 emissions, which is about half of total CO_2 savings before 2030 and then one-third of total CO_2 savings by 2050. Another growing source of carbon mitigation potential is the rapid expansion of nuclear generation, which increases from accounting for only 5% of CO_2 savings in 2030 to almost 40% in 2050. Of the CO_2 savings from power sector technology and fuel switching, greater shifts in coal generation technology (i.e., greater use of supercritical coal generation) and higher renewable and hydropower capacity each contribute similar magnitude of savings by 2050. These results emphasize the significant role that energy efficiency improvements will continue to play in carbon mitigation in the power sector (vis-à-vis lowering electricity demand), as efficiency improvements and can actually outweigh CO_2 savings from decarbonized power supply through greater renewable and non-fossil fuel generation prior to 2030.

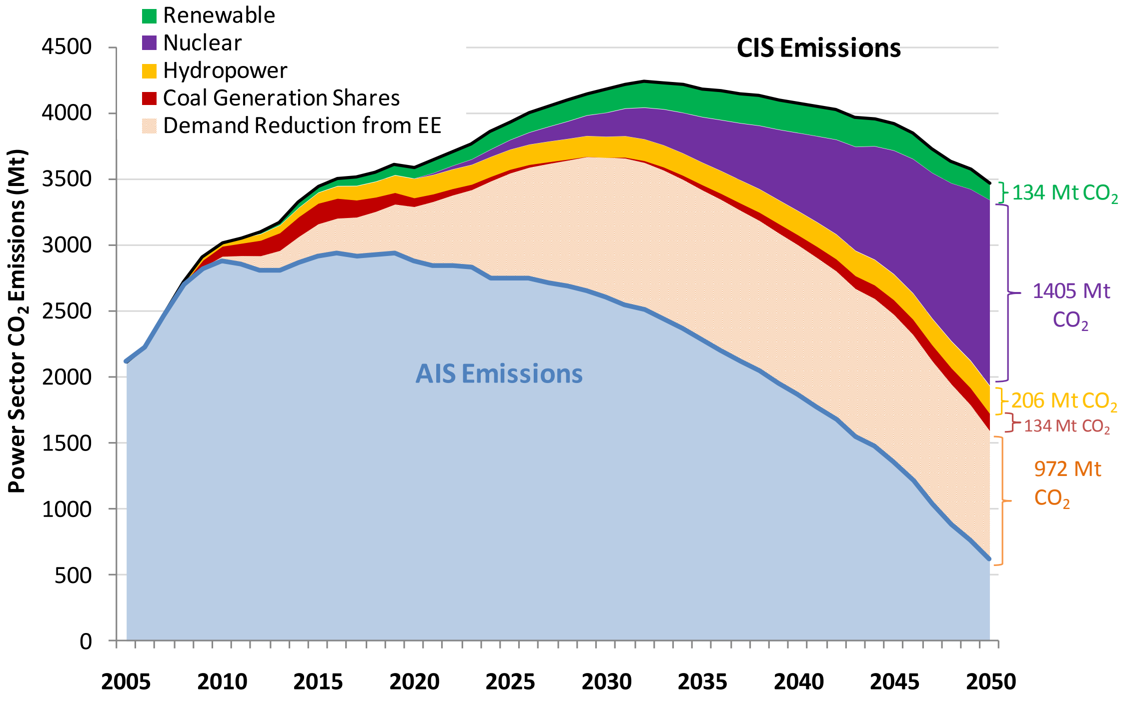
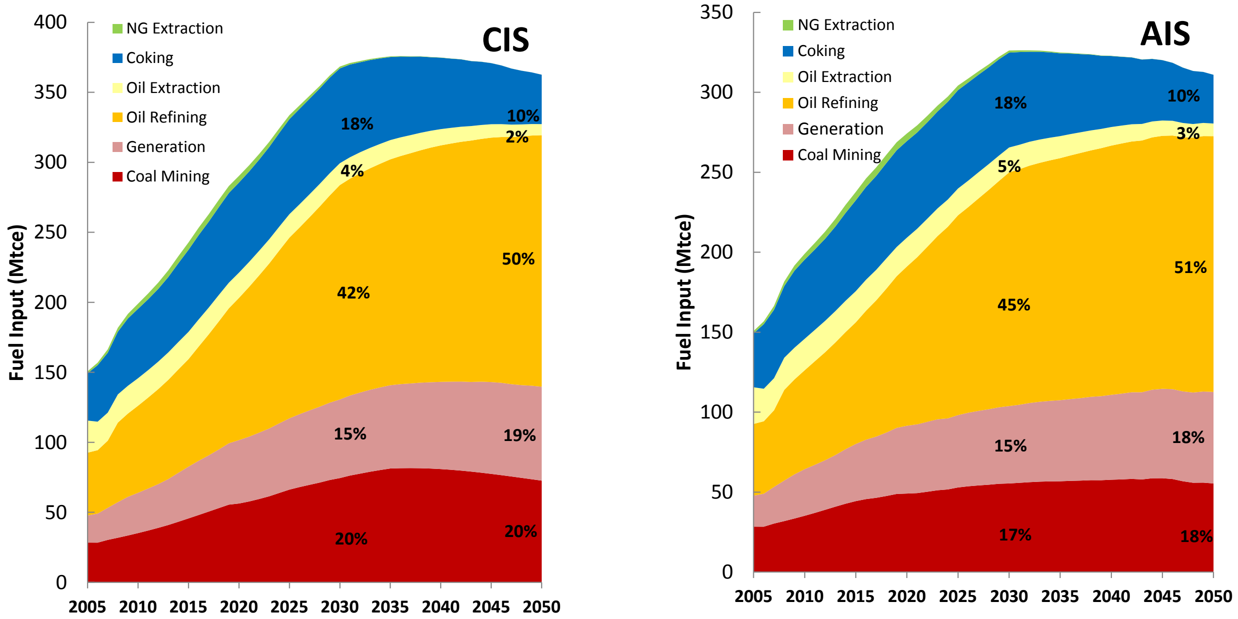


Figure 63 AIS Power Sector CO2 Emissions Reduction by Source

Energy Extraction

As a major energy producer, China is also a major consumer of energy used to produce energy (this excludes the energy used as a feedstock to produce another form of energy, such as coal for power generation or coal for coke production). In 2005, the total 150 Mtce energy required for energy extraction as well as for conversion or processing ranks only behind the major heavy industrial sector of iron and steel production. This total volume of energy use for energy extraction will more than double to 368 Mtce in 2030 in CIS then decline slightly to 362 Mtce in 2050. In AIS, energy use will reach 326 Mtce in 2030 and decline slightly to 311 Mtce in 2050 (Figure 64). Energy use in petroleum refining, coal mining and power generation dominate with total shares of 50%, 20% and 19%, respectively, in 2050 while energy use in oil and natural gas extraction will decline over time from current levels of 10% and 2% to 2% and 0%, respectively, as domestic production declines. Overall, there is a peak in the 2030s under both scenarios as a result of the dramatic decline in coking input after 2030 following significant declines in coal extraction after 2030 (Figure 64).

For coal, in the CIS scenario, the total energy input to coal extraction will increase from 28 Mtce in 2006 to 82 Mtce in 2037 before declining to 73 Mtce in 2050 as production of coal declines. In the AIS scenario, which displaces coal more aggressively, coal mining energy consumption by 2050 falls to 55 Mtce. For oil and natural gas, the total energy input will increase gradually from 22 Mtce in 2006 to 25 Mtce in 2015 before declining to 8 Mtce in 2050 as production of oil and gas decline. In both the CIS and AIS scenarios, domestic oil and natural gas extraction falls short of demand, resulting in continued import dependency, so the domestic extraction projection is identical in both scenarios. In terms of energy consumption, the coking sector (both captive and independent) consumed 40 Mtce in 2006. In the CIS scenario, this rises to a peak of 68 Mtce in 2020, declining to 35 Mtce by 2050. In the AIS scenario, peak consumption is reached sooner in 2025 at 62 Mtce, declining to 30 Mtce by 2050. In the power sector, plant self-use is expected to rise from the current 20 Mtce (final energy) to 67 Mtce in 2050 under CIS, compared to 57 Mtce in AIS in 2050.Although the efficiency of the extraction and production processes and equipment are expected to continue to improve, the decline in resource quality over time (deeper coal mines, lower coal quality, secondary recovery in the oil and gas sectors) is expected to increase total required energy investment into these sectors. For the refining sector, a major challenge is the trend toward heavier and high-sulfur crudes as the premium light crudes decline in availability at the same time that product quality requirements (e.g. lower sulfur, higher cetane) become more stringent. This result in increasing energy use per unit of crude oil processed as additional energy-intensive units such as hydrocracker and hydrotreaters are needed to meet output standards.



Note: Fuel input for power generation and coal input to coking is not included in these calculations.

Figure 64 Fuel Input to Energy Extraction and Processing, CIS and AIS Scenarios

Powering China's economy is expected to become increasingly energy-expensive. Currently, final energy use[8] in the energy extraction and processing sectors is equal to 14% of the industrial sector's energy end-use. By 2030, this is expected to rise to 18%, and further to 19.3% by 2050.

Uncertainties

Sensitivity analyses of the drivers in the key economic sectors was undertake to evaluate uncertainties that exist in the model. In each sensitivity analysis scenario, a specific variable such as the urbanization level was tested and all other variables were held constant. All the sensitivity analysis scenarios conducted and their subsequent impact on the total primary energy demand are listed in the table below.

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[8] Because the output of these energy sectors becomes inputs to industry, it is not possible to compare consumption in primary energy terms, since it would double-count the transformation sector's energy use.

Table 5 Sensitivity Analysis Scenarios

Scenario Name	Scenario Description	Sensitivity Impact
MAC 67% Urban	Macroeconomic: 67% urbanization by 2050	Medium
MAC -25% GDP GR	Macroeconomic: 25% lower growth rate in GDP/cap	High
MAC +25% GDP GR	Macroeconomic: 25% higher growth rate in GDP/cap	High
RES +25% FA	Residential: 25% more floor area/cap	Medium
COM -25% FA	Commercial: 25% less floor area/cap	High
COM +25% FA	Commercial: 25% more floor area/cap	High
COM 25 Life	Commercial: 25 years building lifetime	Medium
COM 50 Life	Commercial: 50 years building lifetime	Medium
COM +25% LOI	Commercial: 25% higher lighting & other intensity	Medium
COM -25% LOI	Commercial: 25% lower lighting & other intensity	Medium
TRA 40% EV AIS*	Transport relative to AIS*: 40% EV by 2050	Low
TRA 20% EV CIS	Transport: 20% EV by 2050	Low
TRA -25% OFA	Transport: 25% lower ocean freight activity	Low
IND +25% OIGDP GR	Industry: 25% higher growth in OI GDP growth rate	High
IND -25% OIGDP GR	Industry: 25% lower growth in OI GDP growth rate	High
IND -2% OI EI GR	Industry: 2% annual reduction in other industry energy intensity	High
IND -4% OI EI GR	Industry: 4% annual reduction in other industry energy intensity	High
IND +25% HI P	Industry: 25% higher heavy industry production levels	High
IND -25% HI P	Industry: 25% lower heavy industry production levels	High
IND 60% EAF	Industry: 60% EAF furnace penetration by 2050	Medium
IND 25% EAF	Industry: 25% EAF furnace penetration by 2050	Low

Among the different sensitivity analysis scenarios tested, variables in the industrial sector had the largest impact on total primary energy use, implying that there is a higher level of uncertainty surrounding these variables. For example, a 25% increase in the growth rate of other industry GDP which directly affects steel production can result an increase of nearly 800 Mtce in total primary energy use by 2050. Likewise, uncertainties in the production of heavy industrial output and energy intensity of the other industry subsector can result in changes in total primary energy use in the range of 300 to 700 Mtce in 2050. As important drivers of energy demand, commercial floorspace and GDP growth rate are also highly sensitive variables that have an important impact on total energy use.

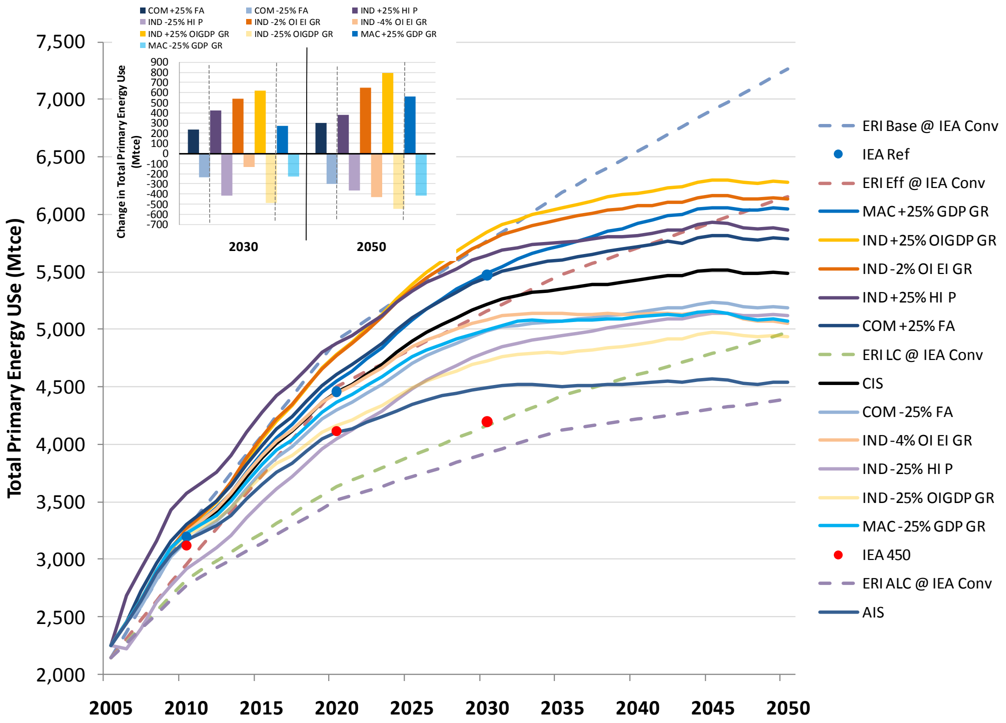


Figure 65 Sensitivity Analysis Scenario Results with Greatest Uncertainty

The sensitivity analysis also reveals that urbanization, building lifetime, commercial lighting and other end-use intensity and residential floor space are variables that have medium impact in the range of 100-200 Mtce on total primary energy demand. Specifically, total primary energy use would be 101 Mtce lower if urbanization only reaches a level of 67% in 2050. Building lifetime can also have an important effect on total primary energy use, as extending the life of a building to 50 years can reduce total energy use by over 200 Mtce in 2050..

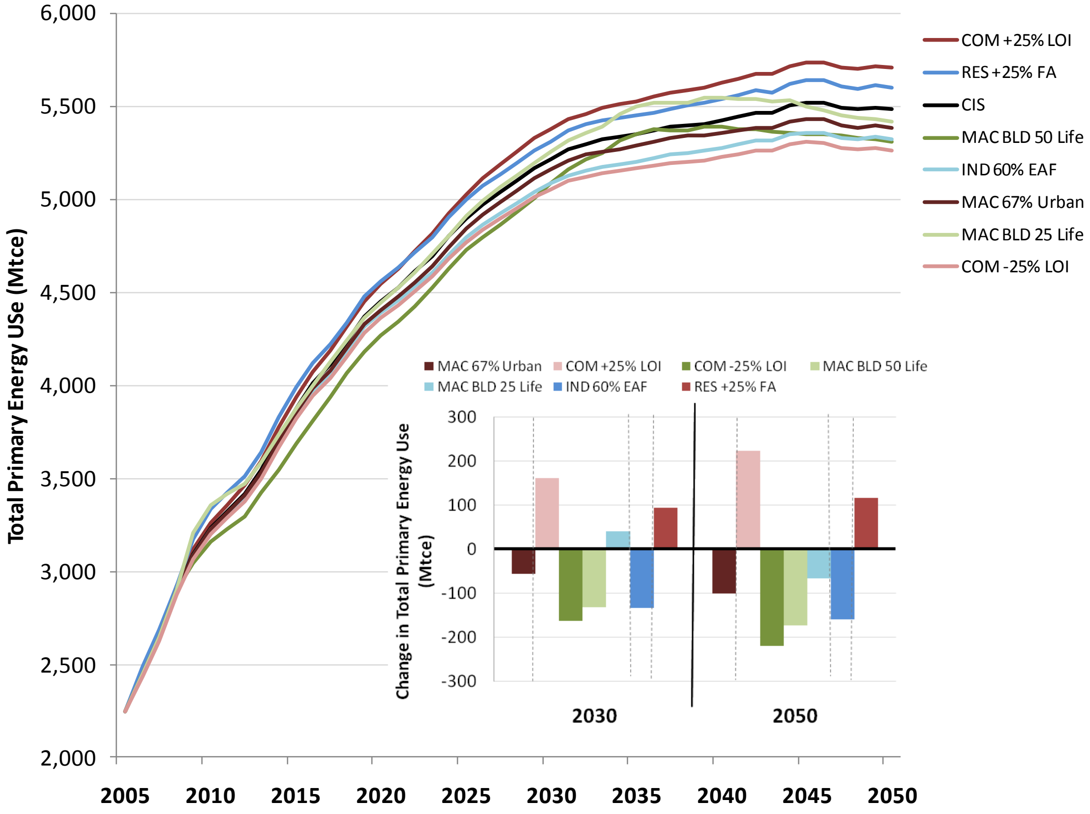


Figure 66 Sensitivity Analysis Scenario Results of Medium Uncertainty

Lastly, transport variables such as lower penetration of electric vehicles and lower ocean freight activity as well as slightly lower EAF penetration in the iron and steel subsector have minimal impact of less than 35 Mtce on total primary energy use.

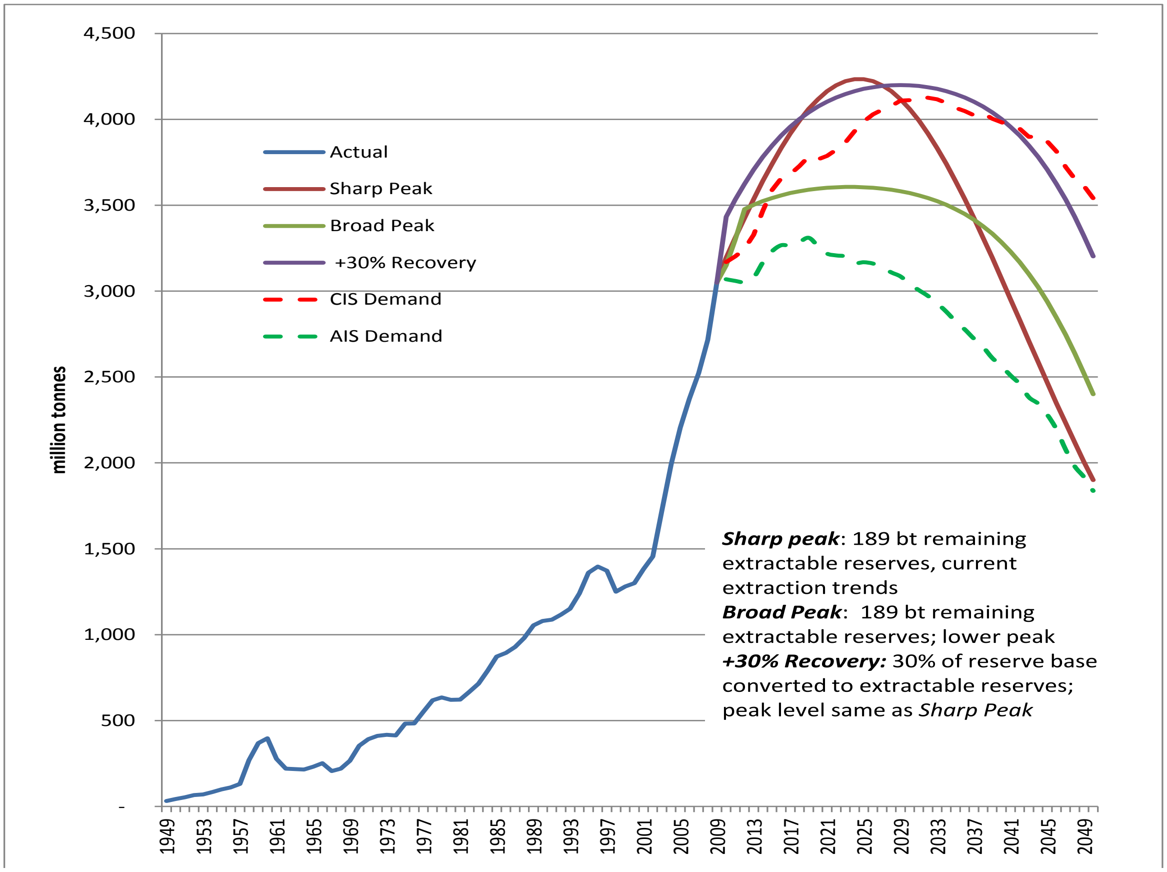
Assumptions in Fossil Energy Supply Scenarios

In order to constrain the future supply of non-renewable fossil-fuel energy supply, derivative logistics curve calculations were made to determine possible extraction profiles that accord with the total volume of reserves available for extraction, with maximum extraction levels occurring at about half-way in the depletion of the reserves. These curves were fitted to historical extraction figures from 1949. In the case of oil and natural gas, the extraction profiles demonstrate that China will continue to be a net importer of both of these fossil energy forms, and extraction profiles provided the model with the basis for calculation of imports. In the case of coal, the profiles were created as an aid to interpreting the model results, since coal extraction was not constrained in the model.

Coal

For coal, the remaining extractable reserve figure of 189 billion tonnes is based on the latest (2003-2006) Third National Resource Survey by the Ministry of Land and Natural Resources (Tao and Li, 2007). As an alternative case, it is assumed that 30% of what is considered China's coal reserve base beyond what is now classified as extractable can be converted into extractable reserves. The reserve base (which includes extractable reserves) encompasses all identified resources that meet the physical and economic criteria for extraction as well as those that have potential for becoming extractable in a time horizon beyond proven technology and current economics. Overall, the general high depth of China's coal reserves and priority extraction of highest-quality reserves raises questions if these marginal reserves can be economically and technical exploited, and the 30% assumption used here may be optimistic.

Three profiles were developed and compared with the coal demand projections from the CIS and AIS scenarios (Figure 67). Actual production is shown to 2009. The historical production profile appears to best describe the "sharp peak" production profile based on the current level of remaining extractable reserves. Under the profile, production of over 4 billion tonnes can be accommodated, but only for a fairly short time, and production may not be able to satisfy coal demand by the 2030s in the CIS case. Alternately, the life of existing reserves can be extended under a "broad peak" profile in which peak output reaches over 3.5 billion tonnes, and then declines slowly. This would appear to completely accommodate the demand outlook in the AIS case. Finally, if China were able to increase its extractable reserves by another 30% of the remaining reserve base, then the CIS case appears to be accommodated. A case of lower coal reserves was not tested, although internationally, the trend in many major coal producing countries has been one of reserve downgrades rather than upgrades.



Sharp peak: 189 bt remaining extractable reserves, current extraction trends
Broad Peak: 189 bt remaining extractable reserves; lower peak
+30% Recovery: 30% of reserve base converted to extractable reserves; peak level same as *Sharp Peak*

Figure 67 Coal Demand and Extraction Profiles

Oil

For oil, the two profiles of future extraction are based on the reserves estimates of Feng, Li, and Pang of China's University of Petroleum (Feng, et. al.,, 2008). Scenario 1 is implemented in this modeling exercise, and thus determines the level of crude oil imports to 2050. China became a net oil importer in 1993, and by 2050, under both CIS and AIS, will be importing over 97% of its total crude oil usage.

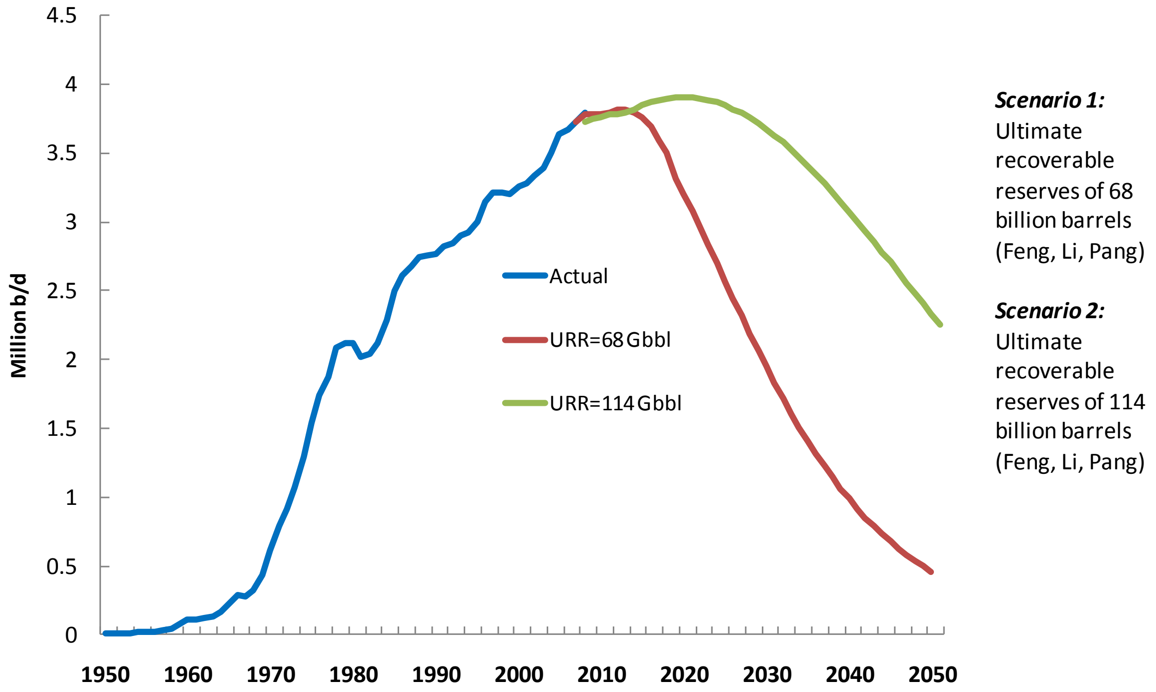
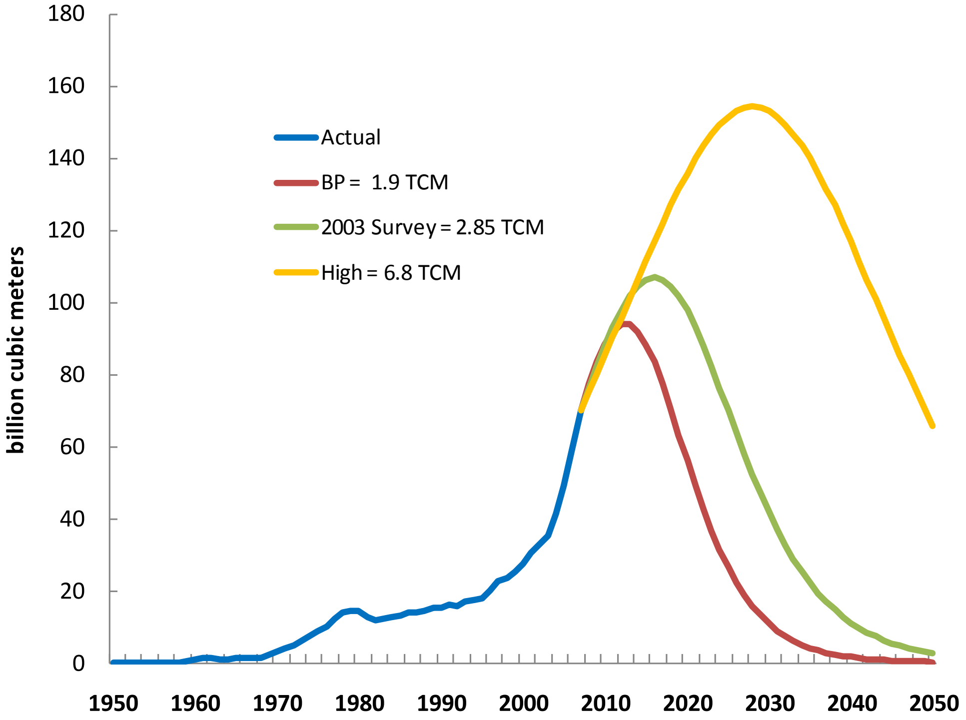


Figure 68 Historical and Projected Oil Supply Curves

Natural Gas

For natural gas, three values for extractable reserves were evaluated, including the figure reported by BP (2009); the result of the Third National Resource Survey (Tao and Li, 2007); and a much higher figure derived by Lahererre (2008) that assumes considerable remaining undiscovered natural gas. In this model, Scenario 2, based on the Ministry of Land and Natural Resources survey results, is used, and thus determines the natural gas import demand to 2050. Under both scenarios, China would be importing 99% of its natural gas in 2050.Even in a case where China tripled its domestic gas reserves, imports in 2050 would account for more than 75% of consumption in both scenarios.



Scenario 1:
Remaining reserves of 1.9 TCM (BP; not used in supply cases)

Scenario 2:
Remaining reserves of 2.85 TCM (as reported by Min. of Land & Water Resources)

Scenario 3:
Remaining reserves of 6.8 TCM (assumes significant undiscovered)

Figure 69 Historical and Projected Natural Gas Supply Curves

Conclusions

As China continues to pursue its social development goals, demand for energy services are set to grow, presenting fundamental challenges as economic growth and projected rapid urbanization will drive up energy demand and CO_2 emissions without changes in energy efficiency and energy supply structure. This study thus evaluated how China can maintain its development trajectory, provide basic wealth to it citizens while being energy sustaining; assessed the role of energy-efficiency as well as structural change in potential CO_2 emissions abatement policies for transitioning China's economy to a lower-carbon trajectory; and evaluated China's long-term domestic energy supply in order to gauge the potential challenge China may face in meeting long-term demand.

Primary energy consumption will rise continuously in both scenarios but reach a plateau around 2040, with a cumulative energy reduction of 26 billion tonnes of coal equivalent under the AIS from 2005 to 2050. Future energy demand reduction potential is greatest in the industry sector in the earlier years and from the buildings sector in the long run. The result also shows that total annual energy savings potential of over one billion tonnes of coal equivalent exists beyond the expected reference pathway (CIS) under AIS pathway in 2050. Both scenarios must meet all announced and planned policies, targets and non-fossil generation targets, or an even wider efficiency gap will exist. The primary source of savings is from electricity rather than fuel, and electricity savings are magnified by power sector decarbonization through increasing renewable generation and coal generation efficiency improvement.

CO_2 emissions under both scenarios could experience a plateau or peak around 2030, with AIS peaking slightly earlier at 9.7 billion tonnes of CO_2 as a result of more aggressive energy efficiency improvement and faster decarbonisation of the power supply. The single largest end-use sector emission reduction potential could be seen in the buildings sector, particularly commercial buildings, followed by the industry sector. Further reduction of CO_2 under these scenario assumptions would require even higher levels of non-carbon-emitting electricity. The total national CO_2 emissions mitigation potential of moving from a CIS to AIS trajectory of development is 3.8 billion tonnes in 2050 with the power sector having the greatest mitigation potential.

Both the CIS and AIS scenario demonstrates that with continuous improvement, the goal of 40% CO_2 emissions intensity reduction by 2020 announced in the Copenhagen Accords in 2009 is possible, but will require strengthening or expansion of energy efficiency policies in industry, buildings, appliances, and motor vehicles, as well as further expansion of renewable and nuclear power capacity. These results emphasize the significant role that energy efficiency policies and subsequent improvements will continue to play in decreasing the growth of energy demand and leading China on a lower carbon development pathway. The crucial impact of energy efficiency improvements on CO_2 emissions mitigation is most readily apparent in the power sector (vis-à-vis lowering electricity demand), as efficiency improvements and can actually outweigh CO_2 savings from decarbonized power supply through greater renewable and non-fossil fuel generation prior to 2030.

It is a common belief that China's CO_2 emissions will continue to grow throughout this century. We believe this is not likely to be the case for the following reasons: appliances, residential and commercial floor area, roadways, railways, fertilizer use, etc. will saturate in the 2030 time frame; urbanization will approach peak after 2030 or 2035; exports of energy-intensive industry will decline; and low population growth. Until around 2025 – energy demand growth will be highly uncertain in China as the country continues to build out its infrastructure. This is in contrast to developed countries who can count on an energy growth of ~1% with current policies.

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