Title

What Can China Do? China's Best Alternative Outcome for Energy Efficiency and CO2 Emissions

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What Can China Do?

China's Best Alternative Outcome for Energy Efficiency and CO_2 Emissions

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Executive Summary

After rapid growth in economic development and energy demand over the last three decades, China has undertaken energy efficiency improvement efforts to reduce its energy intensity under the 11^{th} Five Year Plan (FYP). Since becoming the world's largest annual CO_2 emitter in 2007, China has set reduction targets for energy and carbon intensities and committed to meeting 15% of its total 2020 energy demand with non-fossil fuel. Despite having achieved important savings in 11^{th} FYP efficiency programs, rising per capita income and the continued economic importance of trade will drive demand for transport activity and fuel use. At the same time, an increasingly "electrified" economy will drive rapid power demand growth. Greater analysis is therefore needed to understand the underlying drivers, possible trajectories and mitigation potential in the growing industrial, transport and power sectors.

This study uses scenario analysis to understand the likely trajectory of China's energy and carbon emissions to 2030 in light of the current and planned portfolio of programs, policies and technology development and ongoing urbanization and demographic trends. It evaluates the potential impacts of alternative transportation and power sector development using two key scenarios, Continued Improvement Scenario (CIS) and Accelerated Improvement Scenario (AIS). CIS represents the most likely path of growth based on continuation of current policies and meeting announced targets and goals, including meeting planned appliance efficiency standard revisions, fuel economy standards, and industrial targets and moderate phase-out of subcritical coal-fired generation with additional non-fossil generation. AIS represents a more aggressive trajectory of accelerated improvement in energy intensity and decarbonized power and transport sectors. A range of sensitivity analysis and power technology scenarios are tested to evaluate the impact of additional actions such as carbon capture and sequestration (CCS) and integrated mine-mouth generation. The CIS and AIS results are also contextualized and compared to model scenarios in other published studies.

The results of this study show that China's energy and CO_2 emissions will not likely peak before 2030, although growth is expected to slow after 2020. Moreover, China will be able to meet its 2020 carbon intensity reduction target of 40 to 45% under both CIS and AIS, but only meet its 15% non-fossil fuel target by 2020 under AIS. Under both scenarios, efficiency remains a key resource and has the same, if not greater, mitigation potential as new technologies in transport and power sectors. In the transport sector, electrification will be closely linked the degree of decarbonization in the power sector and EV deployment has little or no impact on China's crude oil import demand. Rather, power generation improvements have the largest sector potential for overall emission mitigation while mine-mouth power generation and CCS have limited mitigation potential compared to fuel switching and efficiency improvements.

Comparisons of this study's results with other published studies reveal that CIS and AIS are within the range of other national energy projections but alternative studies rely much more heavily on CCS for carbon reduction. The McKinsey study, in particular, has more optimistic assumptions for reductions in crude oil imports and coal demand in its abatement scenario and has much higher gasoline reduction potential for the same level of EV deployment. Despite these differences, this study's scenario analysis of both transport and power sectors illustrate the necessity for continued efficiency improvements and aggressive power sector decarbonization in flattening China's CO_2 emissions.

1. Introduction

During the period 1980 to 2002, China's strong energy-efficiency policies and programs contributed to a 5% average annual reduction in energy consumption per unit of gross domestic product (GDP). The period 2002-2005 saw a dramatic reversal of the historic relationship between energy use and GDP growth: energy use per unit of GDP increased an average of 3.8% per year during this period. Over the last ten years, rising per capita income and the continued economic importance of trade has driven and will continue to drive transport activity. At the same time, the economy is becoming increasingly electrified across all sectors and thereby driving rapid power demand growth. In 2007, China also overtook the U.S. in energy-related CO_2 emissions to become the largest annual emitter of greenhouse gases. To meet its energy and carbon challenges, China has recently set several reduction targets starting with the 11th Five Year Plan (FYP), which covers the period 2006-2010. Another key target was announced in the 2005 Renewable Energy Law, which set a legally binding target of meeting 15% of China's total energy demand in 2020 with non-fossil fuel energy sources including hydropower and nuclear power. In November 2009, China also announced carbon intensity reduction target of 40% to 45% reduction below 2005 levels by 2020. Many policies and initiatives have been launched in recent years, particularly under the 11th FYP, to facilitate meeting of these goals by improving energy efficiency and increasing carbon mitigation. In order to understand China's progress towards these goals, it is important to first consider what has been achieved under the 11th FYP.

1.1 Energy Efficiency Progress under 11th Five Year Plan

China's 11th FYP required all government divisions at different levels to reduce energy intensity by 20% in five years in order to regain the relationship between energy and GDP growth experienced during the 1980s and 1990s. The national energy intensity reduction target was then decomposed into provincial targets, which in turn affects industrial activity on the provincial level. In addition, the 11th FYP also set quantitative targets for industry through the Top 1000 program, which set energy-saving targets for China's 1000 highest energy-consuming enterprises that total in saving 100 million tonnes of coal equivalent (Mtce). The Top 1000 program was implemented on the provincial level through collaboration between energy saving authorities and related organizations and the savings target was achieved ahead of schedule in 2009.

Energy, GDP, and energy intensity data were reviewed for 2005 through 2008 to evaluate China's progress towards achieving the national energy intensity goal (Table 1). Energy use values are reported by the National Bureau of Statistics while the energy intensity reduction values are from sources in the National Development and Reform Commission. GDP values were then derived using these two values. This method was chosen because the energy values and energy intensity reduction values were the most clearly reported values; GDP values have undergone a series of revisions and may continue to be revised. On July 15, 2010, NBS released revised GDP and energy data for as early as 2001 based on the results of its second economic census conducted in 2008.[1] Unlike previous economic censuses, the sampling methodology for the 2008 economic census was much more complex and differs significantly from prior reporting in capturing energy consumption below the county level, particularly in industry, construction and services.[2] With a re-verified GDP value for 2008 and energy and water resource consumption data preliminarily identified, earlier energy numbers were backcasted using the same historic growth rates. Therefore, the energy intensity reduction values for 2006 through 2008 have changed from originally reported values with a new total energy intensity reduction of 16.59% thus far in the 11th FYP period (Table 1).

Table 1 Energy Use, Energy Intensity, and GDP Data (2005-2008)

Indicator	Unit	2005	2006	2007	2008	2009
Energy	Mtce	2,247	2,463	2,656	2,850	
GDP	Billion 2005 RMB	18,322	20,449	22,982	25,848	
Energy Intensity (EI)	Kgce/RMB	0.1226	0.1204	0.1156	0.1103	
Energy Intensity Reduction	% per year		-1.79%	-4.04%	-4.59%	
NBS Revised EI	Kgce/RMB	0.1276	0.1241	0.1179	0.1118	0.1077
NBS Revised EI Reduction	% per year		-2.74%	-5.04%	-5.20%	-3.61%

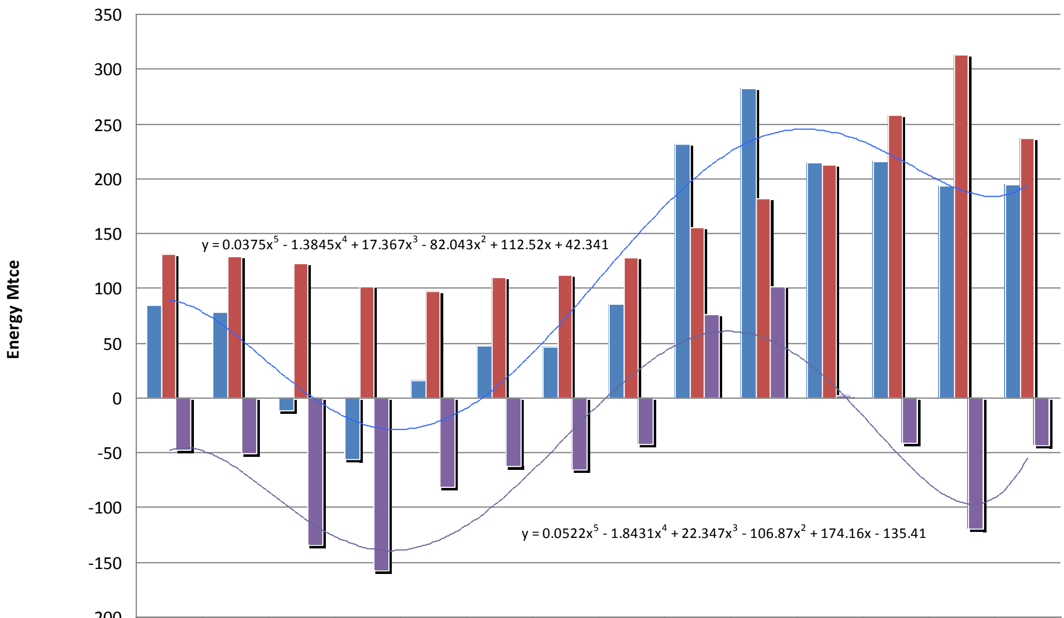
Source: Original data from Levine, M.D., et.al. 2010. *Assessment of China's Energy Saving and Emission Reduction Accomplishments and Opportunities during the 11th Five Year Plan*. LBNL-3385E. Berkeley, CA: Lawrence Berkeley National Laboratory. NBS revised data from National Bureau of Statistics Release on July 15, 2010. Available at: http://www.stats.gov.cn/was40/gjtjj_detail.jsp?channelid=4362&record=1 (In Chinese).

Figure 1 provides a decomposition of the energy use of China's economy and provides a historic context for understanding the trends during the 11th FYP. The blue bars in the figure represent the change in energy use from the previous year. While the change in energy use has been both positive and negative during the 1995-2008 period, increases of 216 million tonnes of coal equivalent (Mtce), 193 Mtce, and 194 Mtce were experienced during 2006, 2007, and 2008, respectively. The red bar illustrates how much of the annual increase (or decrease) was due to a change in "activity", such as the production of raw materials or manufactured goods. The purple bar illustrates how much of the annual increase (or decrease) was due to a change in "intensity" or the amount of energy used per unit of activity. Adding these two effects as represented by red bar and the purple bar results in the total energy use (the blue bar). This decomposition shows that during the 11th FYP to date, the growth in energy use was due primarily to the large growth in activity (red bar) that began to increase in 2002 and peaked in 2007. The decomposition further shows that the growth in energy use was dampened by reductions in energy efficiency, especially in 2007, which offset the growth in activity.

[1] The 11th FYP savings analysis was based entirely on original energy and GDP data reported by NBS and NDRC because the newest revisions were not released until July 2010.

[2] State Council Information Office. 2009. Transcript of Press Conference of the Results of the Second National Economic Census on 25 December 2009. Available online: http://www.china.com.cn/zhibo/2009-12/25/content_19120084.htm

Figure 1 Trends in Energy Use, Activity, and Energy Efficiency for the Chinese Economy, 1995-2008

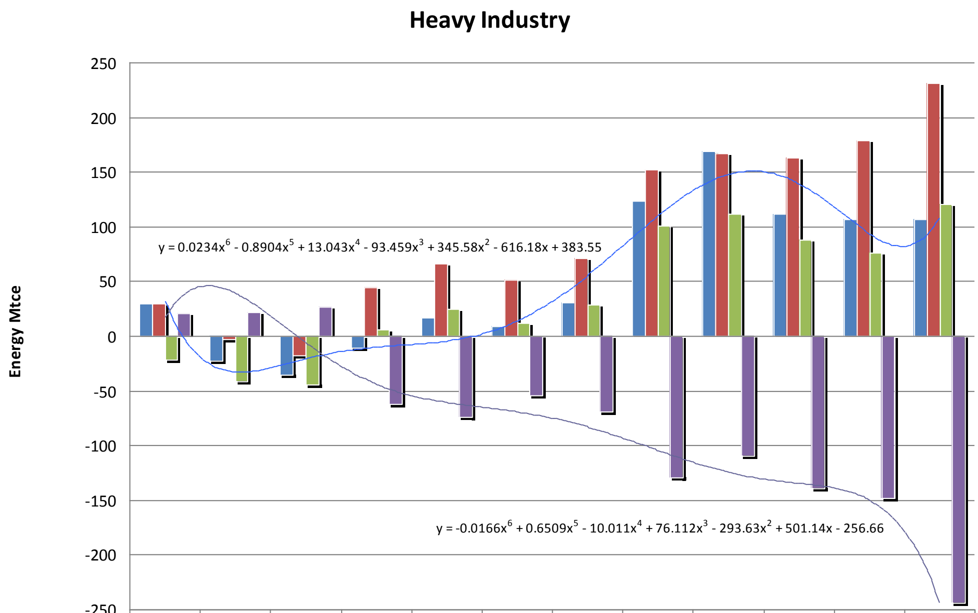


	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Δ Energy Use	84.39	77.72	-11.50	-55.84	16.17	47.22	46.46	85.98	231.93	282.37	214.55	215.88	193.13	194.17
Activity	131.585	128.80	123.01	101.80	97.68	110.23	112.32	128.18	155.85	181.36	212.14	257.70	312.64	237.15
Efficiency	-47.195	-51.08	-134.51	-157.64	-81.51	-63.01	-65.86	-42.20	76.08	101.01	2.41	-41.82	-119.51	-42.98

Reductions in energy intensity in the secondary sector[3] appear to have made the largest contribution. Figure 2 provides a disaggregation of the affects of changes in activity, structure, and energy efficiency for heavy industry (defined as ferrous metals, non-metallic minerals, chemicals, non-ferrous metals, fuel, paper, and textiles). This figure clearly indicates that improvements in energy efficiency offset increases in activity and structural changes, helping to reverse the growth in overall energy use experienced between 2002 and 2004. Energy efficiency improvements were greatest in 2007; unfortunately data are not yet available to assess their impact in 2008.

[3] The primary sector of the economy involves changing natural resources into primary products and includes agriculture, agribusiness, fishing, forestry and all mining and quarrying industries. Most products from this sector are considered raw materials for other industries. The Secondary sector includes those economic sectors that create a finished, usable product: manufacturing and construction. The tertiary sector involves the provision of services to businesses as well as final consumers. Services may involve the transport, distribution and sale of goods from producer to a consumer as may happen in wholesaling and retailing, or may involve the provision of a service, such as in pest control or entertainment.

Figure 2 Trends in Energy Use, Activity, Structure, and Energy Efficiency for Heavy Industry in China, 1996-2007



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Δ Energy Use	29.63	-22.42	-35.97	-11.33	16.94	9.16	30.27	123.76	168.90	111.61	106.57	107.04
Activity	30.05	-3.24	-17.91	44.70	66.44	51.48	70.91	152.58	166.96	162.69	178.64	230.94
Structure	-21.33	-41.40	-44.43	5.98	24.74	11.68	28.76	100.33	111.74	88.17	75.91	120.28
Efficiency	20.91	22.22	26.36	-62.02	-74.24	-54.00	-69.40	-129.15	-109.80	-139.25	-147.98	-244.18

In light of these recent trends, the primary purpose of the 11th FYP target was to reverse China's 2002-2005 trend of increasing energy intensity of GDP growth. Besides the overarching target of 20% reduction in energy intensity of GDP growth during the 11th FYP period, the central government also announced target levels for a number of supporting programs in industrial energy efficiency and restructuring, building and appliance efficiency.

In evaluating China's 2006 to 2008 energy performance, a baseline was calculated based on 2005 energy intensity, i.e. what energy consumption would have been in these years if the amount of energy per unit GDP remained constant. In this approach, achieved energy savings are equal to the difference between the counterfactual frozen 2005 energy intensity baseline and reported actual energy consumption. The frozen 2005 energy intensity baseline was calculated by multiplying the 2005 energy intensity value of 0.1226 kilograms of coal equivalent (kgce)/RMB by the GDP values for each year in order to derive the energy consumption that would have occurred if the 2005 energy intensity had not declined during the 2006-2008 period (see Table 2). According to this methodology, China achieved a 10% reduction of total energy intensity of GDP growth between 2005 and 2008, which resulted in ~530 Mtce less cumulative energy use than would have been the case if energy intensity had remained constant.

Table 2 Frozen 2005 Energy Intensity Baseline and Reported Energy Use (2005-2008)

Indicator	Unit	2005	2006	2007	2008
Frozen 2005 Energy Intensity	Kgce/RMB	0.1226	0.1226	0.1226	0.1226
GDP	Billion 2005 RMB	18,322	20,449	22,982	25,848
Frozen Baseline Energy	Mtce	2,247	2,508	2,818	3,170
Annual Energy Difference	Mtce	0	45	162	320
Cumulative Energy Difference	Mtce	0	45	207	527

Source: Levine et. al., 2010.

In particular, an assessment of selected policies and programs that China has instituted in its quest to fulfill the national goal of a 20% reduction in energy intensity by 2010 was conducted. It was possible to track performance of the overall energy economy in reducing energy intensity; however, evaluating individual energy-savings programs and policies to determine the magnitude of their contributions has been difficult due to lack of data.[4] In addition, the information that is available is often reported in units that are not clearly defined, programmatic targets are not clearly delineated as to whether they represent annual or cumulative savings goals through 2010, and conflicting and difficult to interpret information is provided through interviews, reports, and websites. In most cases, the results are based on calculated savings from known details of the programs (appliance standards), surveys (enforcement of building codes), or statements by government officials indicating the magnitude of savings without documentary sources.

In spite of these limitations, this assessment finds that China has made substantial progress toward its goal of achieving 20% energy intensity reduction from 2006 to 2010 and that many of the energy-efficiency programs implemented during the 11th FYP in support of China's 20% energy/GDP reduction goal appear to be on track to meet – or in some cases even exceed – their energy-saving targets.[5] Table 3 provides information on the primary and final energy savings and CO2 emissions identified for each of the programs included in the assessment. From this analysis, it appears that most of the Ten Key Projects, the Top-1000 Program, and the Small Plant Closure Program are on track to meet or surpass the 11th FYP savings goals. China's appliance standards and labeling program, which was established prior to the 11th FYP, has become very robust during the 11th FYP period, as illustrated by the development of new or revised standards that have met three out of four of the *Medium to Long-term Energy Conservation Plan's* 2010 energy-efficiency targets. The evidence suggests that China has greatly

[4] For the Top 1000 program, only one annual report with detailed savings data was published and the other analysis was based on publications and interviews with experts. There were no reports on savings achieved under the 10 Key Projects and published data points from other sources (e.g., news articles) are unclear as to whether savings are in primary or final energy savings. In the absence of any reports on estimated or actual savings, building efficiency programs were evaluated on the basis of survey results and interviews with key stakeholders and policymakers in the building sector.

[5] For a full report on this assessment and basis for the findings, see Levine, M.D., et.al. 2010. "Assessment of China's Energy Saving and Emission Reduction Accomplishments and Opportunities during the 11th Five Year Plan." LBNL Report 3385-E. Berkeley, CA: Lawrence Berkeley National Laboratory.

enhanced its enforcement of new building energy standards with calculated impacts that are on track to meet the goals. However, the energy-efficiency programs for buildings retrofits, as well as the goal of adjusting China's economic structure to reduce the share of energy consumed by industry, do not appear to be on track to meet the stated goals. The assessment further finds that the successes are mainly due to increases in energy efficiency or energy conservation; these increases have been sufficient to overcome the lack of success in achieving structural change.

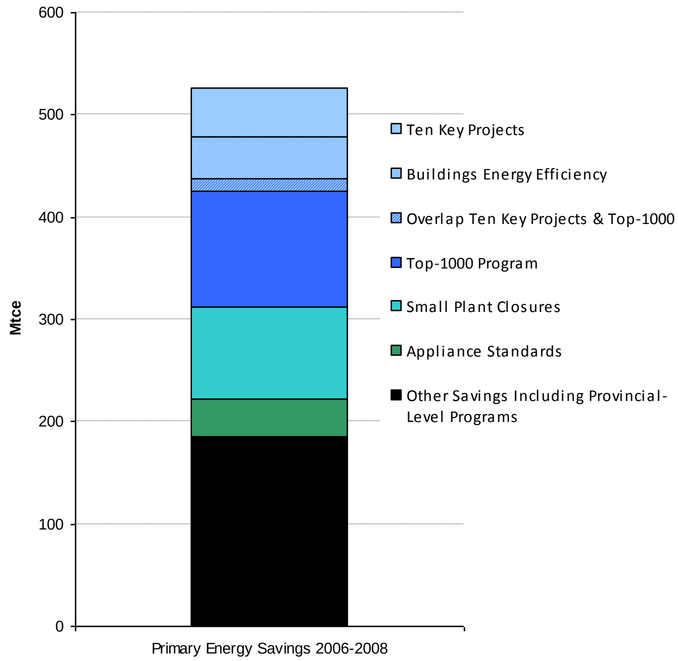
Table 3 11th FYP Energy-Saving Targets and Savings to Date, 2006-2008, Based on Frozen 2005 Efficiency Baseline

Policy/Program	11th FYP Target	Savings to Date 2006-2008
	Final Energy (Mtce)	
Ten Key Projects	245	94
Buildings Energy Efficiency	101	35
(Overlap Ten Key Projects and Buildings Energy Efficiency)	-101	-35
Top-1000 Program	100	96
(Overlap Ten Key Projects and Top-1000 Program)	-26	-10
Small Plant Closures	91	75
Appliance Standards	24	11
Other savings including provincial programs	885	144
Total Final Energy Savings	**1320**	**409**
	Primary Energy (Mtce)	
Ten Key Projects	268	102
Buildings Energy Efficiency	112	41
(Overlap Ten Key Projects and Buildings Energy Efficiency)	-112	-41
Top-1000 Program	130	124
(Overlap Ten Key Projects and Top-1000 Program)	-32	-12
Small Plant Closures	118	91
Appliance Standards	79	37
Other savings including provincial programs	1146	185
Total Primary Energy Savings	**1709**	**527**
	Emissions Reduction (Mt CO_2)	
Ten Key Projects	743	287
Buildings Energy Efficiency	348	100
(Overlap Ten Key Projects and Buildings Energy Efficiency)	-348	-100
Top-1000 Program	235	197
(Overlap Ten Key Projects and Top-1000 Program)	-67	-27
Small Plant Closures	222	171
Appliance Standards	167	78
Other savings including provincial programs	2973	612
Total Emissions Reductions	**4273**	**1318**

Source: Levine, et. al., 2010.

Note: Individual program savings do not add up to the Total Primary Energy Savings value because of overlap between the Ten Key Projects and the Buildings Energy Efficiency and Top-1000 Programs. See report for details regarding how the total primary energy savings was calculated.

Figure 3 2006-2008 Estimated Energy Savings from 11th FYP Programs and Policies



Source: Levine, et. al., 2010.
Note: Other savings represent the balance of total energy savings and savings from efficiency programs that were evaluated. It includes savings from numerous provincial-level activities and programs that were not evaluated due to lack of data and reporting.

With the implementation of the 11th FYP now bearing fruit, it is important to maintain and strengthen the existing energy-saving policies and programs that are successful while revising programs or adding new policy mechanisms to improve the programs that are not on track to achieve the stated goals.

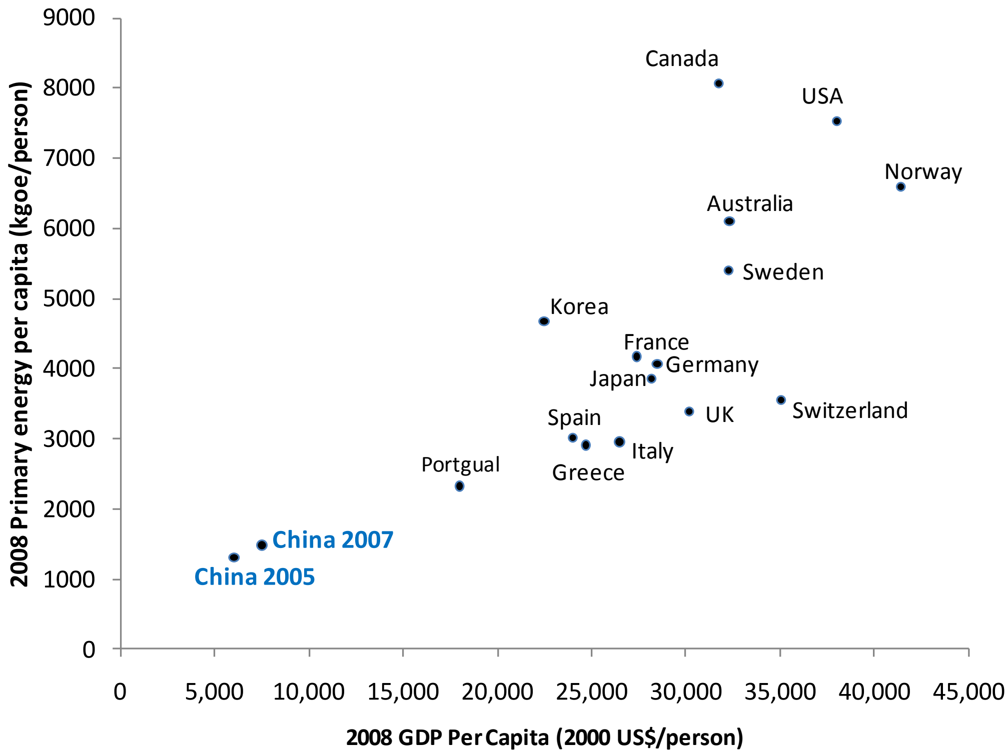
1.2 China's Growth in the International Context

Although China surpassed the U.S. as the world's largest annual CO_2 emitter in 2007, its per capita energy consumption is still much lower than those in the developed world. Relative to the U.S., China's 2007 per capita total primary energy consumption of 1.48 toe/capita was one-fifth of the U.S. level of 7.53 toe/capita in 2008.[6] Given the general trend of higher per capita energy consumption for countries with higher per capita GDP, China's per capita energy demand will rise as it continues to undergo economic growth (Figure 4). The degree to which China's energy demand per capita will grow as its GDP increases will depend on the degree it is successful in decoupling economic and energy growth. For example, after successful reductions in energy

[6] Calculated based on data presented in Figure 5.

intensity from 2005 to 2009 under the 11th FYP, reported energy intensity in first quarter of 2010 has risen year-on-year by 3.2%.[7]

Figure 4 International Comparisons of 2008 Primary Energy Consumption and GDP Per Capita

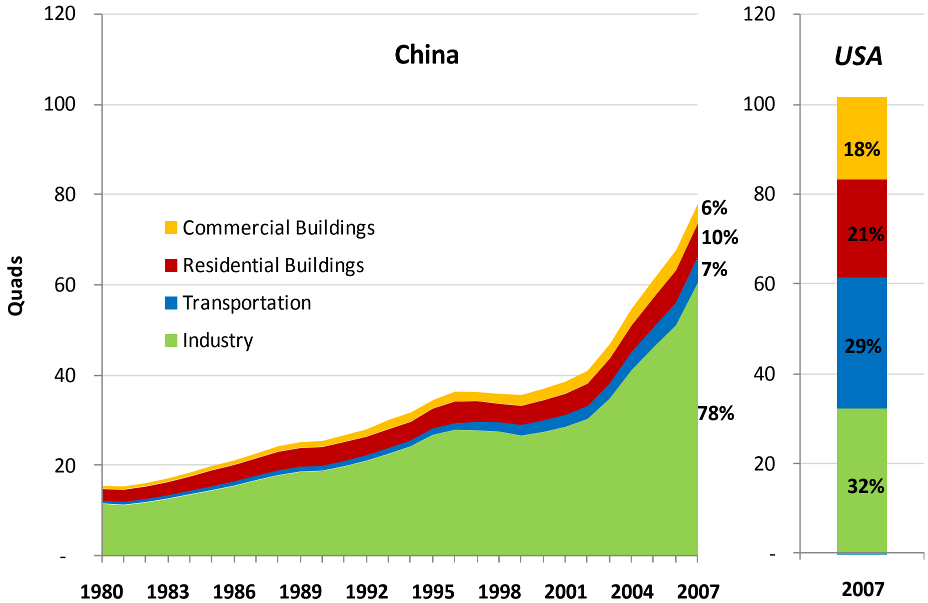


Source: OECD/IEA, 2009, Energy Balances of OECD Countries (2009 edition) and Non-OECD Countries (2009 edition).

China's present and future energy drivers include the industrial sector, which has been responsible for a vast majority of total primary energy demand with a 78% share in 2007. In contrast, the U.S. industrial share in 2007 was only 32% (Figure 5). With economic growth and structural change, which the Chinese government has started promoting in recent years, the industrial share of energy demand will likely decrease. At the same time, however, with quickly rising Chinese car ownership rates still much lower than international levels, the transport sector will become a key sectoral consumer of primary energy demand. This is also reflected in Chinese transport's very small sectoral share of 7% of total primary energy demand relative to the U.S. transport share of 29%. Likewise, commercial and residential buildings' small shares of energy consumption will rise over time as inhabitants' demand for increased comfort and equipment usage grows.

[7] Chen, Eadie and Aizhu Chen. "China's energy intensity rises 3.2 pct in Q1." *Reuters International* [Beijing] 6 May 2010. Available at: http://in.reuters.com/article/idINTOE64500C20100506

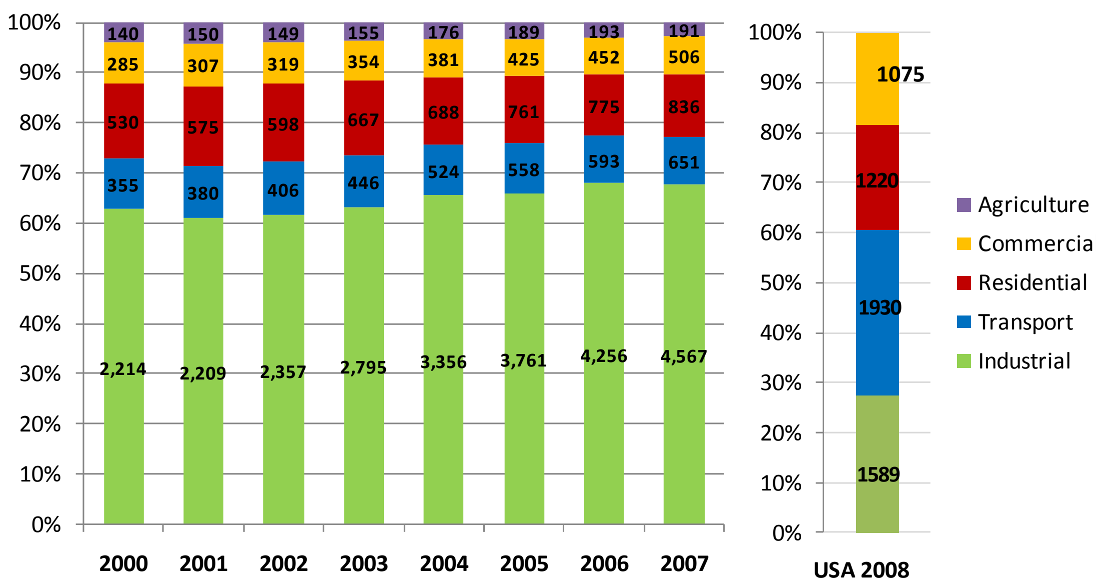
Figure 5 US-China Comparison of Total Primary Energy Use by Sector



Source: Chinese data from China Statistical Yearbook, various years. U.S. data from EIA, Annual Energy Review.

As with primary energy demand, the Chinese industrial sector is also responsible for a very large share of total CO_2 emissions, unlike the smaller industrial share of emissions in the U.S. Compared to the U.S., China's transport and building sectors also have much lower share of CO_2 emissions, indicating the potential for emissions growth in these two expanding sectors.

Figure 6 US-China Comparison of Total CO_2 Emissions by Sector



Source: Chinese emissions calculated based on historical energy consumption data by sector. U.S. data from EIA, 2010.

2. Modeling China's Energy Pathways to 2030

In order to understand the magnitude and related energy and carbon impacts of efficiency and technology policies and programs similar to those in the 11th FYP over the next two decades, a bottom-up, sector-based model is used to conduct scenario analysis with particular emphasis on drivers in the industrial, transport and power sector. This model is built upon Stockholm Environment Institute's Long-range Energy Assessment and Planning (LEAP) system as an end-use based accounting tool. This China energy model addresses end-use energy demand characteristics including sector-based patterns of energy consumption, saturation trends and links between economic growth and energy demand. It also addresses supply-side issues such as generation capacity and dispatch rules, energy used by the energy sector, and carbon capture and sequestration impacts through a power sector module.

The scenarios developed for this analysis represent alternative pathways that China could follow given current trends, macroeconomic considerations and currently available and expected technological developments and efficiency levels. More specifically, the scenarios represent the continuation and strengthening of current portfolio of efficiency and conservation policies and meeting non-fossil targets and industrial efficiency targets. None of the scenarios are intended to represent what would happen in China in the absence of policy intervention (i.e., "Frozen" scenario) or what currently stated Chinese policy goals would achieve (i.e., Business as Usual scenario). Rather, the main scenarios are intended to represent energy and development pathways following different pace and magnitude of energy saving policy implementation and technology deployment across different sectors.

2.1 Model Scenarios

The Continued Improvement Scenario (CIS) assumes that the Chinese economy will continue on a path of lowering its energy intensity with efficiency improvements consistent with moderate pace of "market-based" improvement in all sectors. For the industrial and transport sectors, for instance, this translates into moderate fuel economy improvements in transport fleets and continued rail electrification following stated goals as well as continued technological improvement across major energy-consuming industrial sectors of iron and steel, cement, glass.

The Accelerated Improvement Scenario (AIS) assumes that China will adopt a much more aggressive trajectory towards achieving best practice and implementation of alternative technologies in the short to medium term, while taking into consideration the time necessary for technologies to penetrate the stock or fleet. For the transport and industrial sectors, this means greater deployment and thus faster penetration of efficient and alternative technologies such as electric vehicles, cement rotary kilns and electric arc furnaces for the iron and steel industry.

Table 4 Key Scenario Differences by Sector

	Continued Improvement Scenario (CIS)	Accelerated Improvement Scenario (AIS)
Residential Buildings	Appliance efficiency improve following current revision schedule	Appliance efficiency levels reach near current international best practice by 2020
Commercial Buildings	Efficiency improvements follow current pace	Efficiency levels reach current international best practice levels by 2020
Industry	Industrial efficiency targets are all met	Industrial production technologies all meet current world best practice earlier
Transport	Meet published fuel economy targets for cars and follow international experience in efficiency improvements in other modes. 10% electric vehicle penetration in car fleet by 2030	All CIS improvements, with additional fuel economy improvements in light duty passenger transport. 25% electric vehicle penetration in car fleet by 2030
Power	Moderate phase-out of subcritical coal-fired generation units and targets met for non-fossil energy capacity	Aggressive expansion of non-fossil power following China's targets

Sensitivity analysis was also conducted for the transport and power sector scenarios. Various scenarios were developed to analyze the specific effects of uncertainties in key drivers such as car ownership, rail electrification levels, and electric vehicle penetration levels for transport; and utilization of carbon capture and sequestration and grid penetration of renewable generation on the power grid.

2.2 Macroeconomic Drivers

For all scenarios, the same macroeconomic parameters such as economic growth, population, and urbanization are assumed to be the same (Table 5). International experiences and China's recent experiences with economic development have highlighted the important linkages between industrialization and rising energy demand, particularly in the industrial and transport sectors that fuel GDP growth. To account for economic growth in China's near future, two different rates of GDP growth were assumed for the period between 2010 and 2020, and between 2020 and 2030 (Table 5). Fast 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. Besides economic growth, urbanization is expected to be another major force shaping China's development and energy pathways. The addition of new mega-cities and second-tier cities will drive commercial and residential demand for energy services and infrastructure development, as well as spur inter- and intra-city passenger transport activity. To account for the potential effects of urbanization on energy demand in China, the model included population growth and urbanization, or share of urban population, as macro-drivers in both scenarios. The urbanization rate is projected to increase to 70% in 2030 from 43% in 2007.

Table 5 Key Macroeconomic Parameters for All Scenarios

	2005	2030
Population	1.31 Billion	1.46 Billion
Urbanization Rate	43%	70 %
GDP Growth		
2000-2010	9.4%	
2010-2020	7.7%	
2020-2030	5.9%	

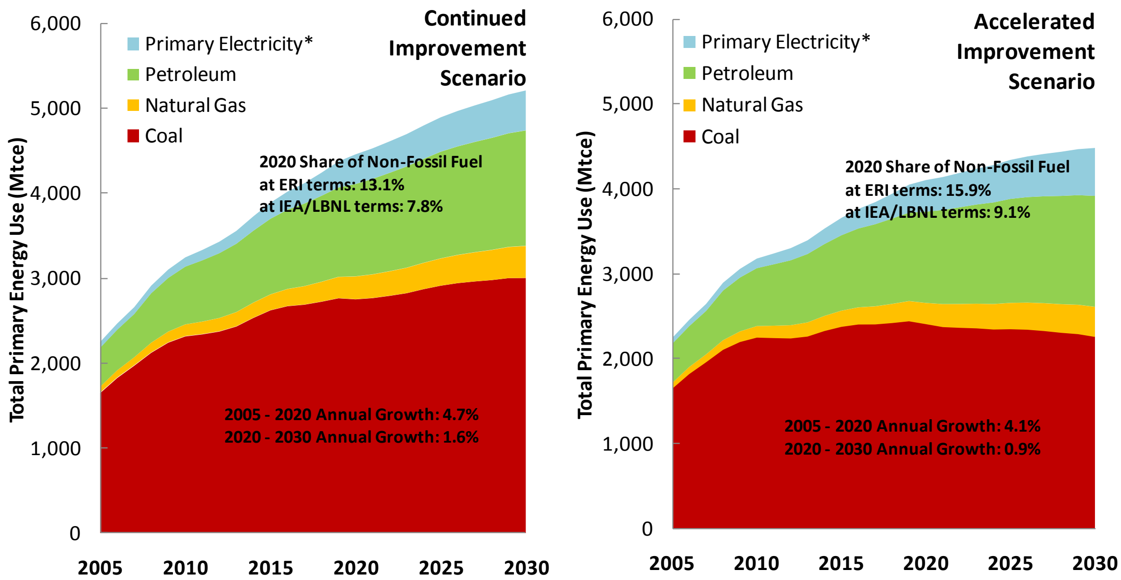
On the sectoral level, key drivers such as appliance ownership and saturation, floorspace, industrial production output and transport activity are also held constant between scenarios so as to capture only the effect of more efficient technologies or policies. These drivers are described in the sector subsections of the report.

2.3 Macro-level Results

2.3.1 CIS and AIS Primary Energy Outlook

Under CIS, total primary energy use will continue rising at an annual average rate of 4.7% from 2005 to 2020 before slowing to 1.6% after 2020 (Figure 7, left). This same trend is reflected in AIS, though the average annual rates of growth in primary energy are slower and approaching a plateau by 2030 (Figure 7, right). Total primary energy use will be reduced by 738 Mtce in 2030 if the more aggressive trajectory of AIS was followed rather than CIS. Cumulatively from 2005 to 2030, this would translate into energy reductions of over 8.2 billion tonnes of coal equivalent.

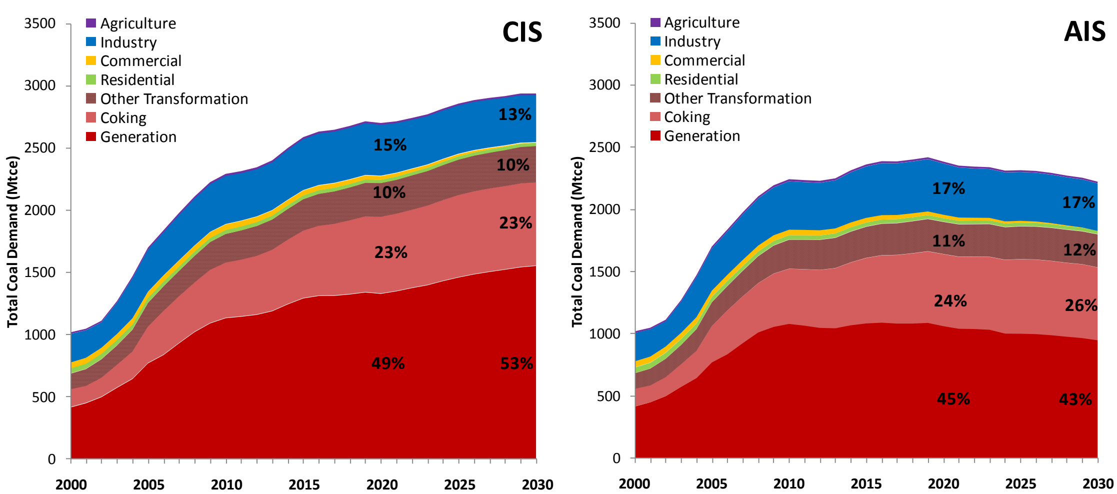
Figure 7 Total Primary Energy Demand Outlook by Fuel, CIS and AIS



Note: Primary Electricity includes hydropower, wind, solar and other renewables at calorific equivalent for conversion.

Coal continues to be the primary fuel consumed, though the shares of petroleum and non-fossil fuel electricity rise under both scenarios while natural gas share remains relatively flat. As seen by the shifting end-uses of coal demand, the decline in coal shares is actually the result of a decarbonized power supply, particularly under AIS. In fact, the transformation sector is responsible for the vast majority of coal end-uses, with industrial end-use flat or declining. Of the transformation end-uses, coal demand for generation flattens and declines as a share of total coal demand under accelerated decarbonization in AIS.

Figure 8 Coal Demand by End-use, CIS and AIS



Thus, depending on the convention used for converting non-fossil fuel electricity to nominal primary energy, China could meet its 2020 non-fossil fuel energy target of 15% only under AIS if ERI's conversion factors are used. In particular, ERI differs from IEA and LBNL in using fossil-fuel power generation equivalent for converting all non-fossil fuel electricity to primary energy. In other words, the nominal efficiency of nuclear, hydropower and renewable energy sources are taken to be the same as efficiency of fossil fuel electricity generation at 33.2%. Comparing LBNL and ERI conversion factors, the primary energy content of hydropower, biomass, solar and wind is higher by a factor of 3.01 under ERI's conversion methodology (Table 6).

Table 6 Gross Heat Content Values for Non-Fossil Fuel Electricity Generation (kgce/kWh)

	LBNL	ERI	IEA	EIA
Wind Power	0.123	0.370	0.123	0.370
Nuclear Power	0.381	0.370	0.373	0.384
Geothermal	N/A	0.370	1.230	0.755
Hydropower	0.123	0.370	0.123	0.370
Biomass	0.123	0.370	N/A	0.370
Solar	0.123	0.370	0.123	0.370

Source: IEA and EIA values from American Physical Society. 2010. "Energy Units." Available at: http://www.aps.org/policy/reports/popa-reports/energy/units.cfm

This suggests that China's 2020 renewable energy target is very ambitious as it can only be met with aggressive decarbonization, efficiency improvements and road and rail transport electrification under a pace similar to that of AIS *and* only under given assumptions about the primary energy content of non-fossil fuel electricity generation.

In terms of sector-specific energy consumption trends, industry will remain the largest sectoral energy consumer through 2030, though its share declines slightly under both scenarios (Figure 9). Under CIS and AIS, transport and commercial sectors' share of total primary energy demand will increase, driven by the two fastest sectoral rates of annual growth in demand (Table 7).

Figure 9 Total Primary Energy Demand Outlook by Sector, CIS and AIS

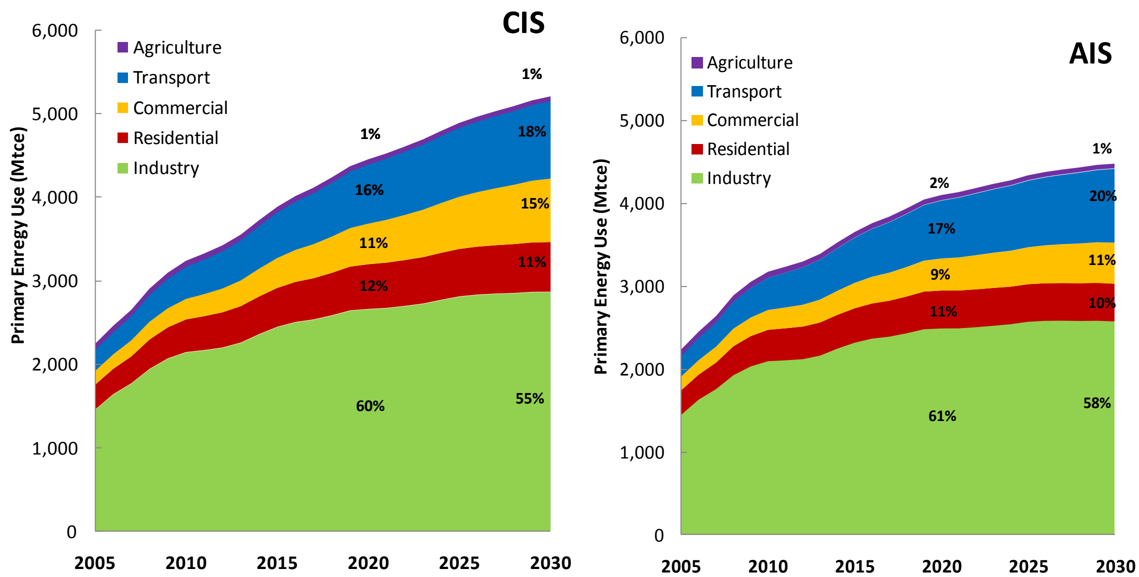
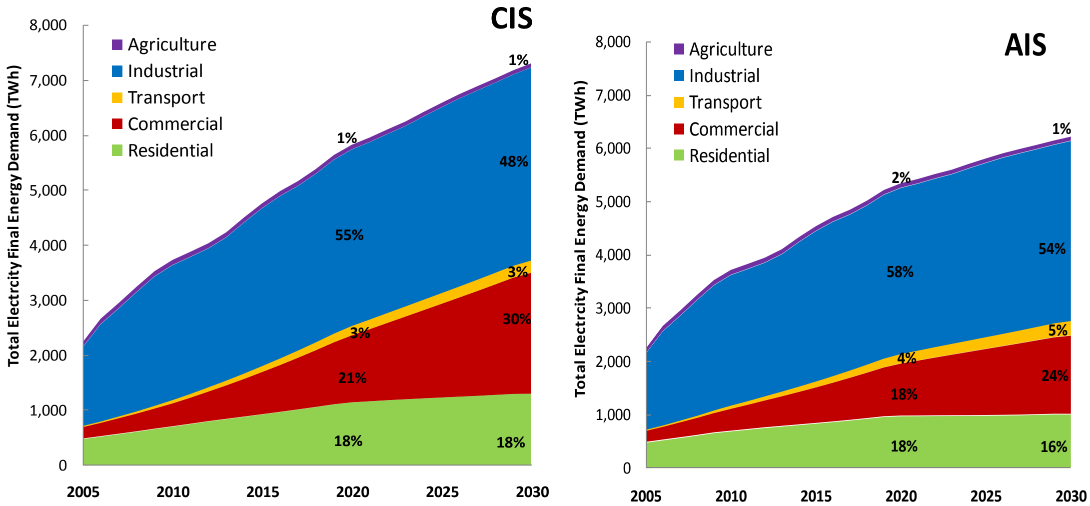


Table 7 Annual Average Growth Rates of Primary Energy Demand by Sector

	2005-30 AAGR	
	CIS	AIS
Residential	2.8%	1.7%
Commercial	6.3%	4.5%
Transport	5.3%	5.1%
Industrial	2.8%	2.3%
Agriculture	-1.1%	-1.3%
Total	3.4%	2.8%

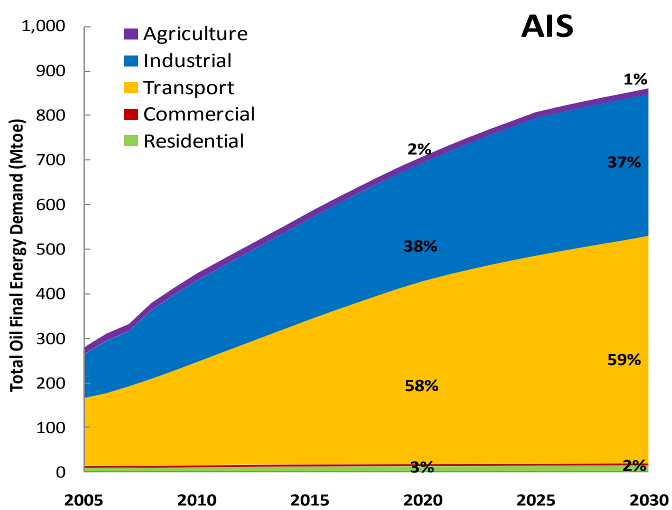
The commercial sector's emerging role as a major energy consumer is most evident in the rise of final electricity demand, where industry's declining share in electricity demand and relatively flat shares from other sectors are more than offset by the commercial sector's expanding share of total electricity demand (Figure 10). 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.

Figure 10 Total Electricity Final Demand by Sector, CIS and AIS



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 with growing shares. While the other sectors all have declining shares of total final oil demand, the transport sector will have growing shares from 58% in 2020 to 60% in 2030 under CIS and to a slightly lower 59% under AIS with greater transport electrification and efficiency improvements. However, transport sector's share of national oil demand is still lower than the U.S. transport share of 69%.

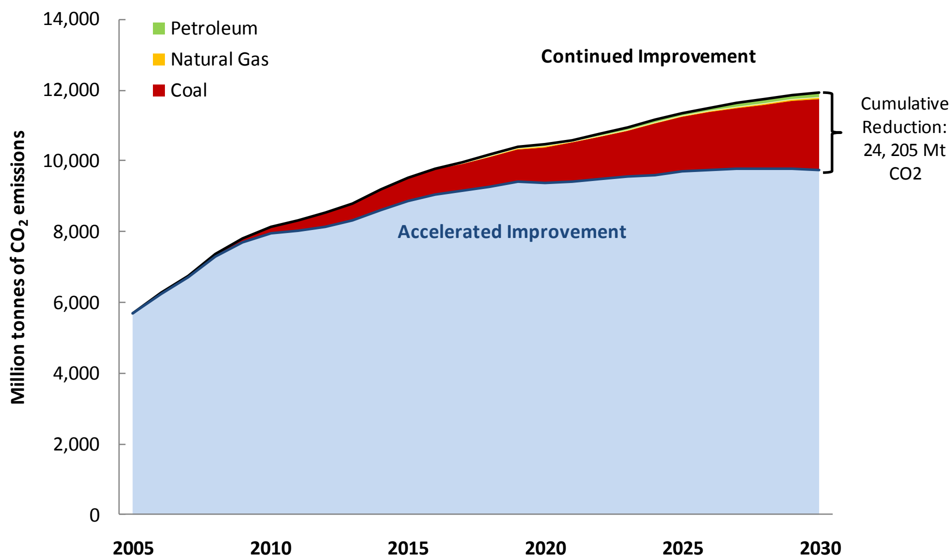
Figure 11 Total Oil Final Energy Demand by Sector, AIS



2.3.2 CIS and AIS CO_2 Emissions Outlook

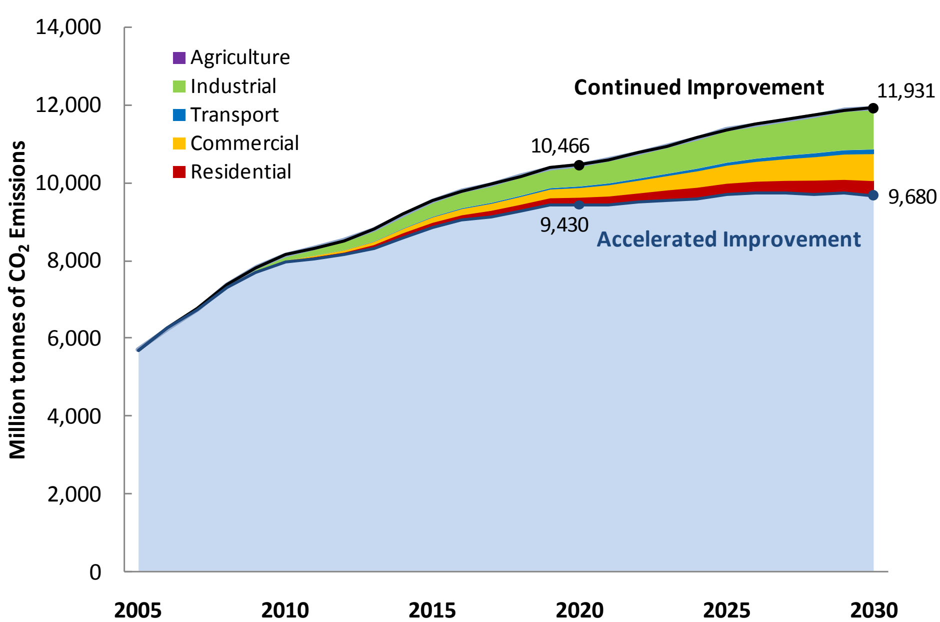
In terms of CO_2 emissions, the difference between CIS and AIS scenarios are greater in magnitude due to more accelerated decarbonization of the power supply under AIS. This is reflected in that the vast majority of CO_2 emission reduction under AIS will be from reductions in coal use, which is dominated by transformation sector (Figure 12). Under AIS, the cumulative reduction in CO_2 emissions amount to 86.5 billion tonnes of CO_2 emissions with 2030 annual reduction of 2192 million tonnes of CO_2 emissions.

Figure 12 Total CO_2 Emissions Outlook under CIS and AIS Scenarios by Fuel



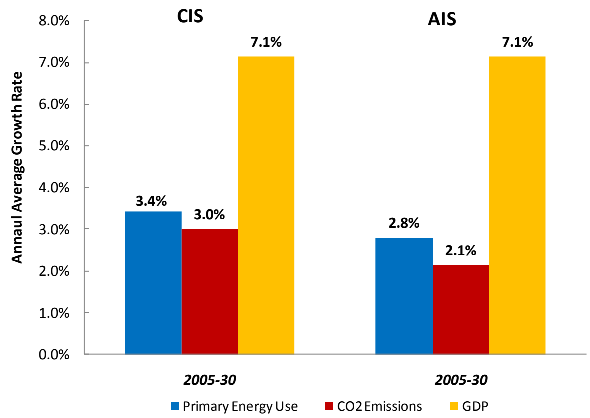
Most of the CO_2 emissions will be from the industrial, residential and commercial sectors, with industry having the largest sectoral share of savings at 46% in 2030 (Figure 13). However, residential and commercial buildings sector combined have the same magnitude of savings as industrial sector, suggesting that industry and buildings have the most important carbon mitigation potential. Despite electrification and fuel economy improvements, AIS CO_2 reduction in transport sector is still very small compared to the other sectors.

Figure 13 Total CO_2 Emissions Outlook under CIS and AIS Scenarios by Sector



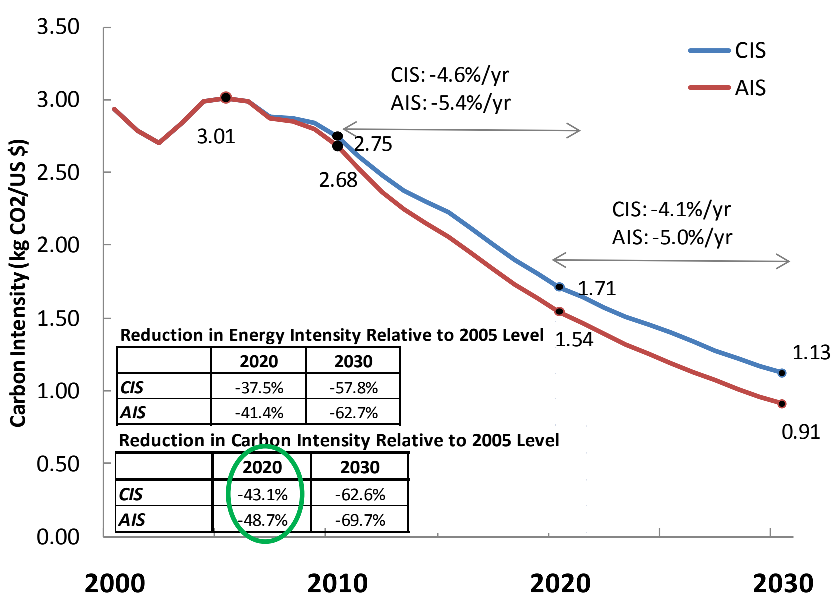
Overall, primary energy use will grow at an average annual rate of 3.4% under CIS and 2.8% under AIS, while carbon emissions will grow at slightly lower rates due to decarbonization (Figure 14). Energy and CO_2 emissions growth will be slower than GDP, which is expected to continue its rapid growth with an annual average rate of 7.1% through 2030.

Figure 14 Growth Rates in Energy, CO2 Emissions and GDP for CIS and AIS



Both energy and carbon intensity will therefore decline after 2005, with energy intensity falling from 1.24 kgce/US $ in 2005 to 0.52 kgce/US$ under CIS and 0.46 kgce/US$ under AIS in 2030. In carbon terms, intensity will fall from 3.01 kg CO_2/US $ in 2005 to 1.71 kg CO_2/US $ in 2020 under CIS and 1.54 kg CO_2/US $ in 2020 under AIS (Figure 15). By 2020, both scenarios will meet China's carbon intensity reduction goal of 40-45% by 2020 with AIS even surpassing the goal with a 48% carbon intensity reduction.

Figure 15 Carbon Intensity Trends under CIS and AIS



To understand the basis for these macro level results, more in-depth analysis of the industrial, transport and power subsector assumptions, drivers and scenarios are presented in the following sections.

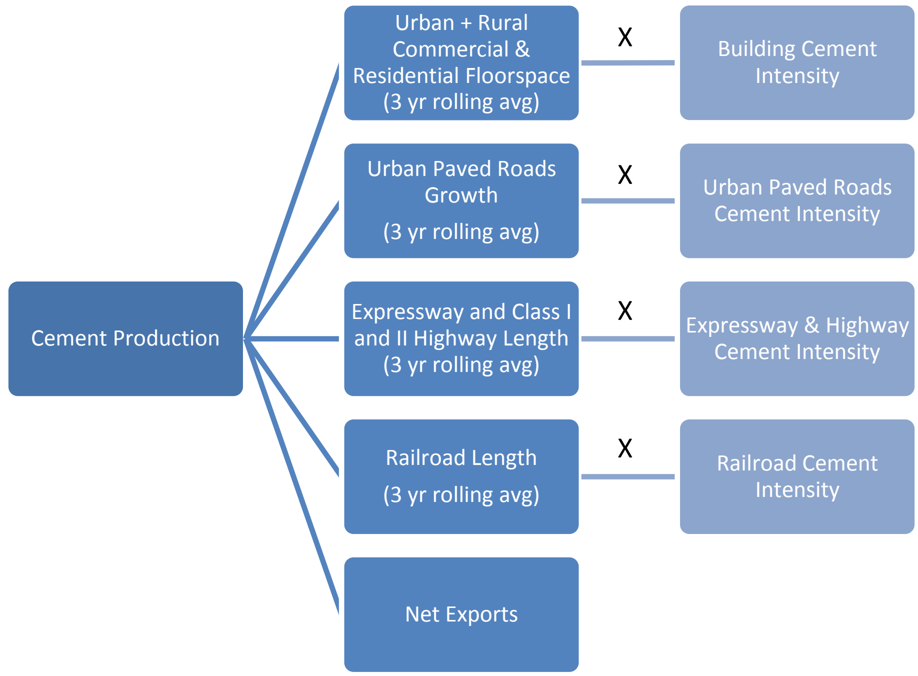
3. Industrial Sector Analysis

For energy-intensive industrial subsectors such as cement and steel, projections of industrial output to 2030 were modeled using major physical driver relationships to built environment and infrastructure requirements for growing urban population. Scenario analysis was then conducted using projected process efficiency requirements and technology shift for material production. The major industrial subsectors of cement and iron and steel are highlighted below to illustrate the methodology for analyzing energy and emission paths of the industrial sector.

3.1 Cement

As the world's leading cement producer, exporter and domestic consumer, the cement industry has remained one of the key industrial subsectors in the Chinese economy. Over the next two decades as China begins to rein in its exports as it transitions into a developed, service-oriented economy, domestic demand will become the most important driver for cement production. In particular, cement demand will be closely linked to construction demand from urbanization and infrastructure development. This has already been exemplified in the ramping up of cement production over the last few years with the surge in infrastructure investment in paved roads and highways and urban housing boom. Thus, in modeling the cement sector, the key drivers for production are new urban and rural commercial and residential construction, urban paved roads, expressways and Class I and II highways (which are made of cement), railways and net exports of cement (Figure 16). This methodology takes into account growing commercial and residential building construction demand as well as targeted expansion of urban paved areas, highways and rail track.

Figure 16 Model Framework for Chinese Cement Production



Building construction is driven by rising per capita residential space and commercial space per tertiary employee, while railway construction is projected according to stated development goals. Based on extensive literature research of Chinese trends and the past experience of developed countries such as Japan and the United Kingdom, paved roads and highways are driven by rising vehicles per kilometer of road and per capita area of paved roads to 2030. For all non-trade drivers, a three year rolling average is used as construction projects often last more than a year and there may be overlap in data reported for projects in progress and completed projects. The specific assumptions for each of the five key drivers are detailed in Table 8.

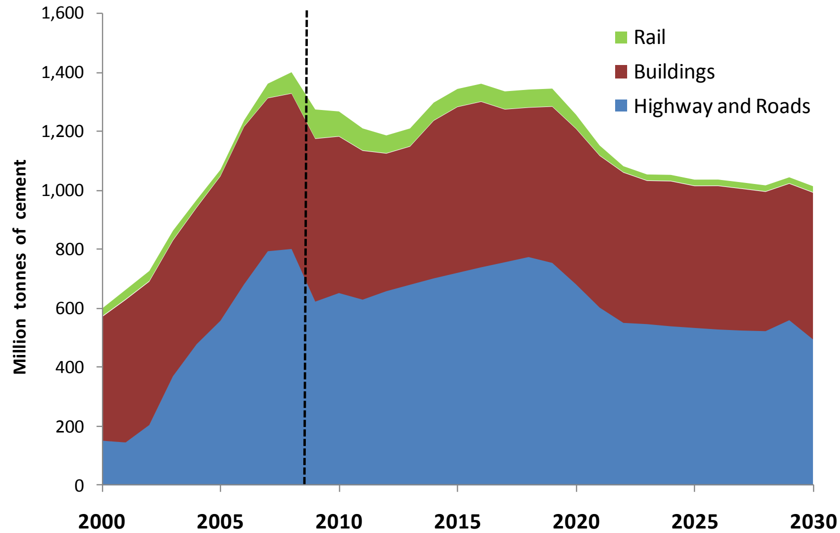
Table 8 Specific Assumptions for Modeling Cement Sector

		Continued Improvement Scenario (CIS)	**Accelerated Improvement Scenario (AIS)**
Production Assumptions	Urbanization	70% in 2030	Same as CIS
	Per-capita building area	24 m2 per capita in 2005; 39 m2 per capita in 2030	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, using projected growing length to ~280 vehicles/km by 2030 based on Japan's experience for highways. Projected paved road area based on doubling of current level to Japan and UK levels of 14.92 m2/person by 2030.	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 2030	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	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
	Fuels	Steady decline from 2005 coal share of 85% to 70% by 2030	Same as CIS

Based on the model assumptions, production is expected to have peaked in 2009 at 1.4 billion tonnes due to the recent infrastructure boom from massive public investment as part of the recent economic stimulus package (Figure 17). Although cement demand is expected to remain above 1 billion tonnes over the next ten years with continued urbanization and infrastructure development, particularly in road and rail networks, production will likely taper off after 2020. In 2030, the bulk of domestic demand for cement will be from buildings and highways and roads with each demanding a 49% share of total cement produced.

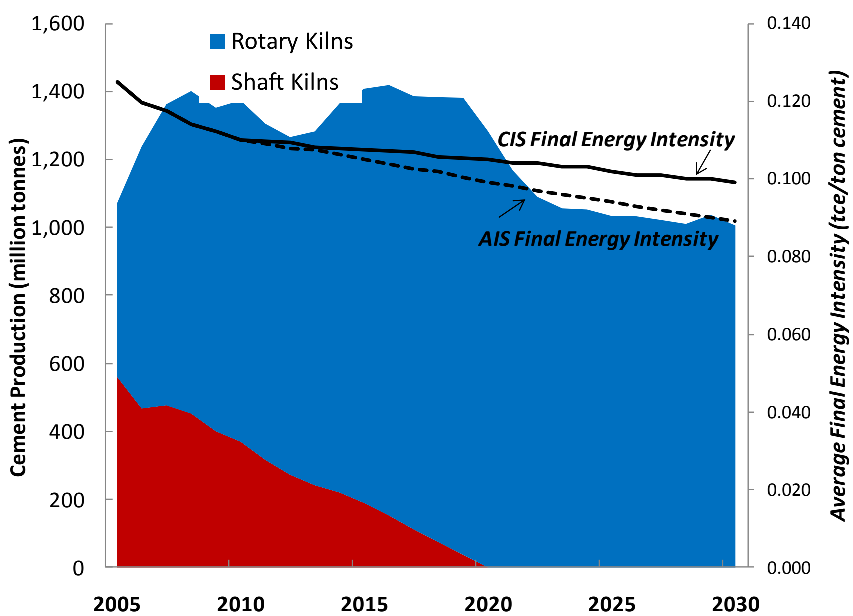
Figure 17 Historical and Projected Cement Production by End-Use, 2000 - 2030



Note: Net exports are not shown due to small magnitude (14 million tonnes from 2009 onwards). Production prior to 2009 is based on a historical total, with estimated breakdowns for end-use demands. Historical data from NBS, 2010.

In terms of modeling the cement industry's energy consumption, the recent technology and efficiency trends of shutting down plants with backwards production lines and shift away from inefficient vertical kiln technology are considered. In particular, these trends towards greater efficiency in cement production are expected to continue with shaft kilns phased out by 2020 in both CIS and AIS as part of China's efforts to reduce its energy intensity. AIS further differs from CIS in that the 2030 final energy intensity of rotary kilns will be slightly higher as it achieves the current world best practice efficiency level five years earlier (Figure 18).

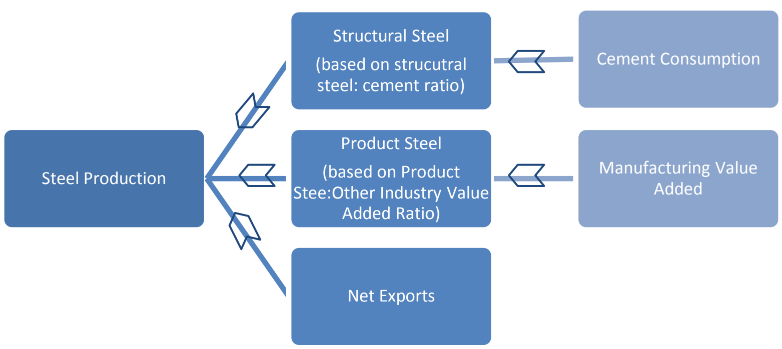
Figure 18 Technology and Energy Intensity Trends in Cement Production



3.2 Iron and Steel

As another leading industry, the iron and steel industry has made China the dominant global producer and net exporter in recent years. Similar to cement, iron and steel production is also largely driven by infrastructural and construction demand (i.e., structural steel) and product steel used for final consumption (Figure 19). In this model, structural steel has the same drivers as cement consumption and is therefore projected using a ratio to cement consumption of 0.17 kg steel per kg of cement in 2007 to 0.25 kg steel per kg of cement in 2025. For product steel, a ratio to other industry value added of 0.19 in 2007 to 0.22 ton of product steel per million $ other industry value added after 2025 is used. Net exports are also assumed to be constant at the 2008 level of 31 million tonnes.

Figure 19 Model Framework for Steel Production



Note: steel production is calculated as the sum of structural steel for construction, product steel, and net steel exports.

In projecting energy consumption of steelmaking, a continuous shift towards the more efficient electric arc furnace is expected with its share rising from 12% currently to 29% by 2030 (Figure 20). The final energy intensity of steel production is also expected to decline from 668 kgce per ton steel in 2008 to 365 kgce/ton in CIS and to 361 kgce/ton in AIS due to the growing share of recycled steel and an increasingly more efficient technology mix (Figure 21).

Figure 20 Steel Production Technology Trends in Scenarios

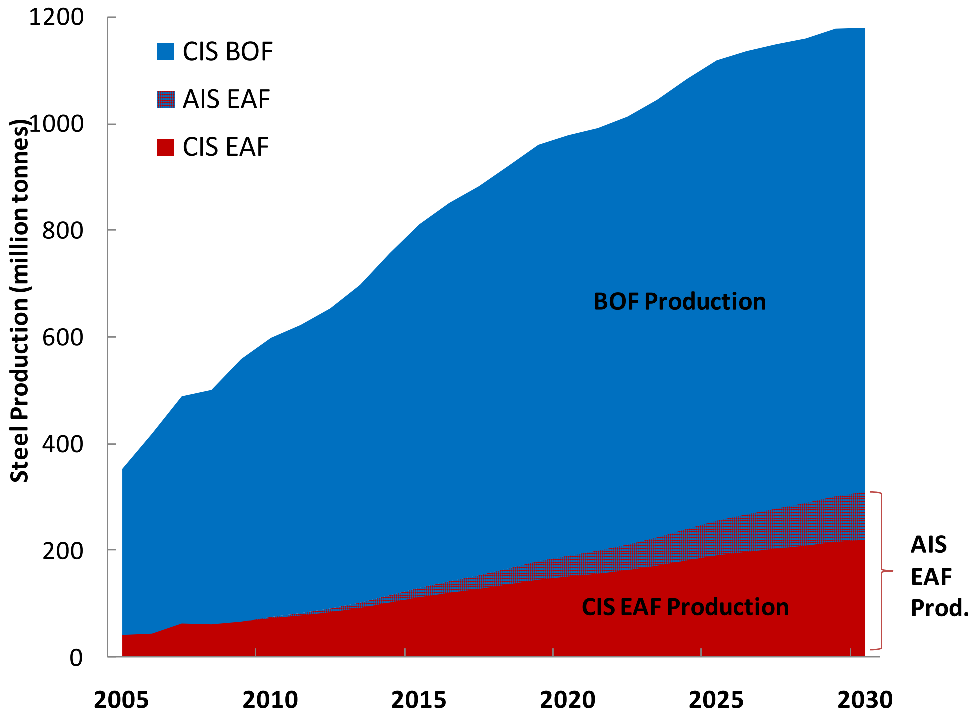
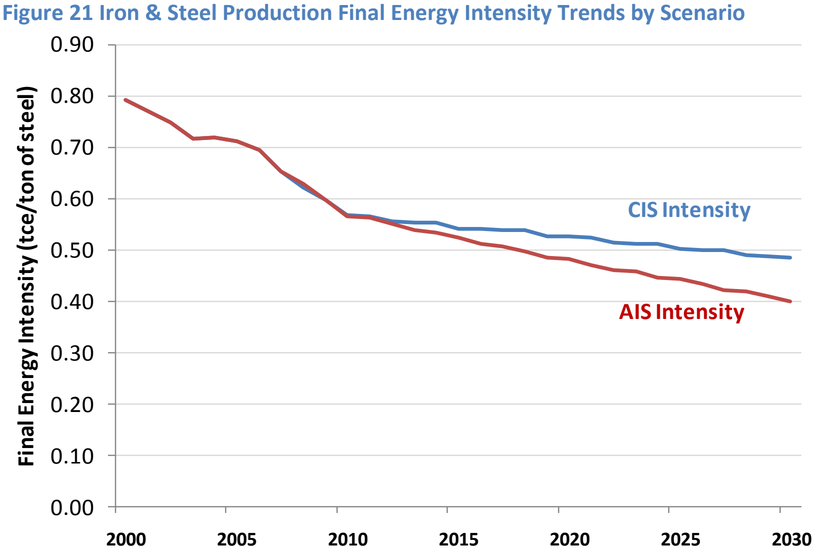


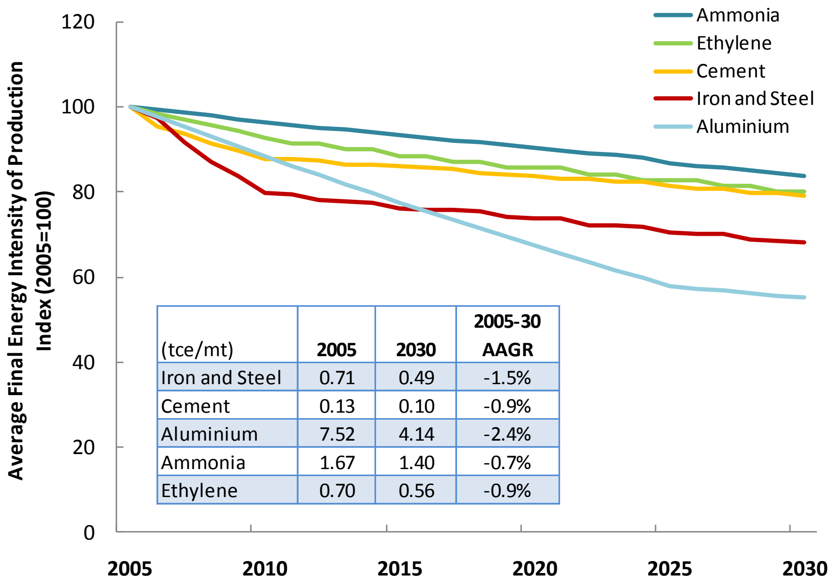
Figure 21 Iron & Steel Production Final Energy Intensity Trends by Scenario



3.3 Scenario Analysis and Outlook

As exemplified by the cement and iron and steel modeling methodology, CIS and AIS are the two key scenarios for analyzing the industrial sector and differ in the assumed pace of process efficiency improvements in terms of different resulting average energy intensity of material production. Under CIS, existing and planned policies as well as expected technology and fuel switching to meet government targets are taken into consideration. As a result, the aggregated energy intensity in all sectors will decrease over time with the most reduction potential in the iron & steel sector, followed by the aluminum and cement sectors (Figure 22).

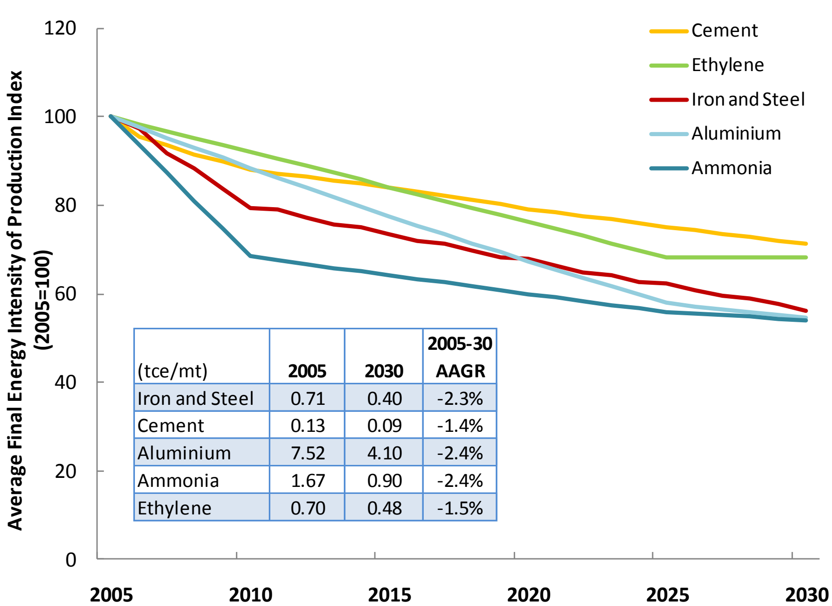
Figure 22 CIS Trends in Industrial Final Energy Intensity, 2005 - 2030



(tce/mt)	2005	2030	2005-30 AAGR
Iron and Steel	0.71	0.49	-1.5%
Cement	0.13	0.10	-0.9%
Aluminium	7.52	4.14	-2.4%
Ammonia	1.67	1.40	-0.7%
Ethylene	0.70	0.56	-0.9%

Under AIS, more rapid adoption of efficient technologies are expected to lower final energy intensities across the major industrial sectors more aggressively. This results in a faster annual rate of decline in energy intensity between 2005 and 2030, ranging from additional intensity reductions of -2.3% per year for iron and steel production to -1.7% per year for ammonia production (Figure 23).

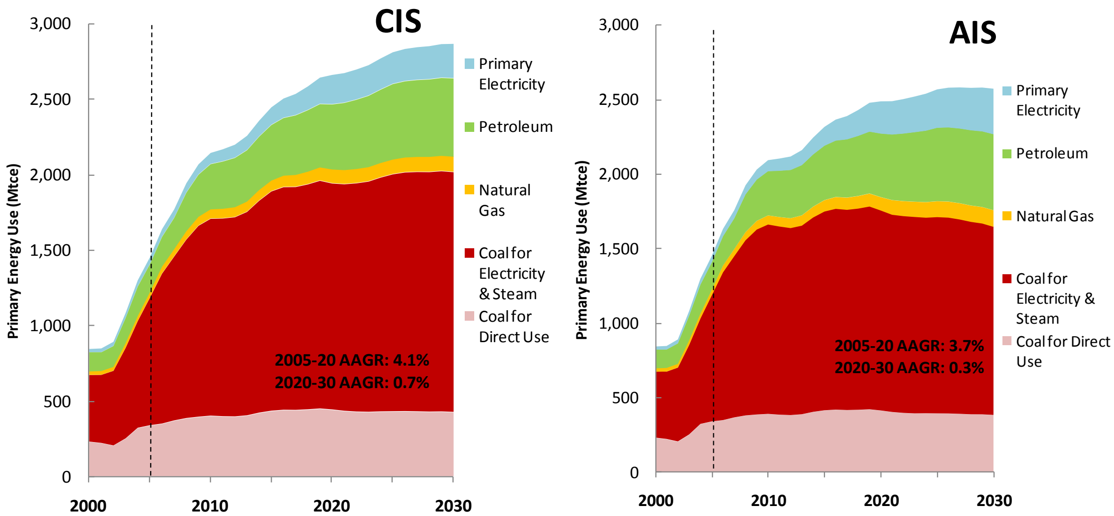
Figure 23 AIS Trends in Industrial Final Energy Intensity, 2005 - 2030



(tce/mt)	2005	2030	2005-30 AAGR
Iron and Steel	0.71	0.40	-2.3%
Cement	0.13	0.09	-1.4%
Aluminium	7.52	4.10	-2.4%
Ammonia	1.67	0.90	-2.4%
Ethylene	0.70	0.48	-1.5%

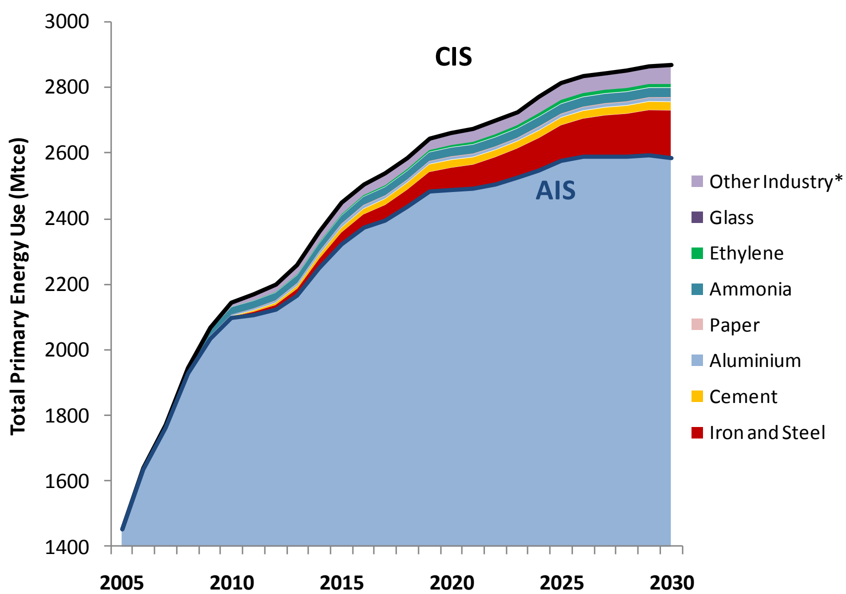
Given the production levels and energy intensity trends under both scenarios, the industrial sector will be responsible for 2867 Mtce of primary energy demand under CIS and 2577 Mtce under AIS. Under both scenarios, coal for electricity and steam is the predominant fuel consumed, followed by petroleum and coal for direct use (Figure 24).

Figure 24 Industrial Primary Energy use by Fuel, CIS and AIS



As a result of the additional reductions in final energy intensity under AIS, the industrial subsector will achieve primary energy savings of 290 Mtce by 2030. Most of the energy savings under AIS will be from improved efficiency in the iron and steel sector and cement sectors (Figure 25).

Figure 25 Industrial Primary Energy Use by Subsector Savings under AIS



* Note: Other Industry includes manufacturing, chemicals, light industry and all other small industrial subsectors.

4. Transport Sector Analysis

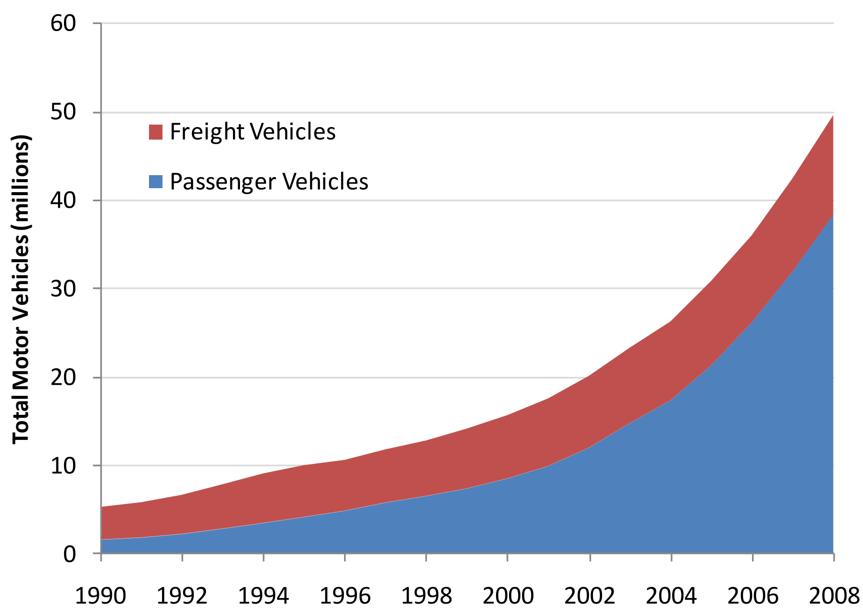
4.1 Major Transport Sector Trends

4.1.1 Road Transport

As the Chinese economy has undergone rapid growth in the last two decades, its transport sector has also experienced astounding growth and expansion. Rising incomes have bolstered private demand for cars and passenger travel, while domestic demand for inputs to industrial activity and increased trade have contributed to continuous expansion in freight transport. In China, motor vehicles are classified into four classes of trucks, four classes of buses, three groups of cars (private, fleet and taxis) and motorcycles. More details on the classification are given in the sections below.

In road transport, both the passenger and freight motor vehicle population have grown exponentially from 1.6 and 3.6 million in 1990 to 38.4 and 11.3 million in 2008, respectively. Passenger vehicle population not including motorcycles have grown at an astounding annual average growth rate of 22% while the freight truck fleet has grown at an average of 6% annually.

Figure 26 Historical Growth in Motor Vehicle Population, 1990 - 2008

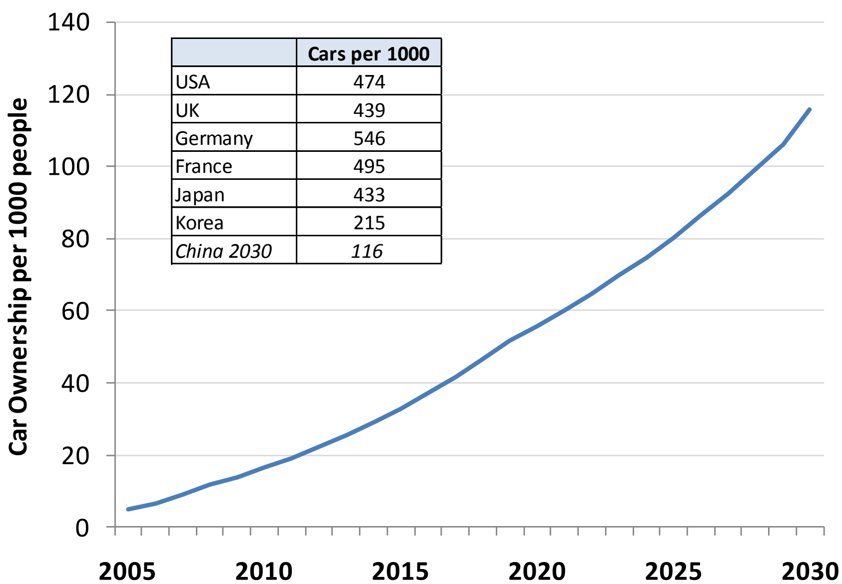


Source: NBS, China Statistical Yearbook, various years.

4.1.1.1 Passenger Road Transport Trends

With private vehicle ownership strictly controlled by the government prior to economic reforms, China's vehicle ownership rate of 5.4 vehicles per 1000 was well below the world average of 110 vehicles per 1000 even in 1990.[8] As a result, economic growth and loosening of controls on vehicle ownership have stimulated strong consumer demand for private vehicle ownership as evidenced by a 120-fold jump in ownership of private motor vehicles since 1990. The significance of the magnitude of private transport demand is further reflected in expanding share of passenger vehicles relative to freight vehicles and the share of private vehicles. The passenger share of total vehicle population rises from a 31% share in 1990 to overtake freight share with 54% by 2000 and further dominates with a 77% share in 2008. Similarly, ownership of private vehicles also grows as a share of civil vehicle ownership from a mere 15% in 1990 to 69% by 2008. Despite this significant growth, China's vehicle ownership rate remains relatively low and implies great potential for future vehicle population growth. For example, the 2007 rate of only 30 vehicles per 1000 was still much lower than the world average and pales in comparison to that in developed countries such as Japan, Germany and the U.S.

Figure 27 Projected Car Ownership Rates, 2005-2030



Source: International data from World Bank Development Indicators

Despite growing car ownership, public buses remain a common mode of transport for urban residents in large cities due to lower costs and relative convenience. Buses are classified according to their vehicle length and include heavy-duty bus (HDB, >10 m), medium-duty bus (MDB, 7-10m), light-duty bus (LDB, 3.5-7m) and light duty bus (MB, <3.5 m). In 2007, public transport comprised of 34.5% and 26.5% of total passenger travel in Beijing and Shanghai, respectively.[9] As private vehicle population continues to grow and road infrastructure struggles to keep pace, traffic congestion will likely sustain demand for public transport options. In fact,

[8] Ou and Zhang. 2010a. "Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions." *Energy Policy* 38 (8): 3943-3956

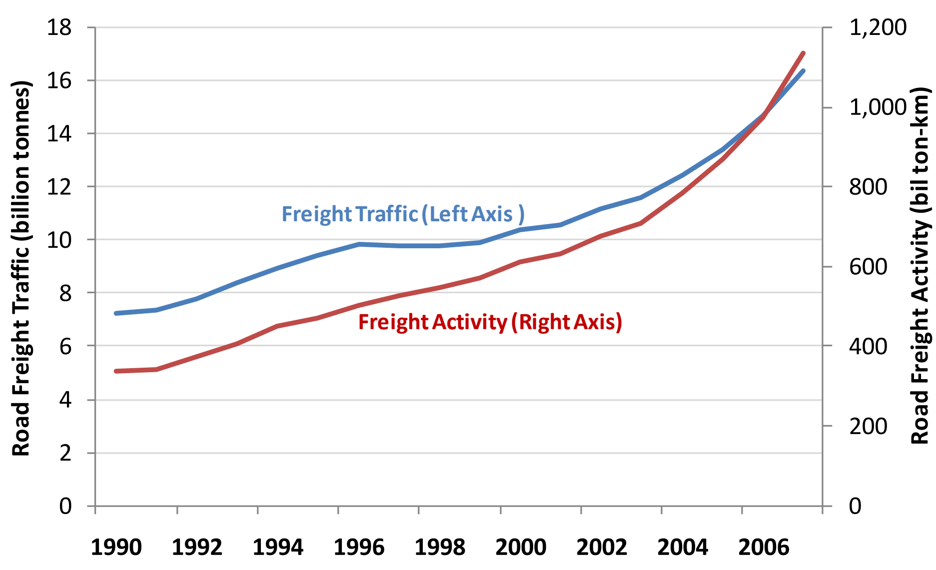
[9] Feng, et. al. 2009. "Thinking and Suggestions for Public Transport Development in Chinese Cities." Available online: http://www.vref.se/search.4.46d8812211a06b927e7800021054.html?query=beijing

major cities have already started providing financial incentives such as reduced bus fares in Beijing and greater investment in public transport infrastructure to improve its quality of service and appeal in Shanghai's recent action plan to prioritize public transport.[10] Therefore, road transport by public buses will remain an important aspect of passenger road transport, with historically popular light-duty and mini buses with under 20 seats continuing to hold vast majority shares of the fleet.

4.1.1.2 Freight Road Transport Trends

With greater public investment in road infrastructure and continued expansion of the highway and expressway system, the use of trucks for freight transport have increased along with passenger transport. Since 1990, freight traffic on highways has grown at an average annual rate of 5.3% from 7.24 billion to 19.17 billion tons in 2008 (Figure 28). Over the last two decades, truck transport has remained the predominant mode of transport for freight traffic with a consistent share of around 75% of total freight traffic. Besides increased freight traffic, the average distance of freight road transport has also risen from 46 km in 1990 to 171 km in 2008. Subsequently, freight activity by road transport has grown at an annual average rate of 13% to 3.29 trillion ton-km.

Figure 28 Road Freight Traffic and Activity, 1990 - 2007



Source: NBS, various years.

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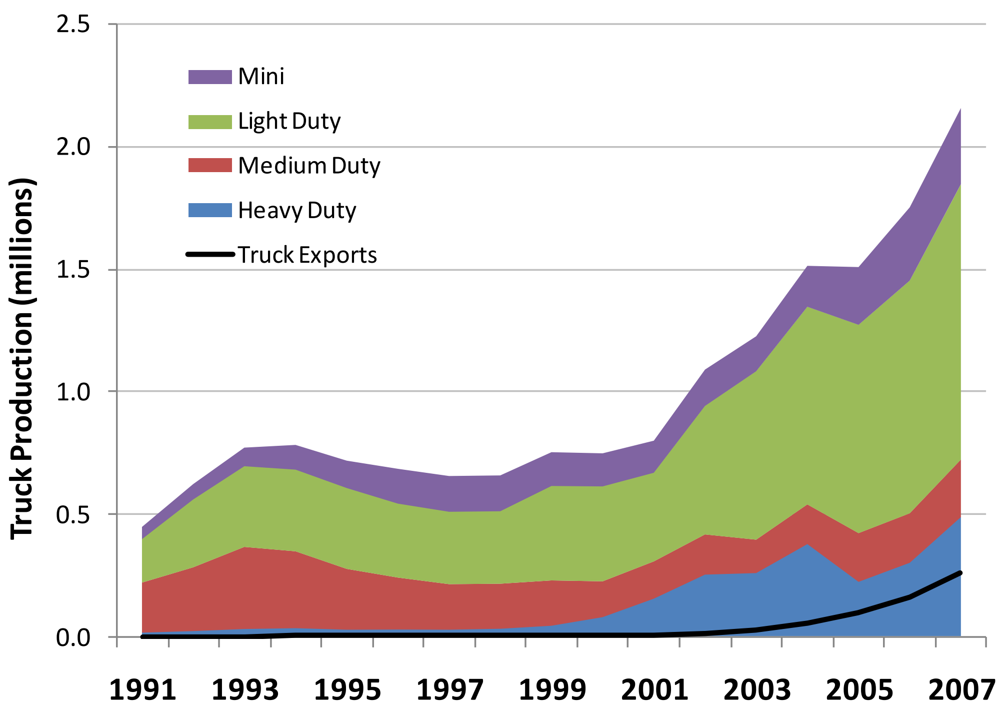
[10] See World Resources Institute. 2007. "Beijing Gives Priority to Public Transportation", http://www.worldwatch.org/node/4895 and Shanghai Government Legislative Information Network, 2007, "Notice of the Shanghai Municipal People's Government on Approving and Transmitting the 'Suggestions on Giving Priority to the Development of City Public Transport in Shanghai,'" http://www.shanghailaw.gov.cn/fzbEnglish/page/normative1820.htm

The road freight transport fleet consists of heavy-duty trucks (HDT) with gross vehicle weight (GVW) of greater than 14 tonnes, medium-duty trucks (MDT) with GVW between 6 to 14 tonnes, light-duty trucks (LDT) with GVW between 1.8 and 6 tonnes and mini trucks (MT) with GVW of less than 1.8 tonnes. Within the truck fleet, medium and light duty trucks have historically dominated with combined production shares of 75-85% prior to 2000.[11] In recent years, however, greater urban infrastructure construction, coal and oil transport needs have increased the demand for heavy-duty trucks that can carry a greater load over longer distances with significant jumps in production shares (Figure 29) and annual average growth rate of 29% from 2000 to 2007. With changing supply-chain demands for logistics such as just-in-time deliveries, subsequently smaller truck loads have led to significant growth in light-duty truck production and use.[12] Specifically, light-duty trucks have increased to over half of all trucks produced with production growing at an average annual rate of 16% since 2000. Mini and medium-trucks have also grown, but at lower rates and are smaller shares of the truck fleet.

Figure 29 Truck Production by Size, 1991 - 2007



Source: China Automotive Technology & Research Center (CATARC) and Chinese Automotive Manufacturers Association (CAAM), 2008, China Automotive Industry Yearbook 2008 (in Chinese).

[11] Since China has been a net exporter of trucks since the mid-1990s, truck production statistics can serve as a good approximation of fleet composition in the absence of fleet stock data.

[12] Ou, X. and X. Zhang. 2010b. Supporting information for "Scenario Analysis on Alternative Fuel/Vehicle for china's Future Road Transport: Energy demand and GHG emissions." *Energy Policy* 38 (8): 3943-3956.

4.1.1.3 Motor Vehicle Technology Trends

Passenger Cars

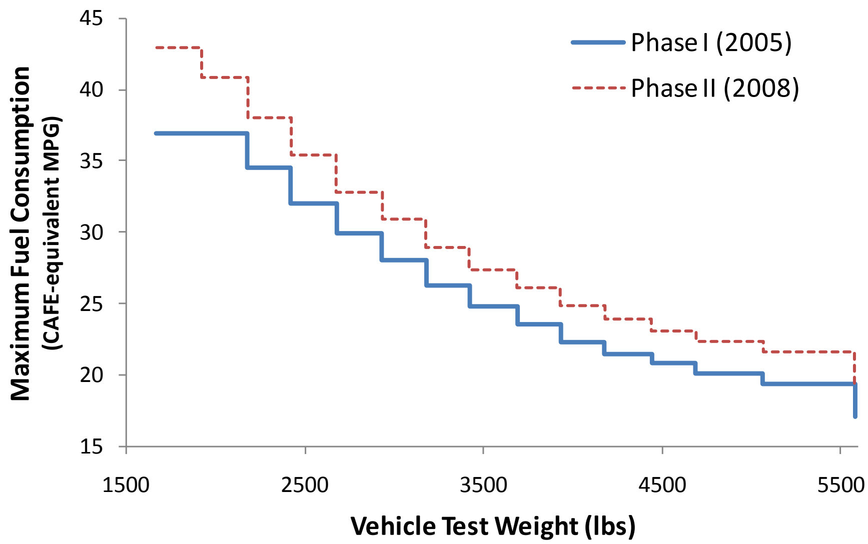
As private car ownership rises amongst Chinese residents, there has been a shift towards cars with slightly larger engines as cars with engine sizes between 1 to 1.6 liters have become increasingly popular in the last decade, holding 48% market share in 2007. The 1.6 to 2.0 liter engine size segment of the car market has also exhibited relatively strong growth, accompanied by steep decline in the share of the smallest engine size of <1.0 liters that had dominated market shares prior to 2002.[13] In terms of fuel share, China is quite similar to the U.S. in that the car market is almost all dominated by gasoline cars with historical shares of between 98 to 100% with only 1% share for diesel after 2006 and 1% share for compressed natural gas cars.[14] The vehicle kilometers traveled per passenger car is also higher in the U.S. than China, with a fleet average of almost 19,000 vehicle km traveled in the U.S. compared to China's average of only 9000 vehicle km per private car and 18,000 vehicle km per office car.[15] Rising car ownership and use will therefore have significant implications for China's gasoline demand.

Fuel Economy Standards

In recognizing the sizable impact passenger cars already have and will continue to have on national gasoline demand, the central government have taken steps to improve the fuel economy of China's car fleet. Although international auto manufacturers have historically played an important role in shaping China's automobile industry through joint ventures, Chinese automobiles have actually been very inefficient due to inadequate technology transfer of advanced engine technology. Prior to the late 1990s, for instance, only nine car models were sold in China with ten to fifteen year old technologies.[16] Currently, however, there are over 40 domestic auto manufacturers and 13 joint ventures, with multiple car models offered by each manufacturer. To help the Chinese fleet reach fuel economy levels more comparable to other leading economies, China adopted its first national vehicle fuel economy standard GB 19578-2004 "Limits of Fuel Consumption for Passenger Cars" (乘用车燃料消耗量限值) in 2004. Phase I of the national standard was implemented on July 1st 2005 for new car models while Phase II was implemented for new models on January 1st, 2008.

[13] Oliver, H.H. et. al. 2009. "China's Fuel Economy Standards for Passenger Vehicles: Rationale, Policy Process and Impacts." *Energy Policy* 37 (11): 4720-4729.
[14] Ou and Zhang. 2010b.
[15] U.S. data from U.S. Department of Transportation. 2010. *National Transportation Statistics 2010.* Available at: http://www.bts.gov/publications/national_transportation_statistics/
[16] Oliver, et. al., 2009.

Figure 30 China's Fuel Economy Standards for Passenger Vehicles in CAFE-equivalent Units



Source: Graphic reproduced based on data from An, F. and A., Sauer. 2004.

Table 9 Maximum Limits for Fuel Consumption in Liters/100 km for Chinese Passenger Vehicles

Weight (lbs)	Phase I (2005)	Phase II (2008)
≤ 1667	7.2	6.2
≤ 1922	7.2	6.5
≤ 2178	7.7	7
≤ 2422	8.3	7.5
≤ 2678	8.9	8.1
≤ 2933	9.5	8.6
≤ 3178	10.1	9.2
≤ 3422	10.7	9.7
≤ 3689	11.3	10.2
≤ 3933	11.9	10.7
≤ 4178	12.4	11.1
≤ 4444	12.8	11.5
≤ 4689	13.2	11.9
≤ 5066	13.7	12.3
≤ 5578	14.6	13.1
> 5578	15.5	13.9

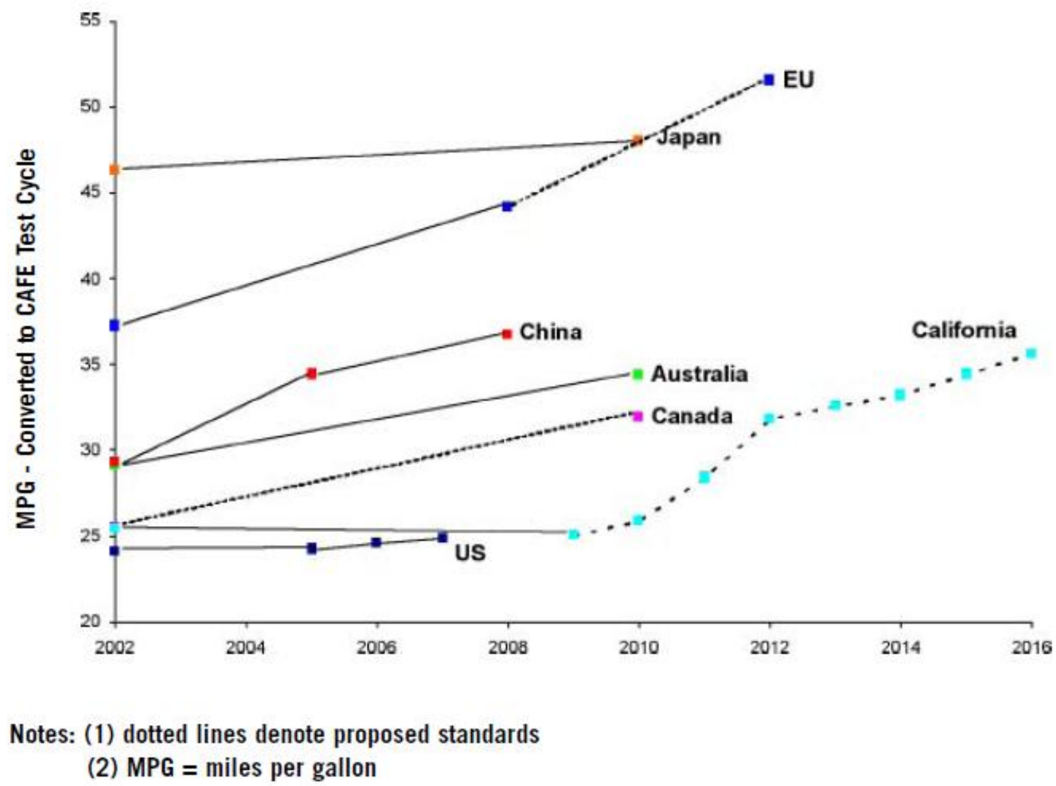
Source: An and Sauer, 2004.

Unlike the sales-weighted average fuel economy standards in the U.S., China adopted weight-based fuel consumption limits for 16 different weight classes for vehicles with gross vehicle weight ranging from 750 to 3500 kg. Within each weight class, there is a sub-category with a 6%

exemption of the limit for "vehicles with special structures" of automatic transmission, three or more rows of seats are sports utility vehicles. China's motivation for adopting weight-based standard rose primarily out of concern for the fragmented automobile industry and to provide all manufacturers with sufficient incentive to produce smaller vehicles as the standards become relatively more stringent in the heavier vehicle classes than in lighter weight classes.[17] The specific limits for each weight class are described in Figure 30 and Table 9. China's fuel economy standard is also unique in that there is no compliance flexibility as every individual model produced by a manufacturer must meet the limit for that specific category. Imported vehicle models, however, are exempted from the fuel economy regulations.

Although China's fuel economy standards differ in structure from existing fuel economy standards, studies that have normalized international fuel economy standards into Corporate Average Fuel Economy (CAFE) standards show that Phase I of the Chinese standards is actually more stringent than US, Australia, South Korea, Canada but less than Japan, the European Union and California's proposed standards for (Figure 31).[18]

Figure 31 International Comparison of Fuel Economy Standards



Source: An, F. and A. Sauer. 2004.

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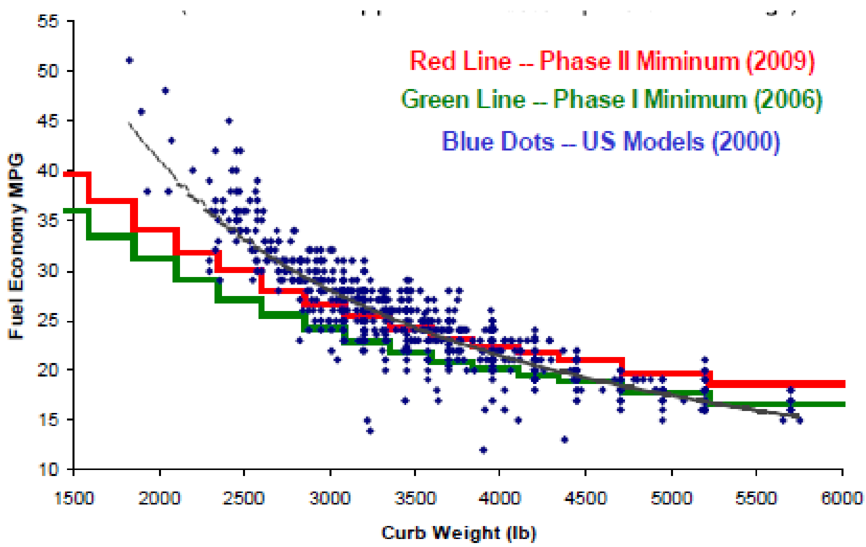
[17] An, F. and A., Sauer. 2004. "Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards around the World." Pew Center on Global Climate Change Report. Available at: http://www.pewclimate.org/global-warming-in-depth/all_reports/fuel_economy

[18] See Oliver et. al. 2009; Yan and Crookes. 2009. "Reduction potentials of energy demand and greenhouse gas emissions in China's road transport sector." *Energy Policy* 37: 658-668.

Relative to the U.S. 2000 fleet and standards, comparative studies have also shown that the Chinese standards appear loose on lighter vehicles as the U.S vehicles have higher MPG than both Phases I and II of the Chinese standards. However, for vehicles heavier than 3500 pounds, the Chinese standard appears more stringent as half of the 2000 U.S. models and most of the SUVs would fail to meet Chinese Phase I equivalent standards.[19]

Figure 32 Chinese Fuel Economy Standards Compared to U.S. 2000 Fleet



Source: An, F. 2006.

In the lapse of a few years, studies have shown that China's fuel economy standards for cars have achieved impressive results in terms of overall compliance and fuel economy improvements. In 2002, 40% of the normal light duty passenger vehicles in the Chinese market failed to meet the Phase I requirements and 82% exceeded Phase II limits. By 2006, however, there have been significant improvements as all normal cars met the Phase I standard and two-thirds even met Phase II standards ahead of time, with an even more impressive 75% share of special structure vehicles already meeting Phase II fuel requirements.[20] On average, the average fuel consumption for normal vehicles were reduced by 7 to 17% across all weight classes and special structure vehicles saw reductions of 10 to 20%.[21]

Besides fuel economy standards, other policies have played important roles in reducing fuel consumption of private vehicles but recent market trends suggest that more policies and improvements in technology are needed to achieve maximum reduction in automobile gasoline

[19] An, F. 2006. "The Chinese Fuel Economy Standards for Passenger Vehicles: How it Works, the Targets, the Effects." *Proceedings from 2006 European-Asian Policy Workshop on Cars, Climate and Energy*: Berlin, Germany.
[20] Oliver, et .al. 2009.
[21] Ibid., 2009.

and diesel consumption. On one hand, limits to future fuel savings include a 10% increase in the average curb weight from 2002 to 2006 and rising popularity of automatic transmission cars. Newer vehicles also have higher specific power and can reach higher speeds at the expense of reduced fuel economy.[22] On the other hand, China has responded to these trends by adopting a mandatory label for passenger vehicles with consumer information on fuel economy in July 2008. Progressively more stringent vehicle manufacturing taxes based on engine displacement sizes were also implemented in September 2008 to limit the growth of larger vehicles with higher fuel consumption.

Developments in Electric Vehicle Technology

In addition to the policy approach to rising fuel economy, China is also pursuing alternative vehicle technologies that will allow it to shift away from relying on oil for road transportation. One of the most promising technologies is all electric vehicles (EVs), which have been actively pursued in China and abroad for the past few years. For China, EVs appear to be a more attractive option as there are several geographic and behavioral advantages for electrifying urban motor transport. First, the predominance of intra-city driving and results in shorter travel distance requirement between battery charges. Second, the commonly short commute at low speeds with traffic congestion also reduces consumer need for higher speeds and quick acceleration, which are often more limited in EVs. Third, social acceptance of EVs is likely to be higher with fourth-fifth of the automobile market composed of first-time buyers that are not yet accustomed to the greater power and range of gas and diesel cars.[23]

In recognizing the potential role of EVs, the government has launched wide-ranging efforts to promote EV development by targeting manufacturers and consumers alike. On the manufacturing side, a $10 billion RMB program was set up to help industry with automotive research and innovation along with a goal of raising annual production capacity to 500,000 hybrid or electric cars and buses by the end of 2011, a significant rise from 2008 production levels of 2100 vehicles.[24] In the last two year, BYD Auto, a former battery technology company, has emerged as a leading manufacturer of hybrid and electric cars with the successful launch of their plug-in hybrid, F3DM (F3 Dual Mode) compact sedan model for fleet sales in December 2008. In 2010, BYD Auto expanded its sales to the general public with the F3DM available for purchase at a price of over $24,000 in Shenzhen in Southern China. BYD has also started producing e6, an EV promised to deliver 0 to 60 miles per hour in 14 seconds with top seed of 87 miles per hour and 200 miles driving range between charges through its proprietary lithium ion

[22] Oliver, et. al., 2009.
[23] Bradsher, K. 2009. "China Vies to be World's Leader in Electric Cars." *The New York Times*. April 2, 2009.
[24] Bradsher, 2009.

phosphate battery.[25] However, BYD scaled back its plans to mass produce e6 in March 2010 with only 100 e6 EVs anticipated to be produced for Shenzhen's taxi fleet.[26]

On the consumer side, subsidies of up to 50,000 RMB per vehicle are offered for taxi fleets and local governments that purchase a hybrid or all-electric vehicle in 13 cities.[27] EV charging stations have also been ordered to be set up in Beijing, Shanghai and Tianjin. Nevertheless, challenges remain for mass deployment of EVs as densely populated cities and the prevalence of high-rise apartments for urban dwellings limit the availability of private space for charging and will intensify demand for public charging centers. China's negative experiences with counterfeit lithium-ion batteries and malfunctioning lithium-ion batteries in computers may also raise performance and reliability concerns amongst potential buyers.[28] Finally, as a new and constantly changing technology, the high and uncertain cost of EV batteries depend on a number of factors including cumulative production volume, design, material composition and the price of raw materials.[29] The highly sensitive price of EV batteries, as demonstrated when post-2006 spike in lead prices has raised the cost of lithium ion batteries, will likely remain a key barrier for rapid EV deployment.

Besides emphasis on improving battery technology, another area of new development in EV technology is the use of ultra-capacitors and super-capacitors. Ultra-capacitors are an attractive storage option as they can endure repeated recharge cycles without degradation, better tolerance of cold weather climate, shocks and vibrations and have a higher rate of energy discharge and recharge through an electrochemical reaction.[30] Compared to batteries such as lithium ion batteries, ultra capacitors are also more environmentally benign due to the absence of heavy ions in its electrolyte. However, a major disadvantage with ultra-capacitors is its limited capacity for energy storage with 25 times less storage capacity than a similarly sized lithium ion battery.[31] In light of this, an alternative approach being studied is the use of super capacitors with lead-acid battery to enhance the battery's power and lifespan.

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[25] BYD Auto, http://www.byd.com

[26] ChinaDaily. 2010. "BYD scales back electric-car plans: report." Available at: http://www.chinadaily.com.cn/bizchina/2010-03/16/content_9597028.htm

[27] Brown, S. et. al. 2010. "Electric vehicles: the role and importance of standards in an emerging market." *Energy Policy* 38 (7): 3797-3806

[28] Bradsher, 2009.

[29] Weinert, et. al. 2008. "The future of electric two wheelers and electric vehicles in China." *Energy Policy* 36 (7): 2544-2555

[30] Brown, et. al., 2010.

[31] Brown, et. al., 2010.

Buses

Historically, China's bus fleet has been dominated by gasoline and diesel fueled buses across all four size classifications and though both petroleum products remain the predominant fuel in public transport system, policies have been adopted to shift public buses away from gasoline and towards diesel and alternative fuels. The government has undertaken policies since 1999 to promote heavy and medium-duty buses fueled with alternative and gaseous fuels such as Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG).[32] Consequently, CNG heavy-duty buses are emerging from a 0% share of HDB fleet in 1997 to 4.6% in 2000 to 10% in 2007.[33] At the same time, the diesel share of heavy duty buses have also increased over time from 64% share in 2000 to 88% share in 2007. The overall diesel share across the entire bus fleet, however, will not change much because declines in diesel heavy duty buses will be offset by rapid growth in the stock of gasoline-dominated light-duty buses and mini buses.

Trucks

As with buses, dieselization of the Chinese truck fleet has also been strongly promoted in the past twenty years. Diesel trucks dominate truck sales, particularly in HDT, MDT and LDT with 100%, 93% and 90% shares of sales in 2004 respectively.[34] The 10th Five Year Plan further set a goal of 100% diesel share in heavy duty and medium duty truck production by 2005. Following this push for dieselization, diesel trucks have also had a rising share of the entire truck fleet (i.e., stock) from 13.8% in 1980 to 53% in 2000 and 63% in 2002.[35]

4.1.2 Air Transport

As the smallest subsector with freight and passenger traffic shares of less than 1%, air transport in China has been marked with tremendous growth over the last two decades. Both passenger and freight traffic has had over 13% annual growth in since 1990. China's commercial air fleet has increased over six-folds from 204 commercial aircrafts in 1990 to 1259 in 2008, with 1600 expected by 2010 and possibly 4000 by 2020.[36] Civil aviation routes more than doubled from 1980 to 1990, and then increased by another five-fold from 1990 to 2008 to its current total of 2.46 million kilometers. Furthermore, China already has the world's second largest aviation market and future growth is expected with a recent Airbus industry report projecting annual market growth rates of 7.9% over the next two decades.[37]

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[32] Ou and Zhang, 2010a.

[33] CATARC, various years, China Automotive Industry Yearbooks.

[34] CAIS, 2005.

[35] He, et. al. 2005. "Oil consumption and CO2 emissions in China's road transport: current status, future trends, and policy implications." *Energy Policy* 33: 1499-1507.

[36] World Bank. 2007. "An Overview of China's Transport Sector – 2007." Available at: http://siteresources.worldbank.org/INTEAPREGTOPTRANSPORT/.../China-Transport-Overview-2007.pdf

[37] Xinhua News. 2009. "China's Aviation Market to Expand 7.9% Annually in Next 20 Years." Available online: http://www.chinadaily.com.cn/bizchina/2009-09/21/content_8714453.htm

As with the other modes of passenger transport, both domestic and international passenger demand for air transport will likely increase along with rising incomes since China's current per capita air transport turnover of 167 passenger-kilometers is well below that of developed countries like the U.S. at 3,170 passenger-kilometers per person per year. On the domestic side, however, some market share of short-haul air passenger transport will likely be replaced by rail as a result of the expanding network of high-speed rail. Freight transport by air have historically been concentrated near major cities, with Shanghai, Beijing and Guangzhou airports amongst the world's top 30 airports for cargo flows. Unlike rail cargo, air cargo is dominated by high value-added products such as consumer electronics, electrical products, machinery and medical equipment.[38]

4.1.3 Rail Transport

Rail transport is another crucial component of both passenger and freight transport in China, representing the second largest mode after road transport with 12.8% of freight traffic and 5.1% of passenger traffic in 2008.[39] Over the last two decades, rail transport has been sustained an expanding rail network from 53,300 kilometers of rail in operation in 1980 to today's 78,000 km of railway track. In the past few years, significant emphasis has been placed on the construction of electrified high speed railway track. At the same time, China has experienced 4.2% annual growth in freight traffic and 2.3% growth in passenger traffic. On one hand, passenger traffic has been driven by greater need for mobility in an increasingly urbanized China as well as a generally greater propensity to travel with rising incomes. On the other hand, urbanization, industrialization and economic growth have also driven freight traffic with rising demand for energy resources such as coal, coke, and petroleum and raw and building materials such as steel and iron, cement, and timber for supporting infrastructure and construction (see Table 10).

[38] World Bank, 2007.

[39] Rail transport in this study refers to intercity rail transport and do not include intracity light rail and subway systems.

Table 10 2008 National Railway Freight by Cargo

	Freight Traffic (million tons)	Share (%)	Freight Activity (billion ton-km)
Coal	1343.25	49.0%	836.03
Metal Ores	297.96	10.9%	86.01
Others	215.11	7.9%	116.24
Steel and Iron, and Non-Ferrous Metals	207.16	7.6%	237.39
Petroleum	126.71	4.6%	193.09
Grain	114.70	4.2%	65.91
Minerals and Building Materials	95.18	3.5%	43.62
Nonmetal Ores	90.54	3.3%	15.84
Coke	87.75	3.2%	41.35
Chemical Fertilizers & Pesticides	78.11	2.9%	114.80
Cement	35.49	1.3%	199.42
Timber	29.35	1.1%	14.98
Salt	14.13	0.5%	11.22
Cotton	3.88	0.1%	360.15

Source: NBS, 2010, China Statistical Yearbook 2009.

Despite rapid increases in its rail network, China has the world's highest traffic density at 40.5 million traffic units (i.e., ton-km of freight or passenger-km) per km of line, which is nearly double that of Russia and almost two and a half times higher than the United States.[40] Recognizing the important role that rail transport plays in China's economy, the government has continued to invest in China's railway network with annual investments of $10 billion RMB from 1995 to 2004, with $42 billion RMB allocated for 2001-2006 under the 10th Five Year Plan for rail construction and modernization.

On July 1st, 2004, the Ministry of Railway also developed a "Mid and Long-term Railway Network Plan" (中长期铁路网规划) with investment targets through 2020. Key components of this plan include:

- By 2020, total operational railway track of 120,000 km by 2020 and rail electrification and double-tracking shares of 50%
- 12,000 km of dedicated high-speed passenger railway tracks with speeds of 200 km/h or above
- 4 north-south high-speed passenger rail networks: Beijing-Shanghai, Beijing-Wuhan-Guangzhou-Shenzhen, Beijing-Shenyang-Dalian, Hangzhou-Ningbo-Fuzhou-Shenzhen

[40] World Bank. 2007.

- 4 east-west high-speed passenger rail networks: Suzhou-Zhenzhou-Lanzhou, Hangzhou-Nanchang-Changsha, Qingdao-Shijiazhuang-Taiyuan, Nanjing-Wuhan-Chongqing-Chengdu
- 3 regional intercity rail networks: Bohai Sea ring in Beijing, Yangtze Delta and Pearl River Delta

As part of China's 2008 Stimulus Plan to promote employment and sustainable growth, 600 billion RMB were spent on railway construction in 2009 with plans to spend 3.5 trillion RMB over the next three years.[41] Rail transport will therefore continue playing an important role in supporting the Chinese economy in the years to come.

4.1.4 Water Transport

As one of the most important modes of transport historically, the water transport sector has been undergoing different changes between passenger and freight water transport. As Chinese residents gain and continually seek greater mobility with rising incomes and urbanization, passenger transport by water has become less common with an overall decline in annual number of passengers transported. In terms of passenger turnover, there is a more significant annual decline of 5.3% with total passenger-kilometers having peaked at 19.5 billion passenger-km in 1992.[42] Demand for freight transport by water, both inland and ocean, have remained strong with 46% share of all freight turnover as resource demands grows throughout China's coastal cities and international trade rises.

First, China has the world's largest inland waterways with a network of 5000 rivers and navigable length of 122.8 thousand kilometers.[43] As a cheaper mode of transport than rail or road, inland waterways are ideal for transporting bulk resources such as sand and gravel, coal, timber, cement and fertilizer. Inland water transport is also advantageous in having lower environmental impacts and energy requirements for bulk transport. Although inland shipping cargo more than tripled from 310 million to 990 metric tons between 2001 and 2006 and further jumped to 1180 million tonnes in 2007, navigable capacity is still greatly underutilized with average utilization rates of only 20%.[44] In order to promote the future role of inland water transport, the 11th Five Year Plan set aside $3 billion RMB investment to advance development in the inland water transport industry with half of the funds dedicated to waterway improvements.

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[41] Jinan Development and Reform Commission. 2009. "Economic Observer News: Railway Investment Starting to Expand Domestic Demand" (in Chinese). Published 27 May 2009. Available online: http://www.jndpc.gov.cn/E_ReadNews.asp?NewsID=5639

[42] NBS, 2009.

[43] Note: navigable inland waterways are defined as waterways with a depth of at least 0.3 meters.

[44] World Bank, 2007.

Second, major coastal ports have been heavily used in recent years to meet growing domestic and international freight transport. As shown in Table 11, the major domestic freight cargo passing through China's large coastal ports consist primarily of energy resources, raw materials and key industrial products. As China's energy resource requirements rise and with continued trade, coastal ports will continue to be an integral part of the water transport system. Moreover, China's rise as a major player in international trade has been accompanied by the increasing use of ocean shipping for imports and exports. In 2004, for example, 85% of all exports were shipped through ports.[45] In 2008, over 4.3 billion tonnes of freight went through China's major coastal ports with a total of nearly 3.3 trillion ton-km of freight turnover in ocean transport. In recognition of the growing use of coastal ports, the 11th Five-Year Plan included key policies to improve China's port and harbor capacities with $5 billion investment on port-related infrastructure and a multi-year, $10+ billion project to build Yangshan Deepwater Port, China's largest port outside Shanghai. Completion of the project's first phase in December of 2005 put five new berths into operation with all construction expected to finish by 2012.

Table 11 Major Domestic Freight Cargo Handled by Coastal Ports

Unit: million tonnes	**Total**	**Share (%)**	**Outbound**	**Inbound**
Coal and Its Products	*889.5*	21%	555.2	334.3
Petroleum, Natural Gas & Products	*449.7*	10%	153.8	295.9
Metal Ores	*676.4*	16%	144.2	532.2
Steel & Iron	*182.7*	4%	118.7	63.9
Minerals, Building Materials	*302.3*	7%	101.2	201.1
Cement	*32.5*	1%	13.0	19.5
Timber	*18.2*	0.4%	9.6	8.6
Nonmetal Ores	*60.3*	1%	25.2	35.1
Chemical Fertilizers & Pesticides	*14.7*	0.3%	8.4	6.3
Salt	*6.3*	0.1%	0.8	5.4
Grain	*91.4*	2%	33.0	58.4
Others	*1,572.2*	37%	817.0	755.2
Total	***4,296.0***	***100%***	***1,980.1***	***2,315.9***

Source: NBS, China Statistical Yearbook 2009.

4.2 Scenario Analysis

The potential impacts of electrification and alternative technologies on the transport sector are modeled and assessed in two different scenarios. To evaluate the energy and emission impacts of these two potential development pathways, China's transport fleets in the four subsectors of transport (road, air, rail, water) are modeled in-depth from an end-use technology perspective

[45] World Bank, 2007.

while transport activity is modeled using different drivers of population and GDP growth, rising incomes, and infrastructure development. The two scenarios analyzed are intended to reflect moderate versus accelerated pace of improvement in fuel economy of internal combustion engines and rail electrification.

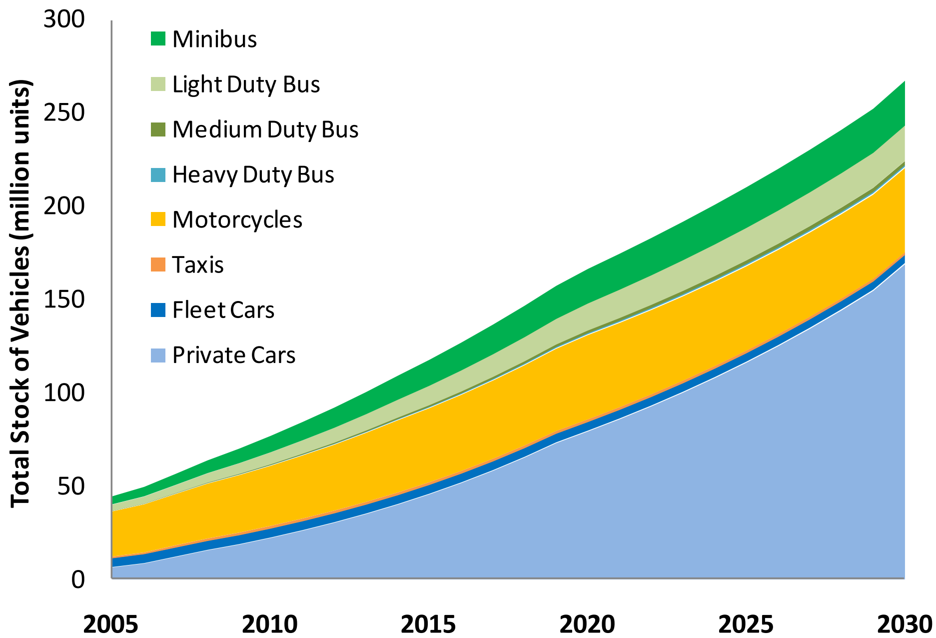
For CIS, continuous efficiency improvements in the fuel economy of aircrafts, buses, cars and trucks are expected through 2030. Moreover, continued dieselization in the truck fleets and moderate penetration of electric vehicles (EV) after 2010 is expected to result in 10% fleet share of EVs by 2030. China is also expected to meet its rail electrification goal for 2020 through moderate electrification efforts and have 63% of the rail network electrified by 2030.

For AIS, there are significant additional efficiency improvements in the fuel economy of light-duty and mini buses through 2030. Additionally, EV deployment is accelerated and will reach 25% fleet share by 2030 while rail electrification will quicken after 2020 to reach over 68% electrification by 2030.

4.2.1 Overview of Transport Model Drivers

In order to perform scenario analysis of the transport sector, China's road, air, water and rail transport fleets were modeled to 2030 using key components such as physical drivers of transport demand (i.e., rising incomes and greater propensity to travel, industrial production and trade), average annual distance traveled and final energy intensity by transport technology. With greater data availability and several published methodologies, the road transport sector was modeled more in-depth using vehicle stock turnover analysis, standards set in fuel economy regulations and a changing mix of vehicle types and fuel shares based on recent market trends and policies. The key assumptions and methodologies for each subsector mode are presented in the sections below.

Figure 33 Passenger Road Transport Stock



4.2.1.1 Passenger Road Transport: Cars, Taxis and Motorcycles

To model China's passenger car stock including private and fleet cars, an econometric model was used to represent the well-known relationship between rising incomes and private car ownership.[46] More specific, household car ownership was forecasted using an econometric model of saturation levels and household income level according to a logistical form where saturation, $S = \frac{1}{1+\gamma e^{\beta I}}$. Taking into consideration a LBNL global model of car ownership and China's historically lower levels of ownership, car ownership was projected as a function of income using the derivative of the saturation equation:

$$\frac{dS}{dI} = \frac{-1}{\left(1+\gamma e^{\beta I}\right)^2} \times \gamma \times \beta e^{\beta \times I}$$

Where *S* is saturation of household ownership, *I* is the average per household income for a given year and *β* and *γ* are scale parameters which are derived using regression analysis by comparing historical diffusion rates to average household income in each year.

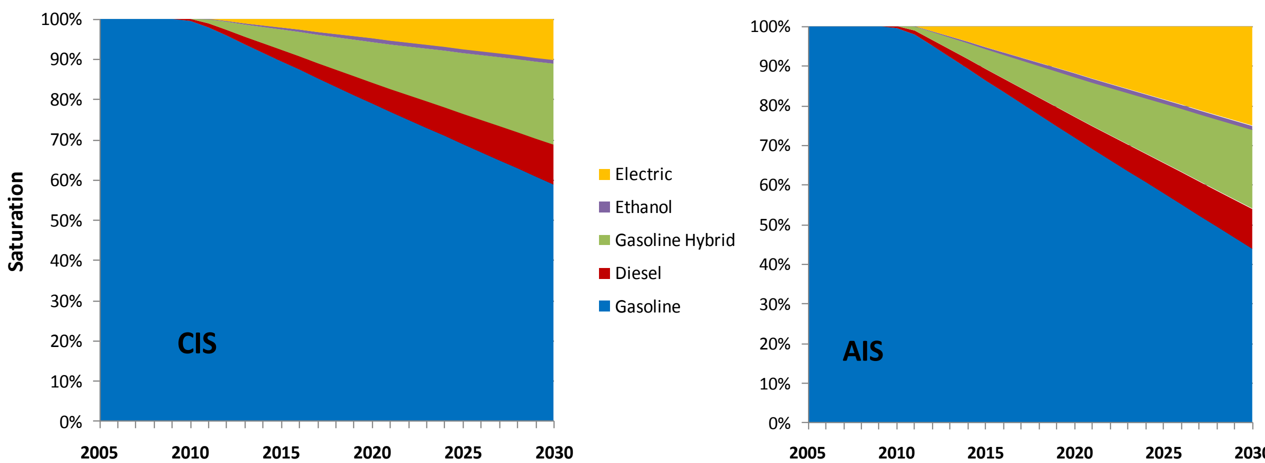
The office fleet car stock is assumed to remain constant at 2006 levels through 2030. In terms of fuel share, the stock of hybrid cars are assumed to rise slowly after 2010 as its current market share of new sales is still very low. Likewise, electric cars are only expected to reach a 10% share by 2030 in CIS given that mass production has not yet started in China (Figure 34, left). Under accelerated mass deployment of EVs in AIS, the share is expected to be 25% in 2030 (Figure 34, right).

[46] For overview of studies and findings regarding this relationship, see Kobos, P. et. al. 2003. "Scenario Analysis of Chinese Passenger Vehicle Growth." *Contemporary Economic Policy* 21 (2):200-217.

Table 12 Historic and Projected Stock of Cars, Taxis and Motorcycles (million units)

	2000	2010	2020	2030
Car	4.52	26.83	83.64	174.3
CIS Gasoline	4.52	26.7	66	103
AIS Gasoline	*4.52*	*27*	*60.6*	*76.5*
Diesel	0	0.13	4.4	17.4
Gasoline Hybrid	0	0	8.4	34.8
Ethanol	0	0	0.84	1.7
CIS Electric	0	0	4	17.4
AIS Electric	*0*	*0*	*10*	*43.5*
Taxi	0.83	1.51	1.52	1.55
Gasoline	0.67	1.18	1.19	1.21
LPG	0.16	0.33	0.33	0.34
Motorcycle	14.8	32.2	45.2	45.2

Figure 34 Passenger Car Fuel Shares, CIS and AIS



A constant fleet average annual distance of 9000 kilometers is assumed for private cars and a higher distance of 18,000 km for fleet cars based on historical trends and discussions with Chinese experts. The annual total car transport activity in vehicle-kilometers is then calculated by multiplying the annual distance by total stock.

To model the final energy demand from the projected act transport activity, energy intensities in MJ per vehicle-kilometer are assumed for each car technology type based on existing fuel economy standards, international experience with fuel economy improvements and projected trends based on China reaching international best ICE technology available after 2030. Hybrid electric vehicles are assumed to be 30% more efficient than gasoline fueled vehicle as is the case now while for EVs, a constant energy intensity of 0.5 MJ/veh-km is taken from a published Chinese article.[47]

Table 13 Key Assumptions in Modeling Passenger Car Transport

	CIS	**AIS**
Fuel Share (% of Fleet)		
Gasoline	79% in 2020 to 59% in 2030	72% in 2020 to 44% in 2030
Diesel	5% in 2020 to 10% in 2030	Same as CIS
Gasoline Hybrid	10% in 2020 to 20% in 2030	Same as CIS
Ethanol	Constant at 1% after 2020	Same as CIS
Electric	4.7% in 2020 to 10% in 2030	11.8% in 2020 to 25% in 2030
Distance (km/year)	9000 for personal cars; 18,000 for office/fleet cars	
Total Activity (bil veh-km)		
Gasoline	742 in 2020 to 1030 in 2030	676 in 2020 to 768 in 2030
Diesel	49 in 2020 to 175 in 2030	Same as CIS
Gasoline Hybrid	94 in 2020 to 349 in 2030	Same as CIS
Ethanol	9.4 in 2020 to 17.5 in 2030	Same as CIS
Electric	44.5 in 2020 to 175 in 2030	111 in 2020 to 437 in 2030
Final Energy Intensity (MJ/veh-km)		
Gasoline	reach marginal intensity of 2009 car sales of 2.52 (30 mpg) in 2020 to 2.31 (33 mpg) in 2030	Same as CIS
Diesel	2.20 (34 mpg) in 2020 to 1.97 (38 mpg) in 2031	Same as CIS
Gasoline Hybrid	Constant at 1.5 (50 mpg) thru. 2030	Same as CIS
Ethanol	2.52 in 2020 to 2.31 in 2030	Same as CIS
Electric	Constant at 0.5 (~14.3 kWh/veh-km) based on Chinese literature	Same as CIS

Modeling taxi transport demand follows a similar methodology as passenger cars, except total stock is assumed to grow much slower at an annual average growth rate of 1% due to rising private car ownership rates. A constant annual travel distance of 100,000 kilometer is assumed based on feedback from Chinese experts. Gasoline and diesel-fueled taxis follow the same fuel economy improvement trends as passenger cars while the fuel economy of LPG taxis improve at a slower rate.

[47] See Ou, et. al. 2009. "Analysis of future domestic EV energy consumption and life cycle greenhouse gas emissions." *New Energy Vehicle* 1 (in Chinese).

Table 14 Key Assumptions in Modeling Taxi Transport

	Gasoline	LPG
Fuel Share (%)	Constant at 80%	Constant at 20%
Distance	100,000 km per year based on interviews of transportation experts	
Activity (billion veh-km)	119.4 in 2020 to 120.6 in 2030	33.3 in 2020 to 33.6 in 2030
Final Energy Intensity (MJ/veh-km)	Reach marginal intensity of 2009 car sales of 2.52 (30 mpg) in 2020 to 2.31 (33 mpg) in 2030	2.4 (25 mpg) in 2020 to 2.3 (33 mpg) in 2030

Note: The same assumptions hold for both CIS and AIS

For motorcycles, saturation with a constant stock is expected by 2020 with greater car ownership rates. Noticeable improvements in final energy intensity are not expected in the next two decades.

Table 15 Key Assumptions in Modeling Motorcycle Transport

	CIS/AIS
Total Activity (bil veh-km)	Constant at 361.6 after 2020
Final Energy Intensity (MJ/veh-km)	Constant at 0.7 after 2020

4.2.1.2 Passenger Road Transport: Buses

The transport model for passenger buses is similar to the car transport model in that it also consists of stock turnover analysis, fuel share, calculated total activity and final energy intensity assumptions by technology. Historical and projected stock data for the four size classifications of buses, historical stock data was taken from taken from published sources while a constant annual travel distance of 40,000 km is assumed for heavy-duty and medium-duty buses and 30,000 km for light-duty and mini buses.[48] The projected stock trends follow the recent trend of shift away from larger buses towards smaller buses while the fuel share trend follows the push for dieselization of larger buses.

Table 16 Historic and Projected Stock of Passenger Buses by Size in Millions

	2000	2010	2020	2030
Heavy Duty Bus	0	0.3	0.8	1.1
Medium Duty Bus	0.3	0.7	1.5	2.2
Light Duty Bus	2.2	6.4	14.7	19.5
Minibus	1.4	8.8	18.6	24.1
Total	*3.9*	*16.2*	*35.6*	*46.9*

Note: historical data through 2007

[48] Yan and Crookes, 2009.

The model assumptions of final energy intensity reflect different paces of improvement in the fuel economy of light and mini-duty buses under the two different scenarios. Under CIS, gasoline fueled HDB and MDB improve the fuel economy slightly from 10.5 MJ/veh-km in 2010 to 10.02 MJ/veh-km in 2030. There is a 15% efficiency gain with diesel buses under the assumption that diesel hybrid buses become available before 2030. Natural gas buses are assumed to follow the same improvement trend as diesel buses, but uses 5% more energy/veh-km following findings from a previous California study.[49] Under AIS, there are additional efficiency gains from improvements in LDB and MB, with both following the trend of achieving best currently available ICE technology after 2030.

Table 17 Key Assumptions for Modeling Bus Transport

	Gasoline	Diesel	Natural Gas
Heavy-duty Buses			
Fuel Share	0%	90%	10%
Vehicle Annual Distance	40,000 km		
Activity	0.6 bil veh-km in 2020, 0.9 bil veh-km in 2030	28.6 bil veh-km in 2020, 40.5 bil veh-km in 2030	2.9 bil veh-km in 2020, 4.1 bil veh-km in 2030
Final Energy Intensity	relatively flat intensity after 2020 at 10.03 MJ/veh-km (7.5 mpg)	15% efficiency gain with more diesel hybrids, or 8.65 MJ/veh-km (8.7 mpg) in 2020 to 7.95 MJ/veh-km (9.5 mpg) in 2030	5% less efficient than diesel, assuming same trend of efficiency improvements
Medium-duty Buses			
Fuel Share	Same as Heavy-duty Buses		
Vehicle Annual Distance			
Activity	1.2 bil veh-km in 2020 to 1.6 bil veh-km in 2030	54.8 bil veh-km in 2020 to 77 bil veh-km in 2030	5.6 bil veh-km in 2020 to 7.9 bil veh-km in 2030
Final Energy Intensity	Same as Heavy-duty Buses		
Light-duty Buses			
Fuel Share	90%	10%	N/A
Vehicle Annual Distance	30,000 km		N/A
Activity	396.9 bil veh-km in 2020 to 526.5 bil veh-km in 2030	44.1 veh-km in 2020 to 58.5 veh-km in 2030	N/A

[49] Schuber and Fable. 2005. "Comparative Costs of 2010 Heavy-Duty Diesel and Natural Gas Technologies." Final Report for California Natural Gas Vehicles Partnership.

CIS Final Energy Intensity	relatively flat at 3.31 MJ/veh-km (22.7 mpg) after 2020	15% efficiency gain with more diesel hybrids, or 2.9 MJ/veh-km (26 mpg) in 2020 to 2.66 MJ/veh-km (28 mpg) in 2030	N/A
AIS Final Energy Intensity	Trend of reaching current best ICE technology after 2030; 3.03 MJ/veh-km (25 mpg) in 2020 and 2.65 MJ/veh-km (28 mpg) in 2030	Same as CIS	N/A
Mini Buses			
Fuel Share	Same as Light-duty Buses		
Vehicle Annual Distance			
Activity	502.2 bil veh-km in 2020 to 650.7 bil veh-km in 2030	55.8 bil veh-km in 2020 to 72.3 bil veh-km in 2030	N/A
CIS Final Energy Intensity	Same as Light-duty Buses		
AIS Final Energy Intensity			

4.2.1.3 Passenger Air Transport

In modeling passenger air transport, total air travel activity is expected to continually increase as China's current per capita air travel is very low and will likely be driven by rising income levels. Specifically, it is assumed that China will follow the trend of reaching 25% of current U.S. level of passenger-km per capita after 2030. The total air transport activity in terms of both domestic and international air travel can then be calculated by multiplying projected per capita air passenger-km by total population. A constant ratio of 0.77:0.23 is used for splitting the total activity into domestic and international air travel. In terms of final energy intensity, China is expected to follow the efficiency improvement path of the modern jet fleet in the last fifty years and reach modern air craft energy intensity of 1 MJ/passenger-km after 2030.[50]

Table 18 Key Assumptions in Modeling Passenger Air Transport

	Domestic Air	International Air
Total Activity (bil pass-km)	389.9 in 2020 to 563.3 in 2030	116.5 in 2020 to 268.3 in 2030
Final Energy Intensity (MJ jet kerosene/pass-km)	1.45 in 2020 to 1.3 in 2030	Same as Domestic Air

[50] Peeters et. al. 2005. "Fuel efficiency of commercial aircraft: an overview of historical and future trends." National Aerospace Laboratory Report. NLR-CR-2005-669. Efficiency improvements of 51-55% over the last five decades are included in this study and other aviation industry studies as cited in Rutherford, D and M. Zeinali. 2009. "Efficiency trends for new commercial jet aircraft: 1960 – 2008." International Council on Clean Transportation report.

4.2.1.4 Passenger Rail Transport

Moderate growth of 2 to 3% in total passenger rail activity in terms of passenger-km is expected for China as substitution for short-distance air travel may occur. The fuel share assumptions in the model explicitly accounts for different paces of rail electrification under CIS and AIS. Although rail electrification is expected to quicken from its current level of ~36% to 2020 following the government's recently announced electrification goals, the model accounts for even faster electrification after 2020 under AIS. No significant changes are expected in the diesel or electric rail's final energy intensity.

Table 19 Key Assumptions in Modeling Passenger Rail Transport

	CIS	AIS
Fuel Share (% of Fleet)		
Diesel	40% in 2020 to 36.7% in 2030	40% in 2020 to 31.7% in 2030
Electric	60% in 2020 to 63.3% in 2030	60% in 2020 to 68.3% in 2030
Total Activity (billion pass-km)		
Diesel	251.3 in 2020 to 328.1 in 2030	411.8 in 2020 to 425.6 in 2030
Electric	778.3 in 2020 to 1015.9 in 2030	617.8 in 2020 to 918.4 in 2030
Final Energy Intensity (MJ/pass-km)		
Diesel	Constant at 0.3 through 2030	Same as CIS
Electric	Constant at 0.1 after 2020	Same as CIS

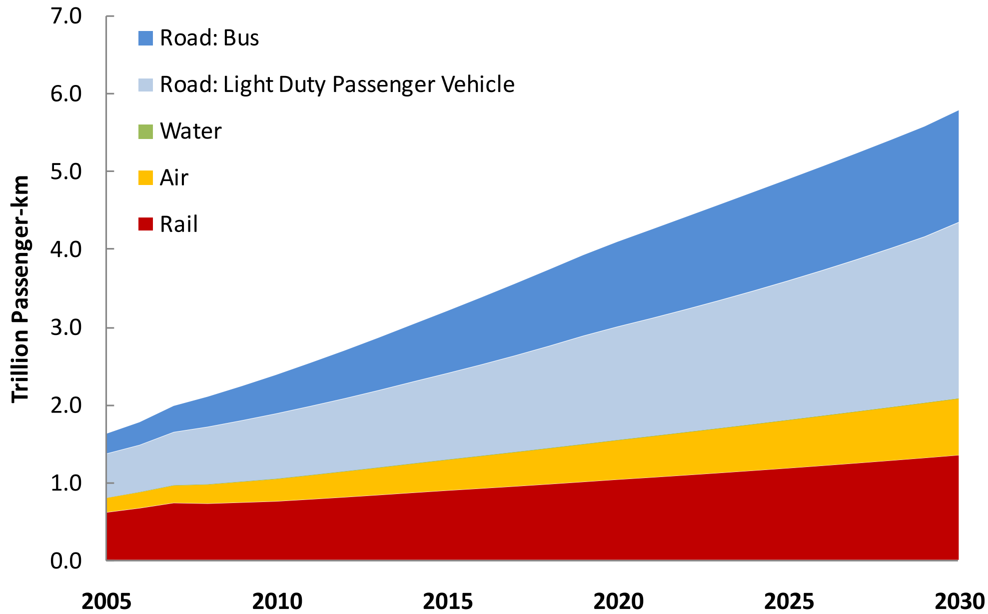
4.2.1.5 Passenger Water Transport

With air and rail transport becoming more common for longer distance passenger travel, overall water transport activity is expected to decrease. The model assumes annual average decline rates of 2-3% in both inland and coastal waterway transport after 2010 following the recent rates of decline in total water passenger-km from 1999 to 2007. No changes are expected in the final energy intensity of either mode of passenger water transport through 2030.

Table 20 Key Assumptions in Modeling Passenger Water Transport

	Coastal Waterways	Inland Waterways
Total Activity (bil pass-km)	2.35 in 2020 to 1.74 in 2030	6 in 2020 to 4.4 in 2030
Final Energy Intensity (MJ/pass-km)	Constant at 0.27 after 2020	Constant at 0.22 after 2020

Figure 35 Passenger Transport Activity by Mode



4.2.1.6 Freight Truck Transport

Similar to modeling passenger road transport, a stock turnover model using assumed sales growth based on recent trends and lifetimes is also used to model freight truck stock out to 2030 (Table 21). Current trends of expanding stock of light duty and mini trucks are expected to continue, with growth in heavy duty and medium duty trucks slowing and even declining, respectively.

Table 21 Historic and Projected Stock of Buses (millions)

	2000	2010	2020	2030
Heavy Duty Trucks (All Diesel)	0.26	2.82	5.88	6.97
Medium Duty Trucks Total	2.35	2.05	2.29	1.40
Gasoline	0.67	0.06	0.07	0.04
Diesel	1.68	1.99	2.22	1.36
Light Duty Trucks Total	2.92	8.37	19.16	25.68
Gasoline	0.57	0.99	2.26	3.03
Diesel	2.35	7.38	16.90	22.65
Mini Trucks Total	0.76	1.66	2.91	3.35
Gasoline	0.76	1.33	2.33	2.68
Diesel	0.00	0.33	0.58	0.67
Total	*6.29*	*14.90*	*30.24*	*37.40*

Note: historical data through 2007.

However, unlike passenger road transport, total freight activity is not derived directly from stock and constant average annual transport distance. Rather, total freight activity is modeled after a logarithmic relationship with industrial production output with value added GDP as a proxy because industrial output is the bulk of freight transported by trucks on highways. The annual transport distance is then derived from total activity and stock by truck size and is consistent with values given in other studies.[51] The assumed fuel shares reflect sales trends in the four different sizes of trucks over the last decade. For final energy intensity, expected fuel economy improvements for each class is based on European Union's experience with 36% improvements for the smallest trucks, 22 to 33% improvements for medium trucks and 32% improvements for the largest trucks from 1978 to 2000.[52]

Table 22 Key Assumptions for Modeling Freight Truck Transport

	Gasoline	**Diesel**
Heavy-duty Trucks		
Fuel Share	0%	100%
Vehicle Annual Distance	N/A	56,900 km
Activity	N/A	334.4 billion veh-km in 2020 to 396.6 billion veh-km in 2030
Final Energy Intensity	N/A	8.53 MJ/veh-km (8.8 mpg) in 2020 to 8.34 MJ/veh-km (9 mpg) in 2030
Medium-duty Trucks		
Fuel Share	3%	97%
Vehicle Annual Distance	56,900 km	
Activity	3.9 bil veh-km in 2020 to 2.4 bil veh-km	126.4 bil veh-km in 2020 to 77.3 bil veh-km in 2030
Final Energy Intensity	8.33 MJ/veh-km (9 mpg) in 2020 to 8.14 MJ/veh-km (9.2 mpg) in 2030	6.60 MJ/veh-km (11.4 mpg) in 2020 to 6.46 MJ/veh-km (11.6 mpg) in 2030
Light-duty Trucks		
Fuel Share	90%	10%
Vehicle Annual Distance	35,000 km	
Activity	591.5 bil veh-km in 2020 to 792.7 bil veh-km in 2030	79.1 bil veh-km in 2020 to 106.1 bil veh-km in 2030
Final Energy Intensity	4.21 MJ/veh-km (17.9 mpg) in 2020 to 4.06 MJ/veh-km (18.5 mpg) in 2030	4.33 MJ/veh-km (17.4 mpg) in 2020 to 4.18 MJ/veh-km (18 mpg) in 2030
Mini Trucks		
Fuel Share	80%	20%

[51] See Huo et. al. "Projection of Chinese Motor Vehicle Growth, Oil Demand and CO2 Emissions through 2050." Argonne National Laboratory Report. ANL/ESD/06-6

[52] Ruzzenenti, F. and R. Basosi. 2009. "Evaluation of the energy efficiency evolution in the European road freight transport sector." *Energy Policy* 37 (10): 4079 – 4085.

Vehicle Annual Distance	35,000 km	
Activity	81.48 bil veh-km in 2020 to 93.8 bil veh-km in 2030	20.37 bil veh-km in 2020 to 23.45 bil veh-km in 2020
Final Energy Intensity	2.16 MJ/veh-km (34.8 mpg) in 2020 to 2.06 MJ/veh-km (36.5 mpg) in 2030	2.1 MJ/veh-km (35.9 mpg) in 2020 to 2 MJ/veh-km (37.7 mpg) in 2030

4.2.1.7 Freight Air Transport

The freight air transport model is very similar to the passenger air transport in that activity is driven by assuming China will approach current international levels after 2030. Specifically, China is assumed to reach the 2006 U.S. per capita freight of 75 ton-km after 2030. For final energy intensity, freight air transport is expected to follow the same efficiency improvement trend as passenger air with a constant ratio between passenger and freight air transport energy intensities.

Table 23 Key Assumptions for Modeling Freight Air Transport

	Domestic Air	**International Air**
Total Activity (bil tonne-km)	18.4 in 2020 to 28.9 in 2030	22.4 in 2020 to 35.3 in 2030
Final Energy Intensity (MJ jet kerosene/tonne-km)	9.43 in 2020 to 8.45 in 2030	Same as Domestic Air

4.2.1.8 Freight Rail Transport

Although fuel shares are the same for passenger and freight rail transport with accelerated electrification under AIS, freight rail transport activity is actually driven by three different factors. In particular, an annual average freight transport distance, total track length at year's end, and freight density in tonnes of freight per km is multiplied together to calculate total freight transport activity. The annual freight transport distance is expected to remain constant at the 1991 to 2007 average of 763 kilometer as few fluctuations have occurred in the past. The total track length is projected linearly based on the government's latest stated goals of railway track construction. Freight density is expected to double between 2007 and 2020 following the doubling of density between 1997 and 2007, and remain constant thereafter. As with passenger rail transport, the final energy intensity for diesel and electric freight rail transport remains constant from 2020 onwards.

Table 24 Key Assumptions for Modeling Freight Rail Transport

	CIS	AIS
Fuel Share (% of Fleet)		
Diesel	40% in 2020 to 36.7% in 2030	40% in 2020 to 31.7% in 2030
Electric	60% in 2020 to 63.3% in 2030	60% in 2020 to 68.3% in 2030
Annual Freight Transport Distance	1991-2007 average of 763 km	
Total Track Length	120,000 km in 2020 to 130,000 km in 2030	
Freight Density	Double 2007 intensity to 80,574 tonne/km by 2020	
Total Activity (bil tonne-km)		
Diesel	251.3 in 2020 to 328.1 in 2030	411.8 in 2020 to 425.6 in 2030
Electric	778.3 in 2020 to 1015.9 in 2030	617.8 in 2020 to 918.4 in 2030
Final Energy Intensity (MJ/tonne-km)		
Diesel	Constant at 0.10 after 2020	Same as CIS
Electric	Constant at 0.12 after 2020	Same as CIS

4.2.1.9 Freight Water Transport

As a relatively stable transport subsector, freight water transport is not expected to have major differences between the two scenarios. Since major changes in activity growth trends are not expected, this study's freight water transport assumptions were aligned with published activity levels for 2010, 2020 and 2030 in China Energy Research Institute's 2050 China Energy and Carbon Emissions Report.[53] However, LBNL estimates of activity shares between ocean, coastal and inland water transport based on historic data is used to allocate the total activity. For both modes of water freight transport, the final energy intensity is assumed to improve 1% from current levels by 2015 and another 1% by 2020 and then remain constant.

Table 25 Key Assumptions in Modeling Freight Water Transport

	Ocean	Coastal and Inland
Total Activity (trillion tonne-km)	7.03 in 2020 to 11.242 in 2030	3.97 in 2020 to 6.49 in 2030
Final Energy Intensity (MJ/tonne-km)	0.228 from 2020 onwards	0.228 from 2020 onwards

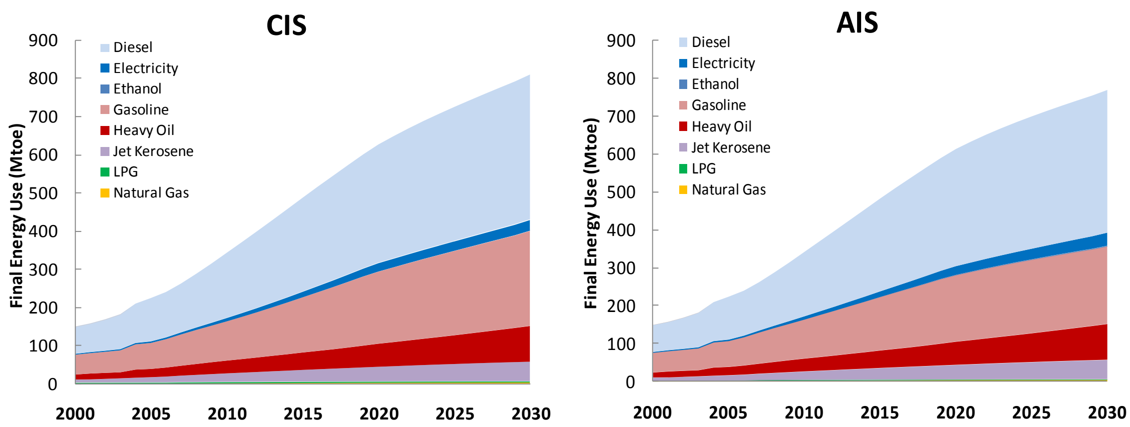
4.2.2 Transport Energy Impacts under CIS and AIS

The total final energy use for the transport sector will reach 809 million tonnes of oil equivalent (Mtoe) under CIS and 770 Mtoe under AIS. The final energy demand is only 39 Mtoe lower under AIS in 2030 and does not reflect any discernible changes in fuel shares (Figure 36). In fact,

[53] China Energy Research Institute (ERI). 2009. *2050 China Energy and CO2 Emissions Report (CEACER).* Beijing: Science Press, In Chinese.

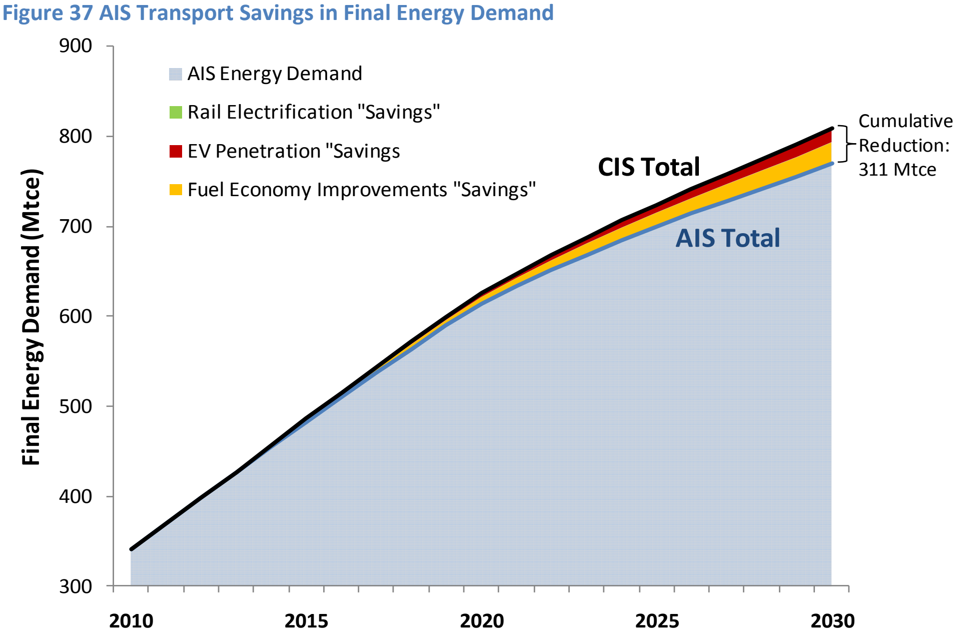
diesel remains the largest fuel consumed, followed by gasoline, heavy oil and jet kerosene under both scenarios.

Figure 36 Transport Final Energy Demand by Fuel, CIS and AIS



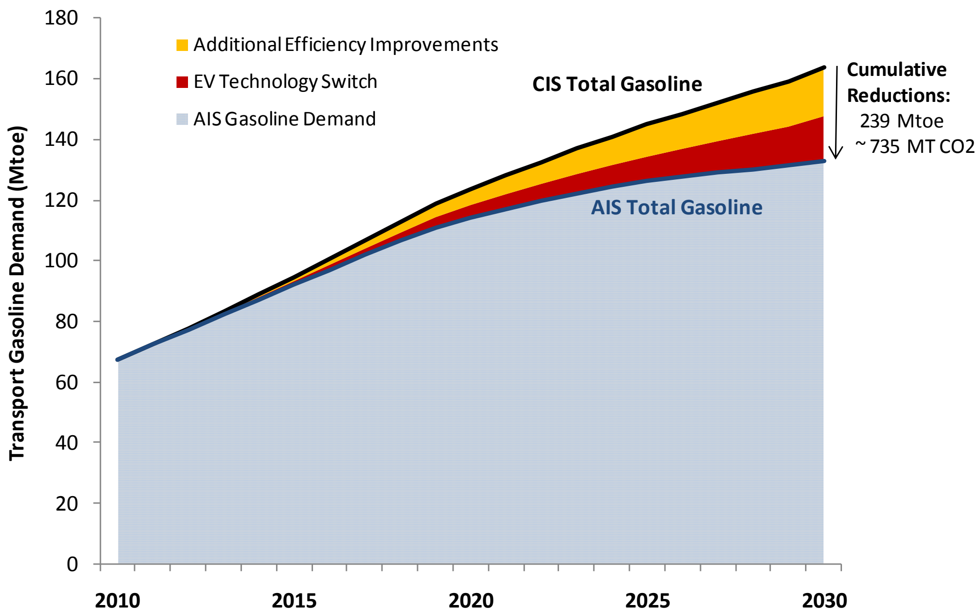
The lower transport final energy demand in AIS can mostly be attributed to savings from more aggressive fuel economy improvements in light-duty bus fleet and greater EV penetration, with rail electrification having a diminutive effect (Figure 37). In particular, additional fuel economy improvements under AIS had the greatest final energy savings with 23.4 Mtce in 2030, followed by accelerated vehicle electrification at 16 Mtce and lastly with rail electrification at only 0.2 Mtce. Rail electrification does not appear to have net savings in part because electric and diesel rail are already very efficient, and also because the magnitude of change (electrification of 63% vs. 68% of rail) in CIS and AIS is relatively small compared to the other two scenario differences.

Figure 37 AIS Transport Savings in Final Energy Demand



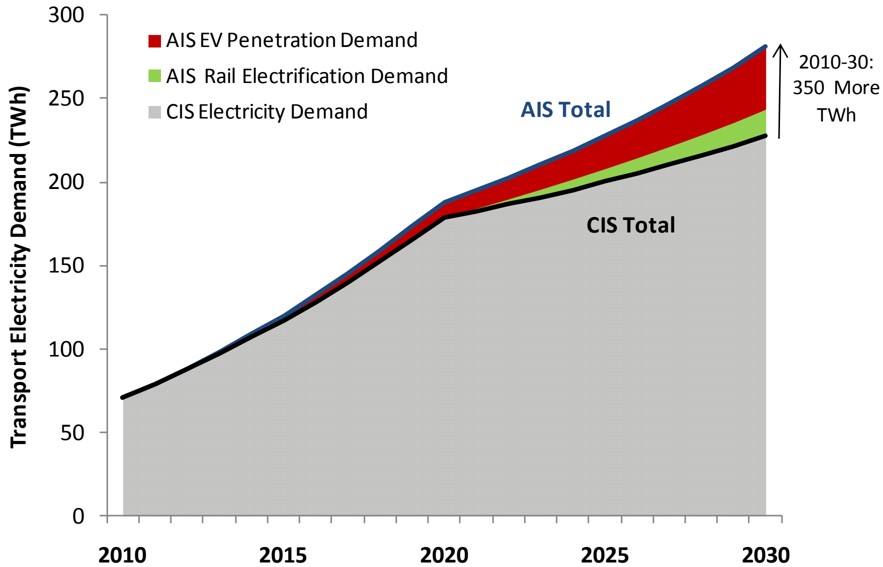
The differing impacts of transport electrification and efficiency improvements on final energy demand can also be seen in the reduction in gasoline demand between the two scenarios. A closer look at motor vehicle transport in terms of gasoline demand in the two scenarios reveals that improved fuel economy in light-duty buses have the same impact on reducing gasoline demand as greater EV technology switch. Under AIS, bus efficiency improvements would reduce gasoline demand by 16.4 Mtoe in 2030 while the additional EV technology switch would reduce gasoline demand by 14.4 Mtoe relative to CIS (Figure 38). The combined impact of these two mitigation strategies could result in cumulative CO_2 reduction on the order of 735 million tonnes of CO_2, assuming IPCC emission factor for gasoline. Rail electrification under AIS, on the other hand, would only result in 1.5 Mtoe less diesel than CIS or cumulative reduction of 22.8 Mtoe from 2010 to 2030.

Figure 38 Comparison of CIS and AIS Transport Gasoline Demand

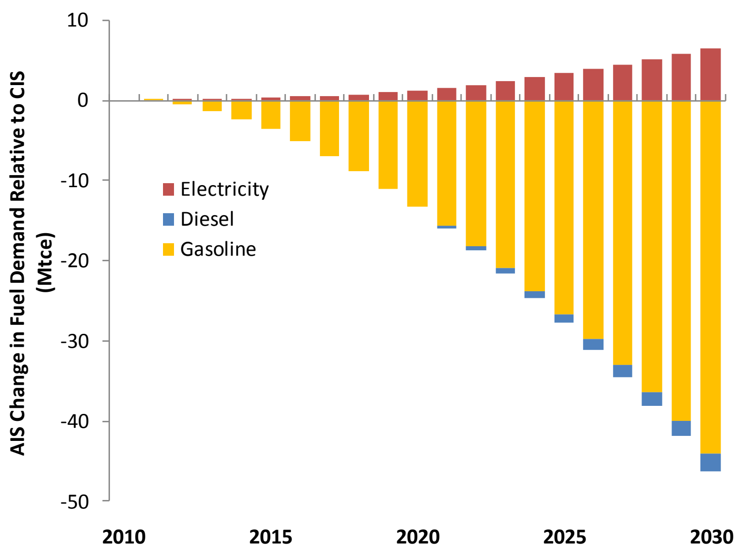


While gasoline and diesel demand will be lowered by greater rail and road electrification, electricity demand from the transport sector will increase under AIS. Most of the increased electricity demand will be to power the larger EV fleet under AIS, with an additional 37.5 TWh needed in 2030 relative to CIS (Figure 39). An additional 16 TWh will be needed for the more electrified rail system in 2030. As a result of greater transport electrification from 2010 to 2030, a cumulative total of 350 additional TWh will be needed under AIS.

Figure 39 Comparison of CIS and AIS Transport Electricity Demand



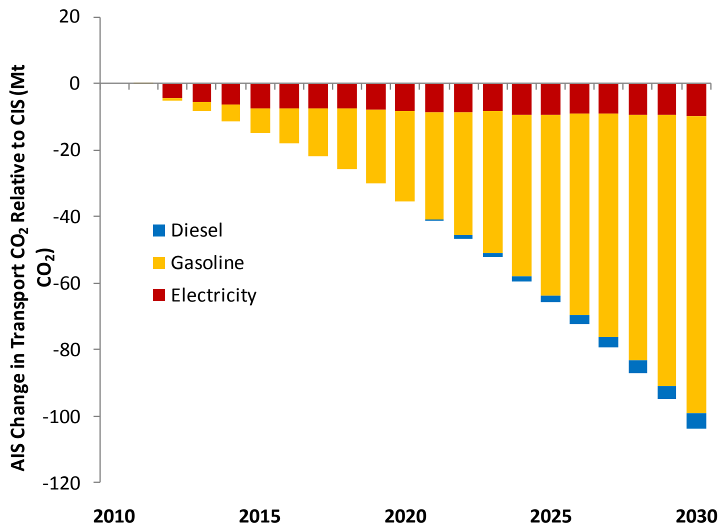
The fuel impact of AIS transport relative to CIS is a substantial reduction in gasoline demand with much smaller reduction in diesel demand (from decreased diesel fuel share of rail transport) with some offset by an increase in electricity demand. Overall, the reductions in gasoline and diesel more than offset the increase in electricity, resulting in a net reduction in final transport fuel demand.



4.2.3 Transport CO_2 Emission Impacts under CIS and AIS

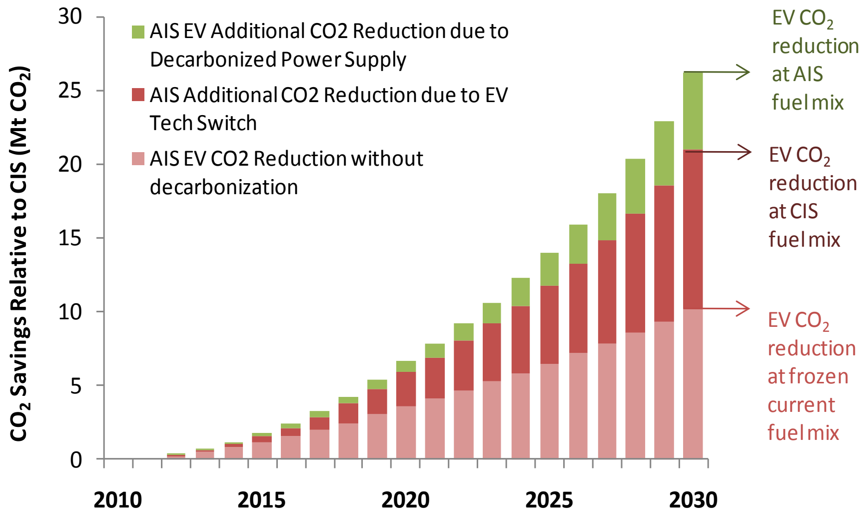
As with the change in transport fuel consumption between CIS and AIS, the majority of transport CO_2 reductions will also be from lower gasoline use resulting from fuel economy improvements and EV technology switch (Figure 40). Moreover, with electrification playing an important role in both CIS and AIS, transport CO_2 emissions outlook will also be interlinked with decarbonization of the power supply. This is most evident in AIS's net CO_2 emissions reduction compared to CIS despite increased electricity demand. 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 because AIS power supply is less carbon intensive than CIS power supply. Specifically, CIS power sector has an emission factor of 0.56 Mt CO_2/TWh electricity generated while AIS has an emission factor of 0.42 Mt CO_2/TWh.

Figure 40 Decomposition of AIS Transport Reduction in CO_2 Emissions



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 15% larger EV fleet share relative to CIS in 2030 actually results from two compounded 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 2005 base level. This results in net emissions reduction of 10 Mt CO_2 in 2030, or cumulative reduction of 85 Mt CO_2 from 2010 to 2030 (Figure 41).

Figure 41 Decomposition of CO_2 Savings from EVs in AIS



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 additional CO_2 reduction is similar in magnitude to the reduction at a frozen fuel mix, with 10.7 Mt CO_2 in 2030 and cumulative reduction of 68.9 Mt CO_2. Finally, accelerated power decarbonization in AIS contributes to additional CO_2 reduction of 3 Mt CO_2 in 2030 because a TWh under AIS has lower emission 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 potential to reduce 16 Mt CO_2 in 2030 and cumulative reduction of 98 Mt CO_2 (i.e., the pink and green sections in Figure 41). 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 green section in Figure 41). This impact amounts to annual savings of 6 Mt CO_2 in 2030 or cumulative savings of 30 Mt CO_2 under AIS.

4.2.4 Transport Sensitivity Analysis

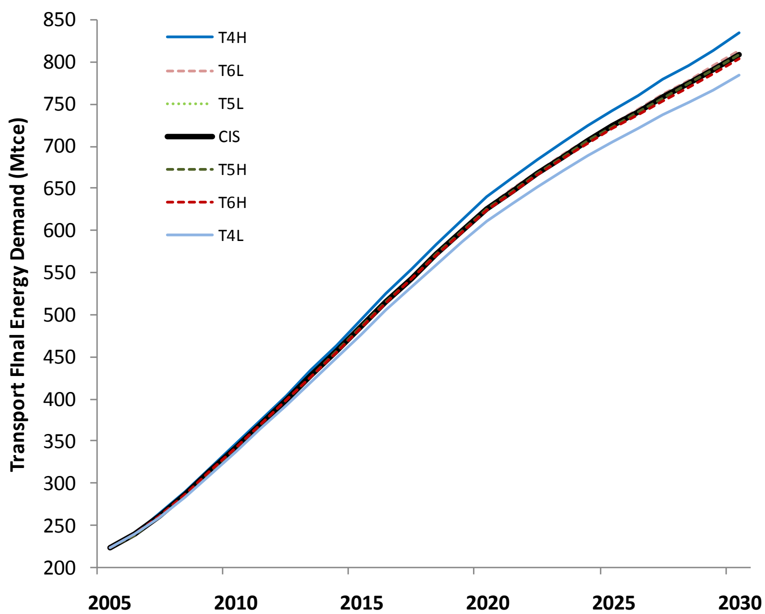
In order to accurately quantify the impacts of different assumptions between CIS and AIS and remaining uncertainties, sensitivity analysis was conducted to test and isolate the effect of rail electrification, car electrification and uncertainty in car stock or ownership. The basis for the sensitivity analysis scenarios are listed in Table 26 below. The sensitivity analysis scenarios were all based off of CIS, with only difference being the specific transport variable being tested.

Table 26 Key Different Assumptions in Transport Scenarios

	Model Scenarios		Sensitivity Analysis Scenarios	
	CIS/Base	*AIS*	*High*	*Low*
Car Stock/Ownership	252 per 1000 persons by 2030	Same as CIS	T4H: 25% higher (=315 cars/1000 persons)	T4L: 25% lower (=189 cars/1000 persons)
Rail Electrification	63% by 2030	68% by 2030	T5H: 68% by 2030	T5L: 58% by 2030
EV Penetration	10% of fleet by 2030	25% of fleet by 2030	T6H: 15% by 2030	T6L: 5% by 2030

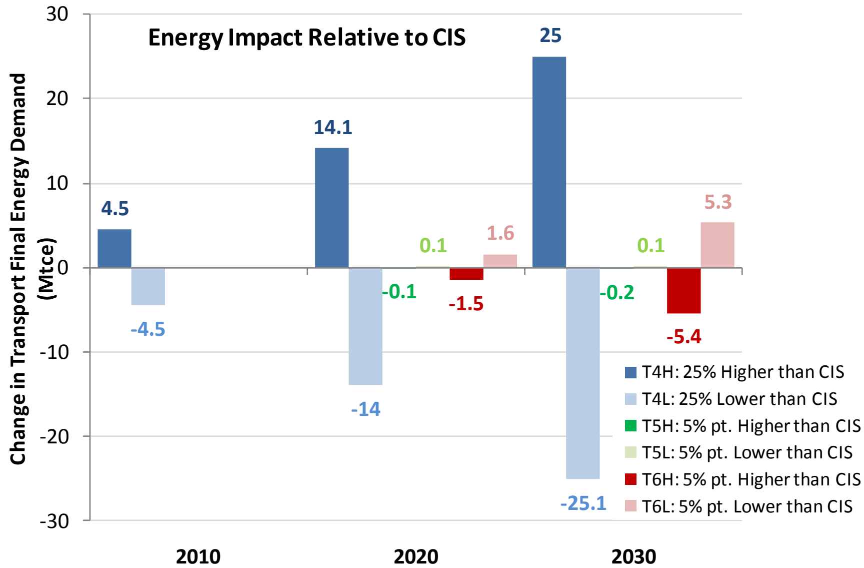
The sensitivity analysis shows that the individual impact of the transport variables being tested is very small and results in small or indiscernible divergence from CIS. Of the three variables examined, changes in car stock as a result of ownership assumptions was the most sensitive with the only visible impact on transport final energy demand (Figure 42).

Figure 42 Transport Final Energy Demand of Sensitivity Analysis Scenarios



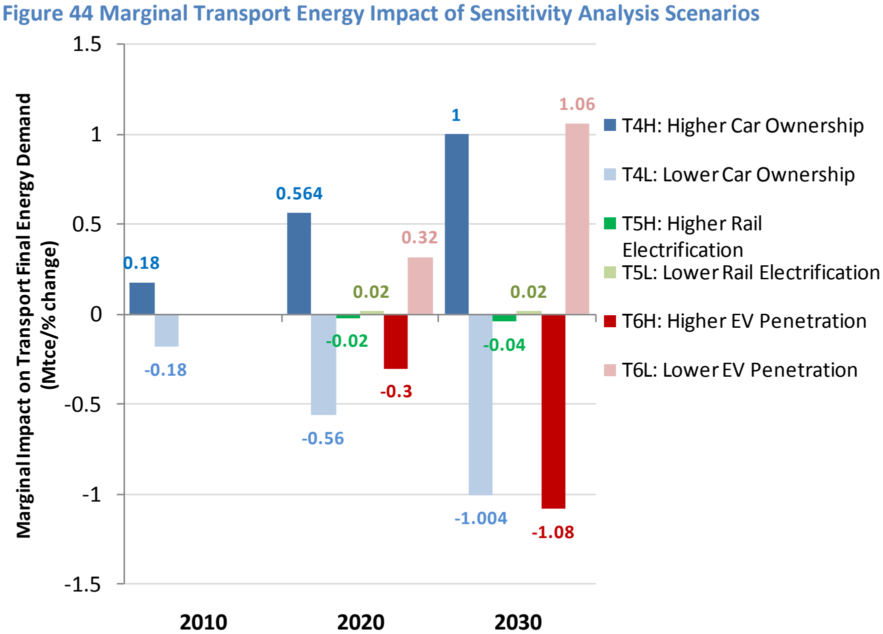
More specifically, 25% higher car ownership corresponded to 25 Mtce higher transport final energy demand in 2030 while a 5 percentage point increase in the share of EV corresponded to 5.4 Mtce lower transport energy demand in 2030 (Figure 43). Rail electrification shows very little gain as a 5% increase in electrification resulted in only 0.2 Mtce lower final energy demand.

Figure 43 Transport Final Energy Impact of Sensitivity Analysis Scenarios



The different magnitude of energy impacts of car ownership, rail electrification and EV penetration is illustrated more clearly in comparing the marginal impact of 1% point in each variable on total transport final energy demand (Figure 44). Interestingly, once the magnitude of change is normalized, 1% of increase in car ownership has almost the same impact as 1% lower EV penetration in increasing total transport final energy demand by 1 Mtce in 2030. The negligible impact of rail electrification is once again highlighted in that 1% more electrification only results in decreasing total energy by 0.04 Mtce in 2030.

Figure 44 Marginal Transport Energy Impact of Sensitivity Analysis Scenarios



4.3 Implications

4.3.1 Impact of Transport Electrification

The transport scenario analysis reveals that power decarbonization is essential in realizing carbon mitigation through transport electrification, particularly with fast EV deployment. While accelerated rail electrification results in little gain in energy or CO_2 savings, more aggressive EV deployment can result in net CO_2 savings depending on the degree of decarbonization in the power sector. The majority of CO_2 reduction from internal combustion engine car switching to EV will be due to cleaner power supply, not merely reductions in gasoline demand. In fact, EV deployment alone actually has no impact on reducing crude oil imports as a reduction in gasoline demand does not directly translate to a reduction in total import demand for crude oil. This is because crude oil is still needed to produce the other products still demanded by the economy such as naphtha, jet kerosene and heavy oil (bunker fuel).

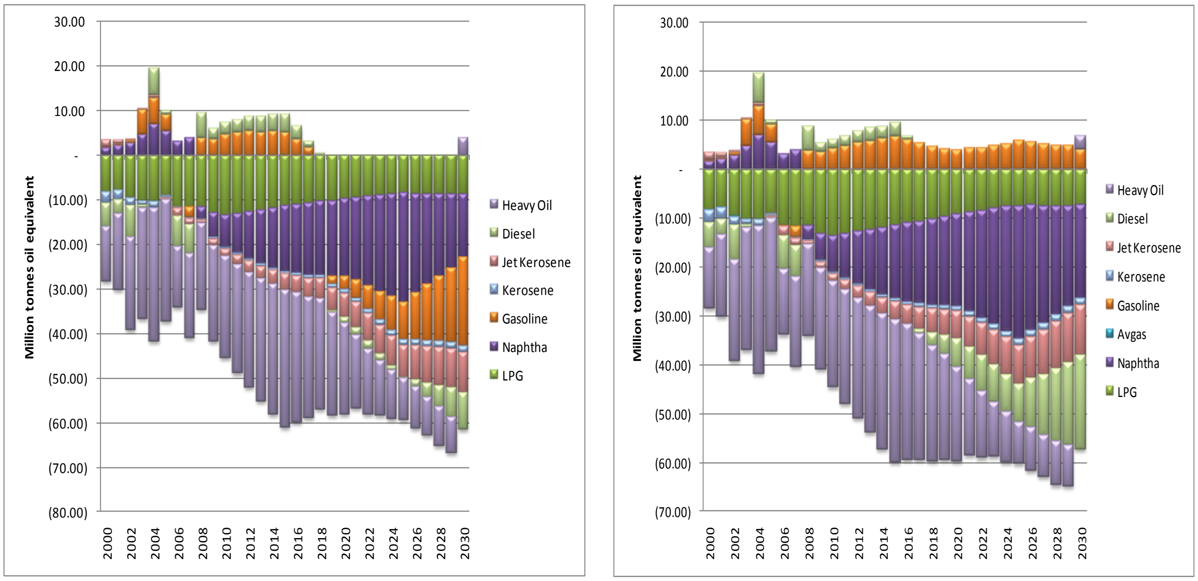
At the same time, fuel economy improvements and efficiency savings can play just as an important role, if not greater role, as vehicle electrification in carbon mitigation. Under AIS, more aggressive efficiency improvements in light-duty buses alone can exceed the carbon mitigation of 15% larger EV fleet. Therefore, it is important to recognize that carbon mitigation in the transport sector should not be pursued with sole emphasis on electrification, but that equally important contributions can be reaped from continued focus on improving fuel economy of existing vehicle technologies.

4.3.2 Crude Oil Demand and Trade Implications

Currently, China is a net importer of both crude oil and refined petroleum products, but it remains a net exporter of gasoline. China's product demand pattern mirrors that of Europe, where diesel is the primary transport fuel and gasoline secondary. This is reflected in the output slate of China's refineries, in which output of gasoline constitutes just 18.5wt% of the total, compared to around 40% in the US.

In the CIS scenario, a continued focus on diesel maximization in refineries combined with improvements in diesel vehicle efficiency and continued electrification of the rail system results in a slight 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 (though with some limits, as gasoline yields by 2030 are further reduced to just 18wt%), 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. In this situation, EVs do not fully supplant gasoline, but leads to the export of the surplus for consumption elsewhere. Crude oil import demand is similarly unaffected by EV deployment itself; efficiency and conservation efforts aimed at reduction in all types of oil consumption are needed to reduce crude oil imports.

Figure 45 Major Oil Products Imports and Exports



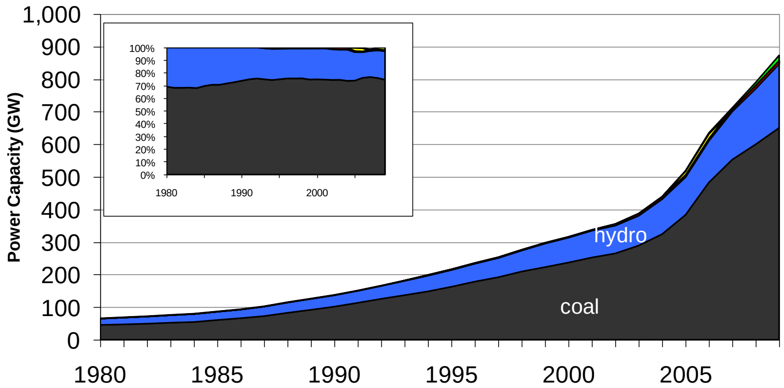
5. Power Sector Analysis

5.1 Electricity Sector Introduction

China's electricity system is growing rapidly to meet rising demand from heavy industry, new urban areas, and export-oriented manufacturing. Since the start of its reform and opening program China's electricity generation has grown at an average rate of more than 9% per year, from 301 TWh in 1980 to 3,597 TWh in 2009.[54] The explosive growth of energy use and related carbon dioxide emissions, particularly after 2001, exceeded the highest forecasts of Chinese and international experts.[55] China's electricity system doubled its capacity between 2000 and 2007 (from 320 to 710 GW) and high growth is expected to continue. The International Energy Agency forecasts China's total generation capacity will expand at an average annual growth rate of 4.5% over the next twenty years to reach 1,900 GW in 2030.[56]

[54] National Bureau of Statistics (NBS). 2008. *China Energy Statistical Yearbook 2008*. Beijing: China Statistics Press.
[55] Levine, M.D. and N.T. Aden. 2008. "Global Carbon Emissions in the Coming Decades: The Case of China." *Annual Review of Environment and Resources*, October 16, 2008, http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.environ.33.012507.172124.
[56] IEA. 2009. *World Energy Outlook 2009*. Paris: OECD Publishing.

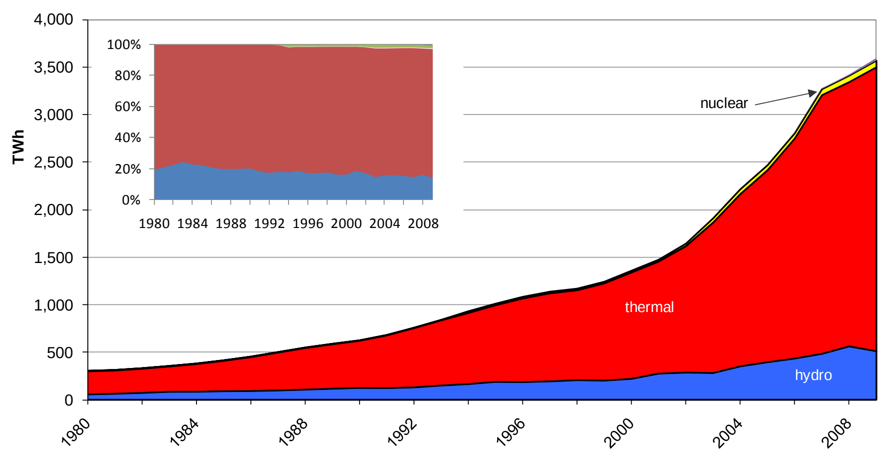
Figure 46 Electricity Generation Capacity by Source, 1980-2009



Source: NBS, various years.

The story of China's recent electricity system development has been one of harnessing coal resources to fuel coastal growth and the construction of new cities. More than 80% of China's electricity was generated from coal combustion in 2009. However, coal combustion presents at least four long-term problems for sustainable development: resources are located far from demand centers, causing transport bottlenecks; political problems from coal mine accidents and fatalities; increasing coastal dependence on international coal imports; and detrimental health and climate effects of local air pollution and carbon dioxide emissions.[57] What could China do to back out its reliance on coal for power generation? This project uses scenario analysis to examine the potential of efficiency improvements and fuel switching to mitigate energy use and emissions from power sector growth to 2030.

Figure 47 China's Electricity Generation, 1980 - 2009



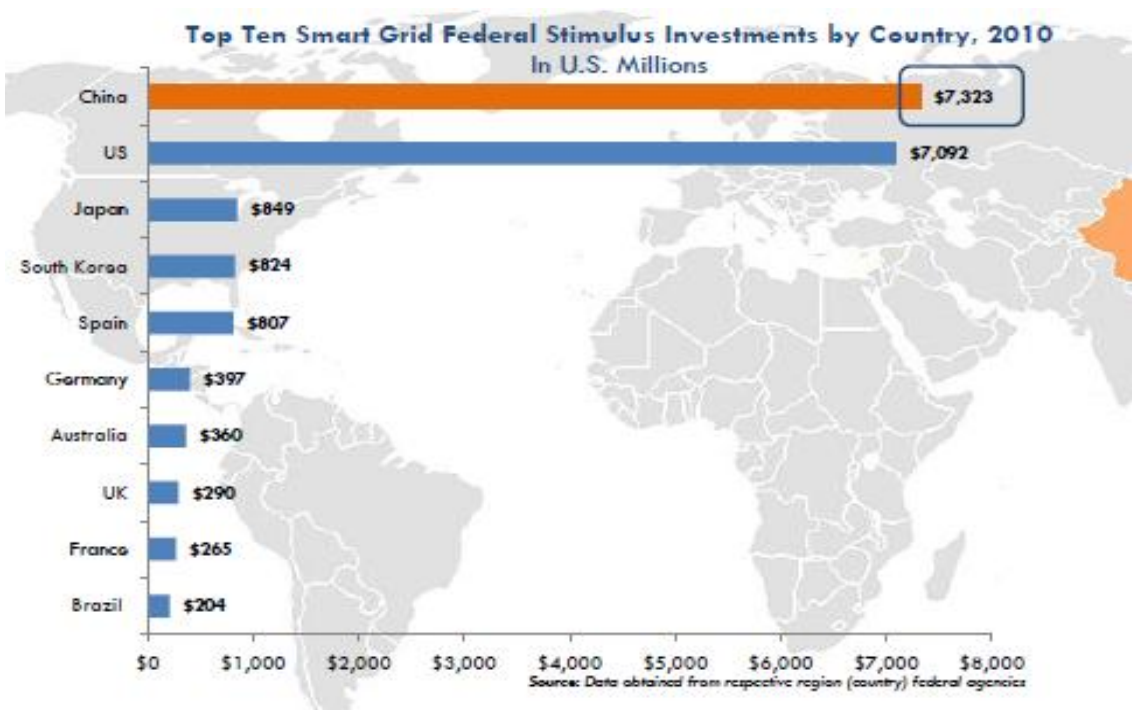
Source: NBS, various years.

[57] For more information on China's coal industry growth, see Aden N, Fridley D, and N. Zheng. 2009. *China's Coal Industry: Resources, Constraints, and Externalities*. LBNL-2334E. Berkeley, CA: Lawrence Berkeley National Laboratory Report.

Figure 47 shows the breakdown of China's historical electricity generation by primary fuel. Thermal power generation is almost entirely coal-based due to limited domestic natural gas resources, lack of gas price competitiveness compared to coal, and low electricity prices.[58] Although hydropower capacity expanded by more than 25 GW between 2008 and 2009, actual generation dropped from 563 to 513 TWh over the same period. The 9% drop of hydroelectricity in 2009 was partially offset by a 7% growth of coal-fired electricity. Increased frequency of droughts in China suggests that increased hydropower may not be a reliable option for decarbonizing the electricity system.

Given the growth of electricity demand in China, two basic mitigation options are switching from coal to less carbon-intensive fuels and improving efficiency. Efficiency can be improved in the coal-fired generator, in the transmission and distribution of electricity, and in the electricity end use. On the transmission and distribution side, China has dramatically increased its investment in grid improvements in recent years with 8% of the 2010 stimulus program dedicated to reducing transmission line losses. This level of investment not only surpasses the investment of countries such as the U.S., Japan, Australia, and EU member states, but also makes China the current largest investor in grid improvement with stimulus funds (Figure 48).

Figure 48 2010 Federal Stimulus Investments in Smart Grid by Country

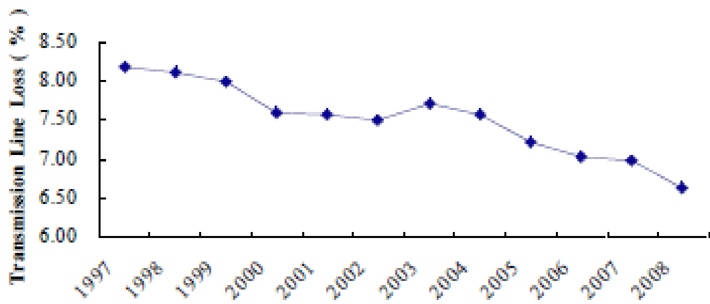


Source: China Electricity Council. 2010. "Smart Grid Snapshot: China Tops Stimulus Funding." Available at: http://www.zpryme.com/reports/smart_grid_snapshot_global_and_china%20federal_stimulus_funding_zpryme_jan27_2010.pdf

[58] Ni, Chun Chun. 2007. "China's Natural Gas Industry and Gas to Power Generation," IEEJ: July 2007.

Correlating to heavy investment in grid improvements, China's transmission line losses have decreased from an average of 8.2% in 1997 to 6.6% in 2008.[59]

Figure 49 Transmission Line Loss Rates, 1997-2008



Source: SERC, 2009.

From 1980 to 2008 the average fleet efficiency of China's coal-fired power generation increased from 27% to 35%. Figure 50 illustrates the corresponding decline of the average amount of coal required to generate a kilowatt-hour from 448 grams coal equivalent in 1980 to 349 gce in 2008. Two mechanisms for improving coal-fired electricity generation efficiency are the closure of small, inefficient generators and the construction of larger, more efficient capacity. As part of the Eleventh Five Year Plan, China has shut down more than 60 GW of less-efficient coal-fired capacity between 2006 and 2009.[60] The pie chart insert in Figure 50 shows the breakdown of coal-fired capacity in 2008; generators with a nameplate capacity less than or equal to 100 megawatts comprised 13% of the total fleet while the most efficient generators were 31% of total capacity.

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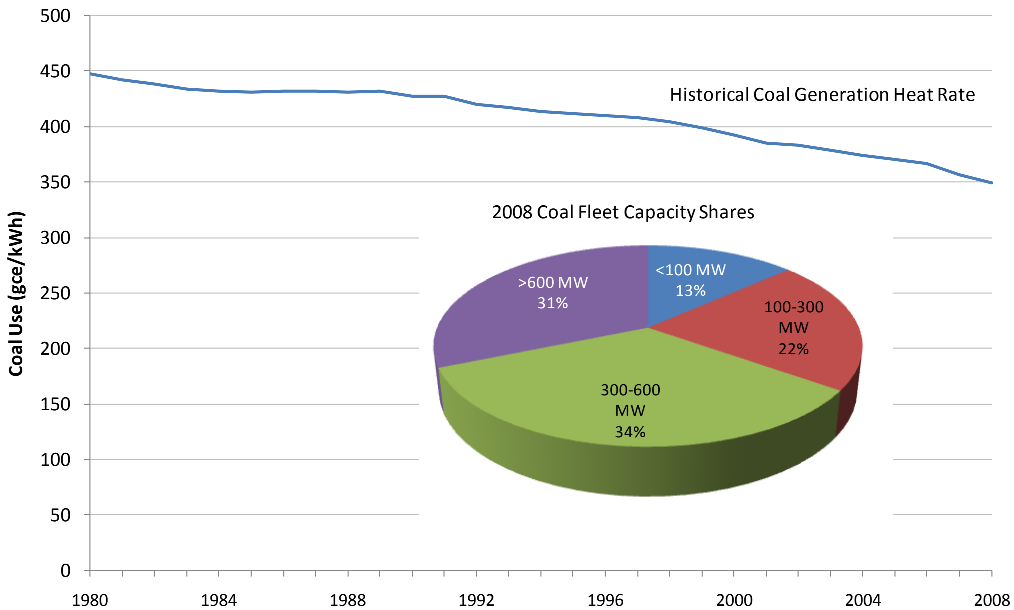
[59] State Electricity Regulatory Commission (SERC). 2009. "SERC Electricity Regulation Annual Report 2008." Translated by Jim Williams, Ding Jianhua, and Fredrich Kahrl; Energy and Environmental Economics, Inc. (E3)

[60] Ministry of Industry and Information Technology of the People's Republic of China. 2010. "2009 National Closure of Small Thermal Power Plants Totaling 26.17 GW Capacity (in Chinese)." Available at: http://www.miit.gov.cn/n11293472/n11293832/n11294132/n12858387/12966802.html.

Figure 50 China Coal-Fired Generation Heat Rates and Technology Shares, 1980-2008



Source: Cai, et. al. 2010. "Revisiting CO2 mitigation potential and costs in China's electricity sector," *Energy Policy* 38 (8): 4209-4213.

5.2 Model Scope and Electricity Scenarios Analysis

The model takes a bottom-up, physical-based approach to quantifying electricity supply, generation efficiency, dispatch, transmission and distribution, and final demand. Reported electricity data from the China National Bureau of Statistics and the State Electricity Regulatory Commission were used to calibrate 2005 base year values. Scenario analysis was extended through 2030 and energy data were used to separately calculate related carbon dioxide emissions. The model uses generation dispatch algorithms, efficiency levels, and capacity factors to calculate the amount of capacity required to serve a given level of final demand.

Power sector primary energy demand and carbon emissions mitigation potential was calculated using four scenarios. The Continuing Improvement Scenario (CIS) incorporates published Chinese government targets for non-fossil capacity growth as well as ongoing efficiency improvements and restructuring of small or out-of-date plants. The Accelerated Improvement Scenario (AIS) is based on more aggressive non-fossil capacity growth and maximum, world best-practice level efficiency improvements. The Carbon Capture and Sequestration (CCS) scenario examines the impact of installing sufficient capacity to capture and sequester 230 million tonnes of carbon dioxide emissions in 2030 based on the China 450 ppm scenario in the 2009 World Energy Outlook.[61] CIS and AIS scenarios do not include CCS capacity. The fourth scenario examines the impact of integrating 42 GW of mine-mouth generation (MMG) capacity

[61] International Energy Agency (IEA). 2009. *World Energy Outlook 2009*. Paris: OECD Publishing.

into China's power system in 2030. Other than the variables described above, the CCS and MMG scenarios are based on CIS assumptions.

Table 27 Scenarios of Power Sector Development

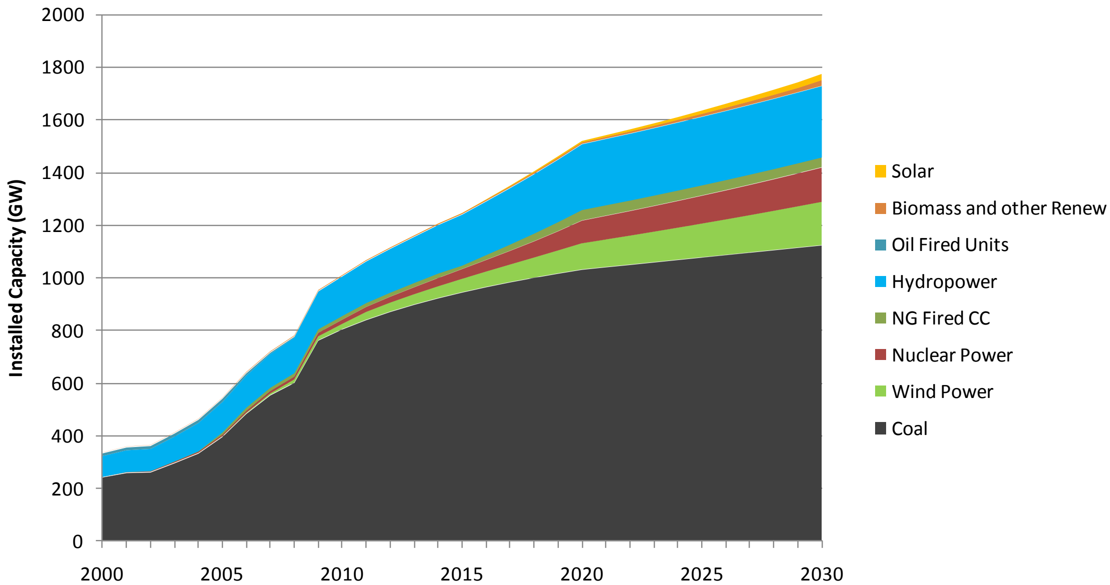
	Key Focus	2030 Primary Energy	2030 CO_2 Emissions	2020 Installed Capacity	2030 Installed Capacity
CIS	Continuing efficiency improvements and fuel shifting	2063 Mtce	4176 Mt CO_2	Solar: 6 GW Wind: 100 GW Nuke: 86 GW Hydro: 250 GW	Solar: 24 GW Wind: 165 GW Nuke: 130 GW Hydro: 270 GW
AIS	High efficiency and renewable eletricity generation	1571 Mtce	2610 Mt CO_2	Solar: 10 GW Wind: 135 GW Nuke: 86 GW Hydro: 300 GW	Solar: 24 GW Wind: 250 GW Nuke: 160 GW Hydro: 330 GW
CCS	Capture and sequestration of 230 Mt CO2 emissions by 2030	2114 Mtce	4164 Mt CO_2	Solar: 6 GW Wind: 100 GW Nuke: 86 GW Hydro: 250 GW	Solar: 24 GW Wind: 165 GW Nuke: 130 GW Hydro: 270 GW
MMG	Integration of 42 GW (4% coal capacity) mine-mouth generation with HVDC by 2030	2062 Mtce	4393 Mt CO_2	Solar: 6 GW Wind: 100 GW Nuke: 86 GW Hydro: 250 GW	Solar: 24 GW Wind: 165 GW Nuke: 130 GW Hydro: 270 GW

Table 27 summarizes key aspects of the four electricity sector scenarios. The middle column shows the modeled 2030 power sector total primary energy requirement of each scenario. Due to the energy requirement for carbon separation, pumping, and storage the CCS scenario has the highest energy requirement. The AIS scenario has the lowest energy requirement, though it is important to note that this analysis focuses on operational energy use and does not include embodied or indirect energy required for equipment manufacturing and technology development. The third column shows that the CIS scenario would generate the highest level of energy-related carbon dioxide emissions, followed by the MMG scenario. The last two columns show the modeled 2020 and 2030 installed capacity for reference.

5.2.1 Continued Improvement Scenario Electricity Assessment

The CIS scenario extrapolates existing policy and market-driven fuel switching and efficiency improvement trends to 2030. Renewable fuels (wind, biomass, and solar) increase their share of total installed capacity from less than 1% in 2009 to 7% in 2020 and 12% in 2030. By 2030 the CIS scenario includes 165 GW of wind capacity, 22 GW of biomass, and 24 GW of installed solar capacity. Non-fossil fuels (renewable plus hydro and nuclear power) increase their share of total from 29% in 2020 to 34% in 2030.

Figure 51 China CIS Electricity Generation Capacity, 2000-2030



Within the CIS scenario fossil fuels have the highest capacity factors, followed by nuclear, hydro, and renewable fuels. Table 28 shows the modeled capacity factor values used in the CIS scenario. However, not all generation technologies are fully utilized due to the generation dispatch algorithm.

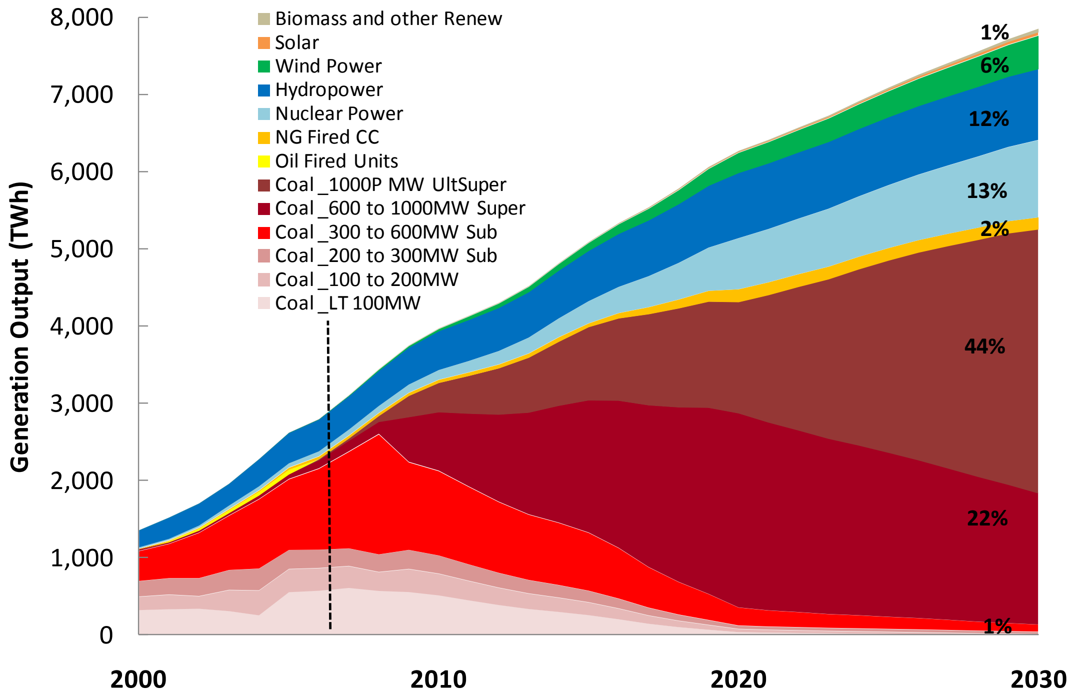
Table 28 CIS Modeled Capacity Factors by Fuel

	Wind	Nuclear	Hydro	Biomass	Solar	Coal
Capacity Factor	30%	88%	39%	25%	19%	90%

In order to focus on fuel switching and efficiency improvements, the model uses a "maximum non-fossil" merit order rather than economic or equally-distributed generation dispatch. Nuclear power is given first priority followed by wind, hydro, natural gas, solar, biomass, and finally coal. Because coal power is last in the dispatch order, actual utilized coal capacity factors are lower than 90% when demand can be satisfied with other fuels. The intermittency of renewable electricity generation is reflected in their lower capacity factors.

Aside from fuel switching, the CIS scenario features efficiency improvements in generation, transmission, and end use. The average generation efficiency of nuclear power rises from 32% in 2005 to 38% in 2020 and 41% in 2030. Coal-fired power generation efficiency also rises with the continued replacement of small, out-of-date plants with state of the art facilities. Transmission and distribution efficiency also continue to improve in line with China's large grid-improvement investments. One impact of China's large-scale grid investment is that average CIS scenario transmission losses decline to 6% in 2030.

Figure 52 China CIS Electricity Generation, 2000-2030



Actual electricity generation in the CIS scenario expands at an average annual growth rate of 4%, from 2,600 TWh in 2005 to 7,900 TWh in 2030. By 2030, renewable fuels provide 7% of total generation and non-fossil fuels account for 31%, as illustrated in Figure 52 above. Actual generation shares are lower than installed capacity shares due to the intermittency of renewable electricity generation.

Table 29: China CIS Electricity Generation (TWh), 2005-2030

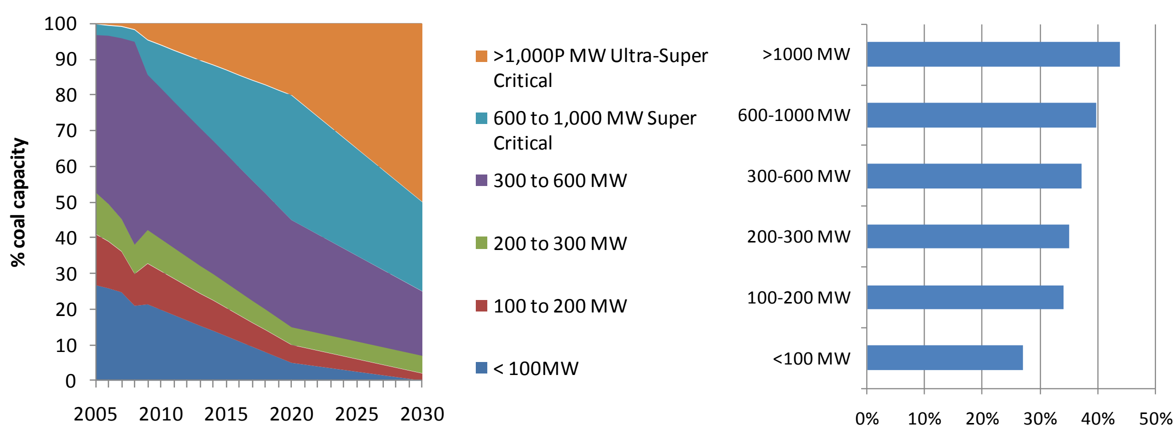
	2005	2010	2015	2020	2025	2030	2010-2030 AAGR
Wind Power	3	29	104	263	338	434	9%
Nuclear Power	53	123	285	662	815	1,004	7%
NG Fired CC	26	42	49	168	163	159	5%
Hydropower	397	510	657	848	884	921	2%
Oil Fired Units	61	-	-	-	-	-	-
Biomass and other Renew	3	6	9	13	23	48	7%
Solar	-	1	2	10	22	40	14%
Coal	2,080	3,266	3,990	4,314	4,853	5,256	2%
Total	2,623	3,976	5,097	6,277	7,097	7,861	2%

Table 30: China Coal-Fired Electricity Generation Efficiency by Technology Type

	g/kWh	efficiency (%)
<100MW	455	27%
100-200MW	360	34%
200-300MW Subcritical	350	35%
300-600MW Subcritical	330	37%
600MW-1000MW Super critical	310	40%
1000MW Utla-Super Critical	290	42%
> Ultra-Sup.-Cri	270	46%

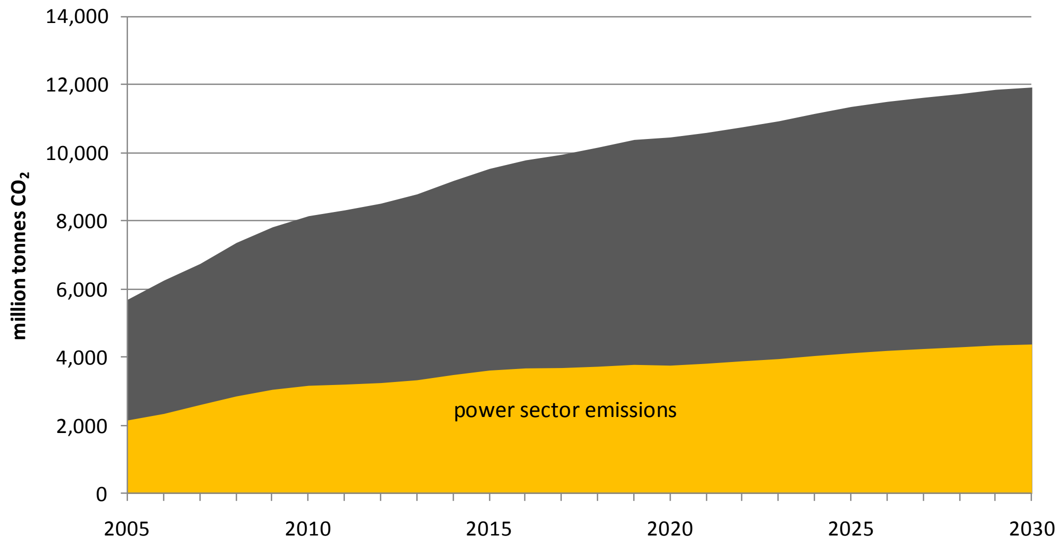
Average coal-fired efficiency improves to 323 grams coal equivalent per kilowatt-hour in 2020 and 304 gce in 2030. This is due to the increasing share of larger, more efficient plants as coal power restructuring policies continue to be implemented. Figure 53 shows the rapid increase of ultra-super critical units larger than 1 GW from less than 1% in 2005 to 50% of total installed coal capacity in 2030; the least-efficient units with a scale of less than 100 MW are completely phased out by 2030. Merit order dispatch is applied to coal generation technologies with the largest, most efficient units coming first. Efficiency improvements are achieved through the structural shift to newer, larger-scale technologies: units larger than 1 GW have an average efficiency of 44% while those less than 100 MW are just 27% efficient.

Figure 53 China CIS Coal-Fired Electricity Generation Technology Shares and Efficiencies, 2005-2030



In this model power sector carbon dioxide emissions are generated by combustion of oil and natural gas (heavy fuel oil electricity generation is completely phased out). CIS power sector emissions double from 2.2 Gt CO_2 in 2005 to 4.4 Gt in 2030. As illustrated in Figure 54 below, the power sector share of total energy-related emissions drops from 38% to 37% over the same period.

Figure 54 China CIS Total and Power Sector Carbon Dioxide Emissions, 2005-2030

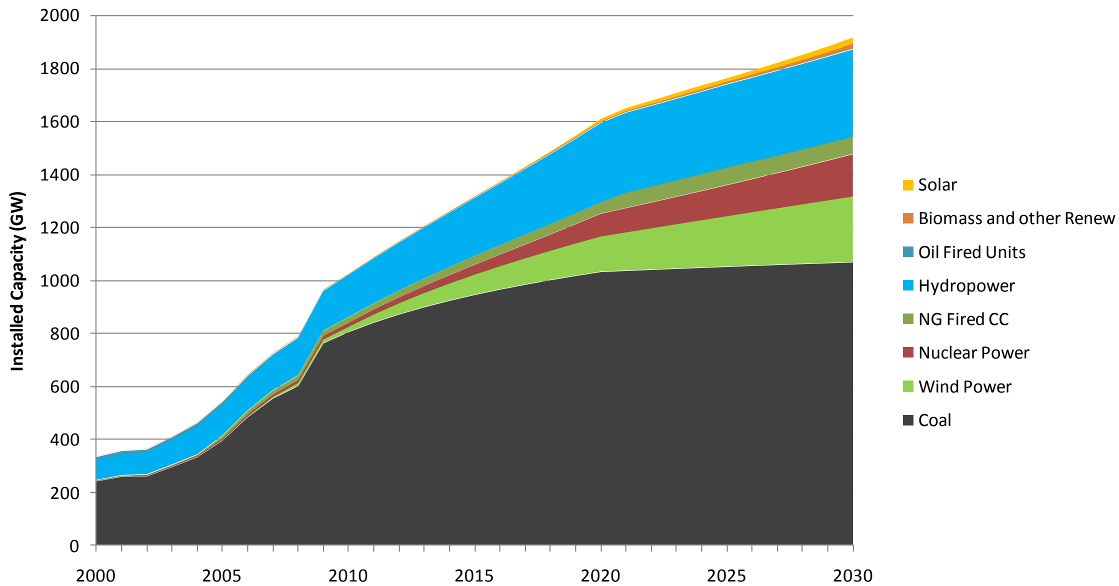


While the power sector share of total emissions remains fairly constant, the energy and carbon intensiveness of CIS electricity production drop due to efficiency improvements and fuel switching. The average primary energy used to generate one kilowatt-hour drops from 330 grams coal equivalent in 2005 to 260 gce in 2030. Carbon intensiveness of electricity production is reduced from 820 grams of CO_2 per kWh to 560 grams of CO_2 per kWh over the same period.

5.2.2 Accelerated Improvement Scenario Electricity Assessment

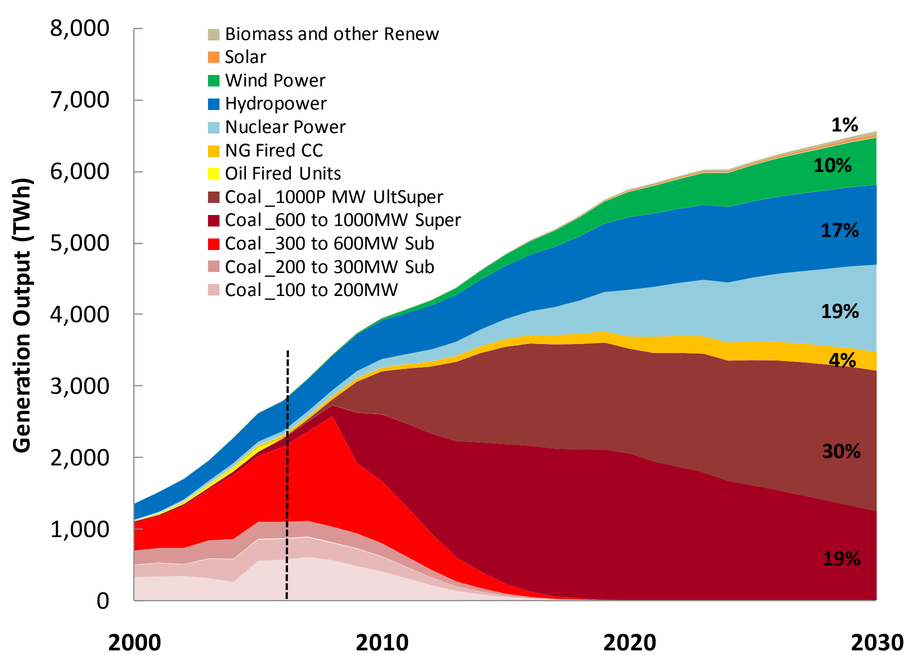
The AIS scenario is based on more aggressive fuel switching and efficiency improvements than the CIS scenario. Renewable capacity grows to 15% and non-fossil fuels comprise 41% of total installed capacity in 2030. Nuclear capacity growth through 2020 is identical to CIS scenario due to the physical challenge of constructing and commissioning more than 13 GW of capacity per year. China's 86 GW nuclear capacity target for 2020 already requires annual capacity additions in excess of 2010 cumulative installed capacity. After 2020 however, AIS installed nuclear capacity grows more quickly, reaching 160 GW in 2030, versus 130 GW in the CIS scenario.

Figure 55 China AIS Power Generation Capacity, 2000-2030



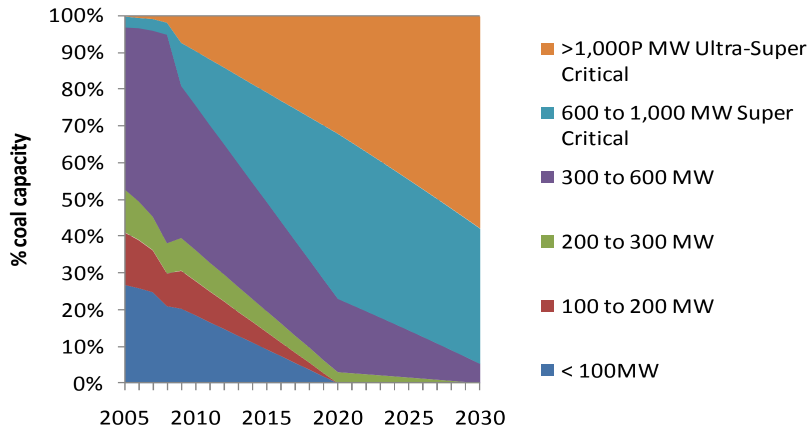
The AIS scenario has higher total installed capacity than CIS because of the intermittency of renewable electricity generation. AIS total installed capacity reaches 1,900 GW in 2030. Solar installed capacity reaches 24 GW, wind 250 GW, biomass 22 GW, and hydro 330 GW in 2030. High non-fossil expansion causes coal installed capacity growth to drop to less than 1% per year after 2020.

Figure 56 China AIS Electricity Generation, 2000-2030



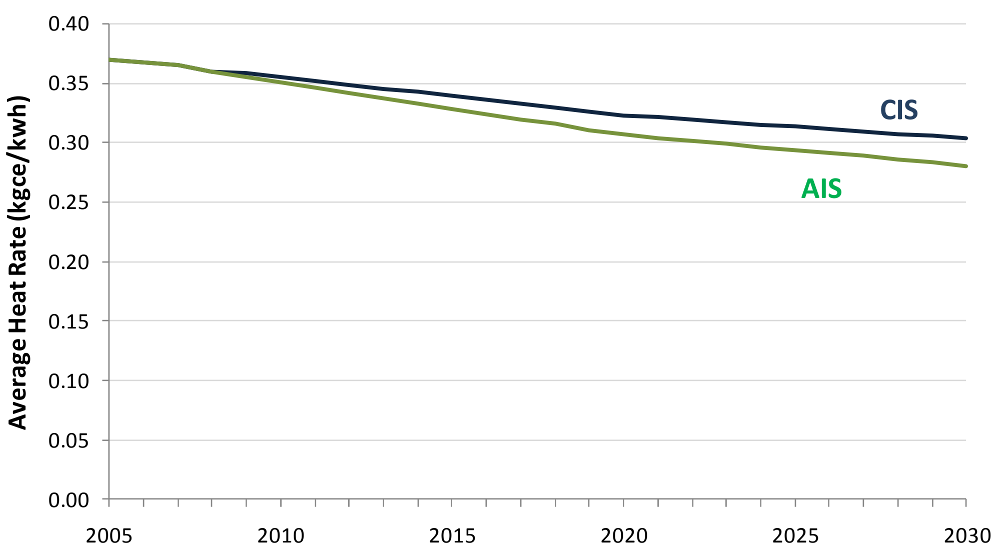
Aggressive renewable energy growth leads to 47% non-fossil electricity generation in 2030, versus 33% in 2030 under CIS. Figure 56 shows the shares of AIS electricity generation by fuel. AIS power sector coal use peaks before 2020 and declines to its 2010 level by 2030. At the same time, the shares of nuclear power generation increased to 19% (from 13% under CIS), of hydropower increased to 19% (from 12%), and shares of wind power increased to 10% (from 6%).

Figure 57 China AIS Coal-fired Electricity Generation Technology Shares, 2005-2030



Coal-fired electricity generation efficiency improves more aggressively in the AIS scenario with a total retirement of less-than-100 MW scale generators by 2020 and a 60% share of greater than one gigawatt ultra-super critical plants by 2030.

Figure 58 China CIS and AIS Average Coal-fired Fleet Heat Rate, 2005-2030



The aggressive shift of AIS coal generation towards larger and more efficient plants is reflected in the lower scenario average heat rate. (Figure 58)

5.2.3 CIS with Carbon Capture and Sequestration Electricity Assessment

The CCS scenario examined the energy and carbon implications of installing sufficient CCS-enabled coal capacity to capture and sequester 230 million tonnes of carbon dioxide in 2030--a level calculated in the 2009 World Energy Outlook 450 ppm scenario.[62] The rationale of the CCS scenario is that China will partially mitigate its carbon emissions while continuing to burn prodigious amounts of coal due to its domestic abundance and benefits for energy security. The costs of CCS, both in terms of capital requirements and additional energy input, have arrested the commercial deployment of CCS.

Table 31 Energy Efficiencies and Penalties by Technology

	Net Plant HHV Efficiency	Total Estimated Penalty
	%	kWh/kg CO_2
Sub-critical PC	24.9%	1.01
Super-critical PC	27.2%	0.83
IGCC pre-combustion	32.5%	0.27

Source: House et. al., 2009. U.S. Department of Energy National Energy Technology Laboratory (NETL). 2007. *Cost and Performance Baseline for Fossil Energy Plants*. DOE/NETL Report-2007/1281.

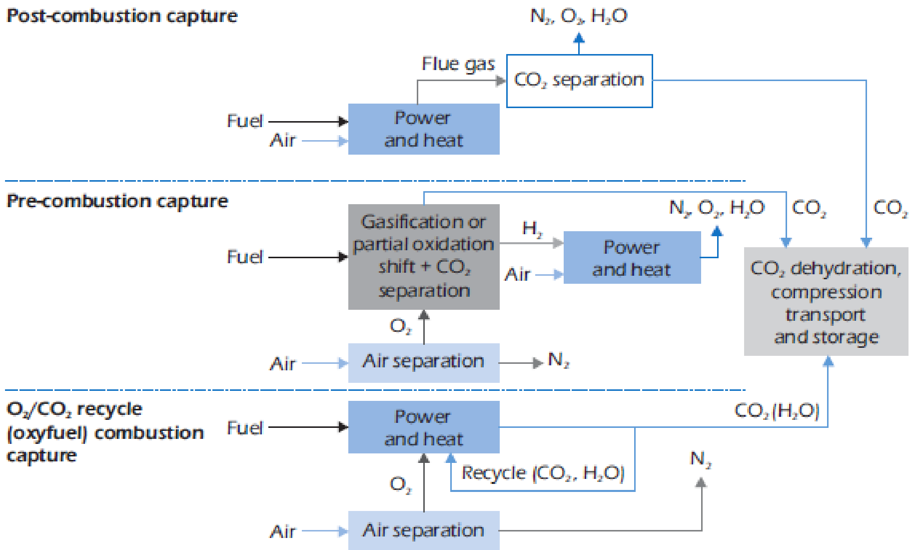
As seen in the table above, published estimates of the energy penalty of post-combustion CCS range from 20% to 80%, with new construction experiencing a smaller penalty than retrofitted plants.[63] There are two reasons for new plants' smaller penalty: they have a lower primary energy requirement for compression due to their higher efficiency; new plants are designed to more easily capture and utilize waste heat for CO_2 separation. The vintage and efficiency of coal-fired power plants influences the CCS energy penalty: the 2007 US fleet ranged from 18.7% to 46.4% thermal efficiency, which would result in energy penalties of 52% and 34%, respectively.[64] As such, the scale of CCS utilization in this scenario would likely require extensive policy support.

CCS capacity is divided between 600-1,000 MW super-critical, greater than one giga-watt ultra super-critical, and integrated gasification combined cycle (IGCC) generation technologies. By 2030 pre-combustion IGCC accounts for 42% of total CCS-enabled capacity and 2% of total coal-fired capacity. This study assumes that the amount of electricity required for post-combustion capture and sequestration of each tonne of carbon dioxide drops from 471 kWh in 2020 to 322 kWh for super-critical and ultra super-critical units in 2030.[65] Oxyfuel carbon capture was not

[62] IEA (2009) *World Energy Outlook 2009*. Paris: International Energy Agency.
[63] Kurt Zenz House et al. 2009. "The energy penalty of post-combustion CO2 capture & storage and its implications for retrofitting the U.S. installed base." *Energy & Environmental Science* 2 (2): 94.
[64] Ibid., 202.
[65] Assuming CCS technology generational improvement as described by Feron, P. 2010. "Exploring the potential for improvement of the energy performance of coal fired power plants with post-combustion capture of carbon dioxide." *International Journal of Greenhouse Gas Control* 4(2): 152-160.

included in this scenario analysis. Figure 59 describes currently-researched CCS technology types.

Figure 59 CCS Technology Types



Source: IPCC, 2005.

This study assumes 90% capture of carbon emissions for pre- and post-combustion technologies. The additional energy requirement of CCS is calculated on the basis of the total electricity penalty per tonne carbon dioxide for each technology type as described above. By 2030 the CCS scenario requires 51 million tonnes coal equivalent more primary energy than the CIS scenario due to the energy requirements of carbon separation, pumping, and long-term storage. In order to supply 2030 electricity demand, the CCS scenario would also require 21 GW more coal-fired capacity, again due to the parasitic load.

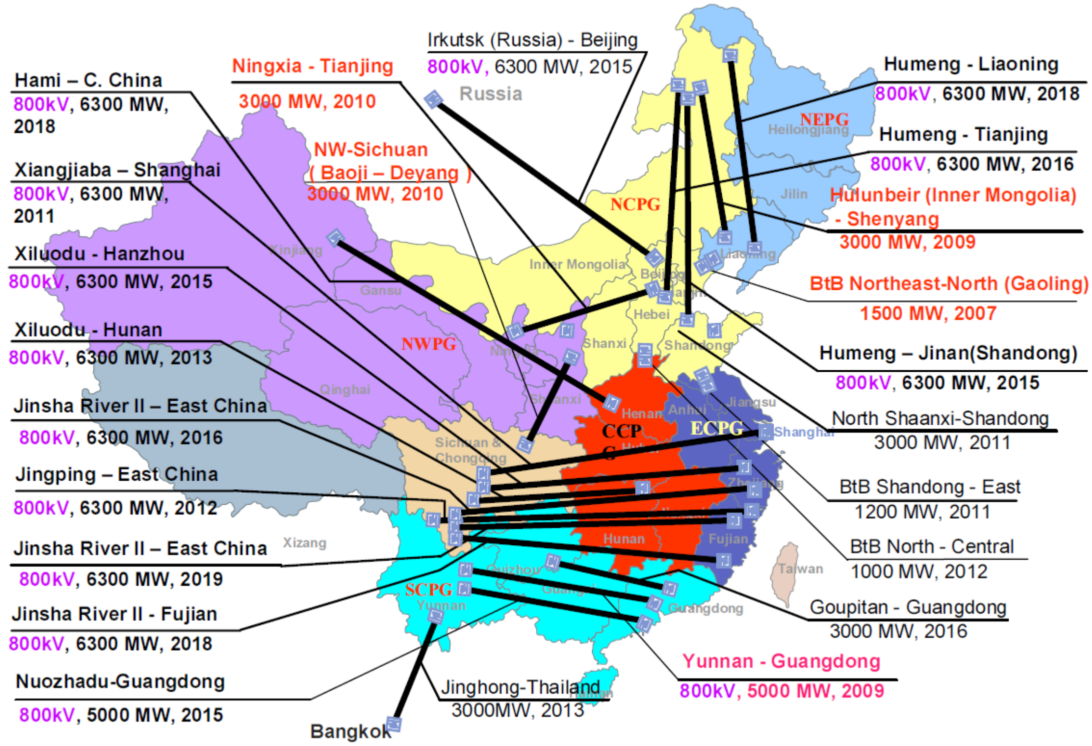
5.2.4 CIS with Mine-mouth Generation Electricity Assessment

The prospect of coal-by-wire serves as a major rationale for implementing high voltage electricity transmission in China. A second rationale for high voltage transmission relates to implementation of China's supply-side rendition of the smart grid. In addition to alleviating coal transport bottlenecks and related transport-fuel demand growth, long-distance transmission can facilitate access to renewable and cleaner energy resources. Hydropower serves as China's second largest source of electricity: in 2007 China generated 15% of its electricity (497 TWh) from hydropower. This portion is likely to grow given China's announced target of deriving 15% of total energy from renewable sources—including hydropower and nuclear—by 2020.[66] Whereas coal resources are concentrated in the northern inland provinces, hydropower is clustered in the west and southwest—274 GW (72% of the country's total exploitable hydropower resource) is located in western China. Moreover, the Chinese smart grid transmission concept envisions south-north grid interconnections that would use hydropower to

[66] China Daily. 2009. "China eyes 20% renewable energy by 2020." Available at: http://www.chinadaily.com.cn/china/2009-06/10/content_8268871.htm

smooth intermittent wind power. Long distance transmission can facilitate access of remote wind and solar resources as well as management of their intermittency.

Figure 60 Planned HVDC Projects in China



Source: CIGRE SC B4 Colloquium on "Role of HVDC FACTS and Emerging Technologies in Evolving Power Systems," 23-24 September 2005 (Bangalore, India); Paper entitled "HVDC Power Transmission for Remote Hydroelectric Plants," p.11.

China's long term electricity policy has focused on the exploitation of western energy resources for coastal demand centers. In 1982 China announced the "West-East power transmission" program to construct three electricity corridors for long distance transmission. In 1989 China completed its first HVDC project—the Gezhouba-Shanghai interconnection of regional grids by +/-500 kV, 1,052 km transmission line. By 2007 there were seven HVDC projects of at least +/-500 kV completed and another four ultra HVDC projects were under construction or in the planning stage.[67] HVDC and HVAC lines serve as the backbone of the West-East power transmission program and the physical interconnectors for China's ongoing grid integration—the government has announced a plan to further consolidate the electricity system to four synchronous grids by 2020. The implementation of high voltage transmission systems has also brought about a host of technical problems; namely: transient instability due to hybrid AC/DC systems and interconnection, voltage instability due to increasingly dense loads, low frequency oscillation, high short circuit current levels, and low thermal stability limits in transmission lines.

[67] Zhou, X., et al. 2010. "An overview of power transmission systems in China." *Energy* In Press, Corrected Proof.

To address these problems and the ongoing need for continued growth, Chinese electricity planners are researching compact transmission lines, parallel and series compensation capacitors, equipment to improve the grid's dynamic reactive power capability, high voltage controlled shunt reactors, high speed protection and special automated control systems. The structure and strategic orientation of China's electricity grid has changed in response to economic development and new policy programs targeting higher renewable energy use. Energy demand surged between 2001 and 2005 to the extent that rolling blackouts disrupted production in coastal and industrial areas for several years. As part of its effort to improve grid security and meet demand, the government is seeking to reduce the coal share of electricity generation by developing an integrated Chinese smart grid. It is clear that the current coal-based electricity system has room for improvement—the question is what transmission system will be most effective for reducing energy losses and emissions while meeting policy goals.

The MMG scenario assumes mine-mouth capacity growth to 42 GW in 2030, divided two thirds-one third between greater-than one giga-watt ultra super-critical and 600-1,000 MW super-critical coal-fired units. In order to move the mine-mouth coal-fired electricity to demand centers, the MMG scenario also includes HVDC transmission with an average loss rate of 3.4%.[68] The energy and emissions impact of the MMG scenario results from the combination of lower transmission losses and displaced rail freight. Assuming that average coal rail freight distances grow from 622 km in 2008 to 800 km in 2030, newly installed MMG capacity would displace 56 billion tonne km of rail freight. However, because rail freight is energy efficient and the scale of MMG generation is still limited, the energy and emissions mitigation impact of the MMG scenario are negligible. Mine-mouth coal generation may help to address logistical bottlenecks, but this analysis suggests that it is not a cost-effective mechanism for reducing carbon dioxide emissions.

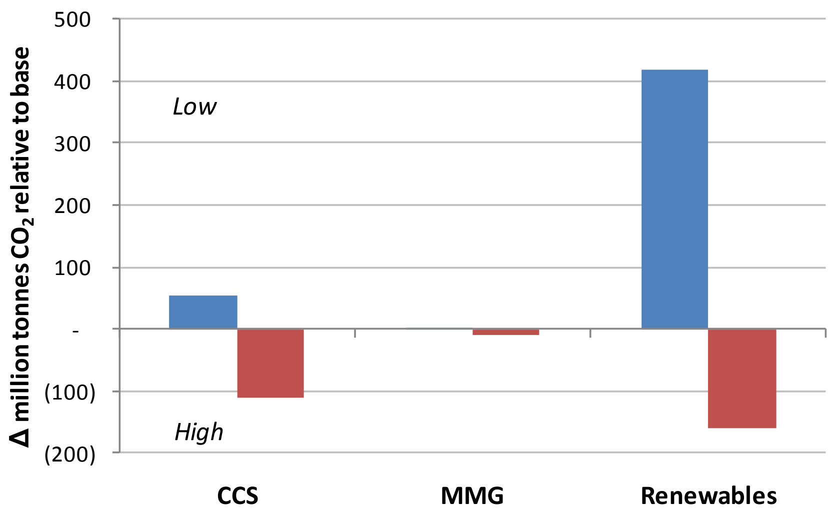
5.2.5 Sensitivity Analysis Scenarios

A sensitivity analysis was performed to compare and contextualize the electricity scenario emissions impacts. The sensitivity analysis varied the levels of CCS and MMG utilization, and the extent of renewable electricity penetration, ceteris paribus. The CCS base scenario featured 48 GW of capacity equivalent to 3% of total power capacity; the CCS low case dropped to 1% of total capacity and the CCS high case rose to 6% of total capacity. The reduction of CCS capacity caused a 55 mt CO_2 increase in emissions while the increased CCS sensitivity case resulted in a 112 mt reduction of CO_2 emissions. The MMG base scenario was based on 42 GW of capacity, thereby comprising 4% of coal capacity; MMG low dropped to 2% and MMG high rose to 9%. Neither of the MMG cases resulted in more than 10 mt change in carbon dioxide emissions. The renewable energy base case assumes 296 GW of renewable capacity in 2030, thereby comprising 15 % of total capacity. The low case drops to 6% and the high case jumps to 20%. Although the low case features a larger change from the base than the high case, both

[68] Bahrman MP, Johnson BK. 2007. "The ABCs of HVDC Transmission Technologies," *IEEE power & energy magazine*, march/april 2007, pp.32-44.

renewable energy sensitivity cases result in almost 300 mt change in carbon dioxide emissions. This suggests that switching to renewable fuels has a larger impact on emissions than CCS or MMG, though this effect also results from the larger base penetration of renewable electricity generation. Figure 61 illustrates the results of the electricity scenario sensitivity analysis.

Figure 61 China Power Sector Sensitivity Analysis Scenarios in 2030

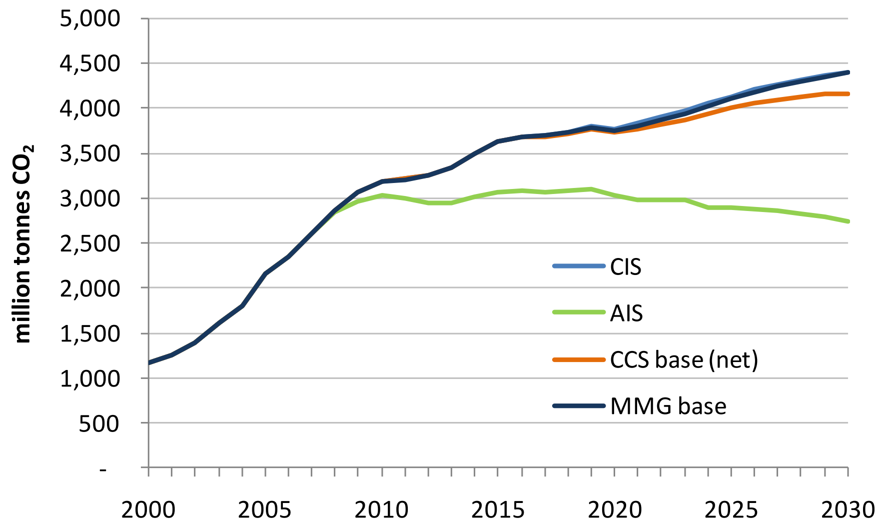


5.3 Electricity Scenarios Implications

5.3.1 Pathways to Decarbonization

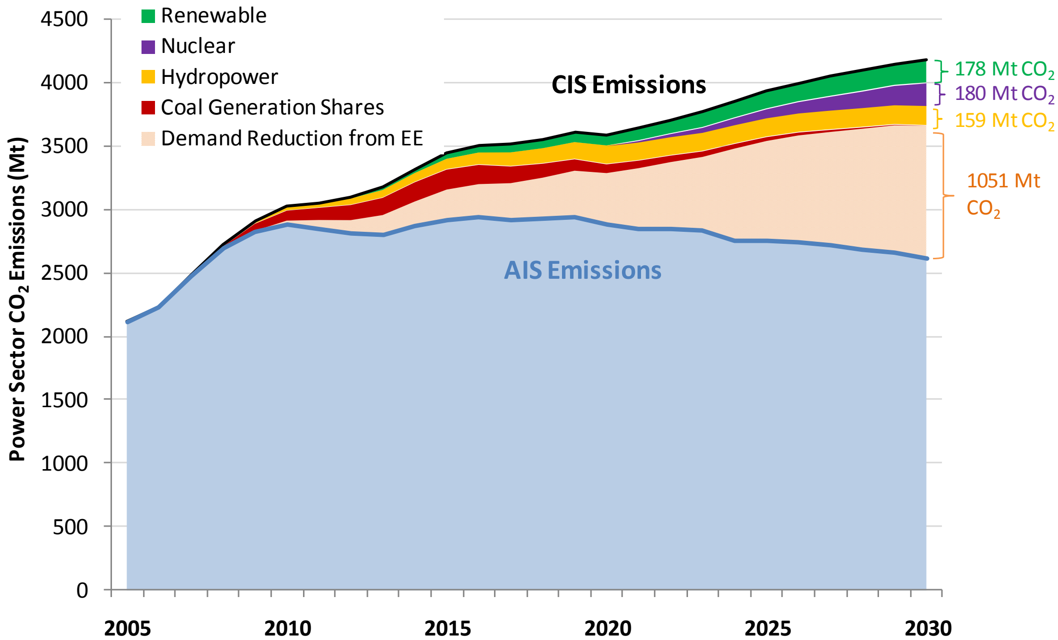
The AIS scenario requires the least primary energy and produces the lowest energy-related power sector carbon dioxide emissions. In fact AIS power sector emissions peak just below 3.1 billion tonnes in 2019 and decline to 2.7 billion tonnes in 2030. The CCS base scenario results in 230 million tonnes less emissions in 2030 than the CIS scenario with a 2% increase in the total primary energy requirement. The MMG scenario has negligible impact on total primary energy demand and related emissions. Figure 62 illustrates the energy-related carbon dioxide emissions of each of the four power sector scenarios.

Figure 62 China Power Sector Emissions Scenarios, 2000-2030



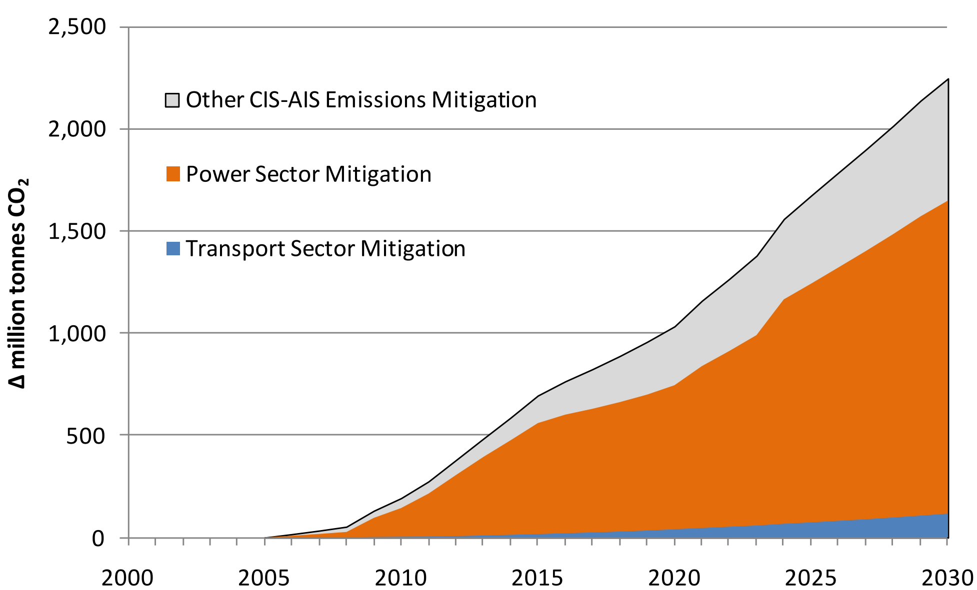
The greatest AIS-CIS inter-scenario carbon emissions mitigation potential within the power sector is from direct electricity demand reduction as a result of more aggressive end-use efficiency improvements in industrial, residential, commercial, and transport sectors under AIS. Figure 63 illustrates five wedges that lead to power sector emissions reductions of 1.5 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. The largest power sector mitigation potential comes from end-use efficiency improvements that lower final electricity demand and the related CO_2 emissions, which is about two-third of total CO2 savings by 2030. Of the CO_2 savings from power sector technology and fuel switching, greater renewable, nuclear and hydropower capacity each contribute similar magnitude of savings by 2030. Although the hydropower installed capacity is 60 GW higher under AIS while nuclear capacity is only 30 GW higher under AIS in 2030, hydropower's lower capacity factor compared to nuclear makes its CO_2 savings slightly lower than nuclear. Prior to 2030, however, CO_2 savings from greater hydropower generation under AIS is the most consistent while both renewable and nuclear CO_2 savings grow over time. The CO_2 savings from shifts in coal generation technology (i.e., greater use of supercritical coal generation) is initially large but declines over time and virtually disappears by 2030 because the merit order dispatch favors renewable generation, which has rapidly growing capacity after 2010. These results emphasize the significant role that energy efficiency improvements play in carbon mitigation in the power sector (vis-à-vis lower electricity demand), as efficiency improvements and can actually outweigh CO_2 savings from decarbonized power supply through greater renewable and non-fossil fuel generation by 2030.

Figure 63 China Power Sector CIS and AIS Carbon Dioxide Emissions, 2005-2030



The total national emissions mitigation potential for moving from CIS to an AIS trajectory is 2.3 billion tonnes carbon dioxide. In 2030, over 70% of the inter-sector mitigation potential is from the power sector. Figure 64 shows emissions mitigation potential according to the sector of origin. Power sector potential is more than thirteen times larger than the transport emissions mitigation effects from vehicle electrification as described in the AIS scenario.

Figure 64 CIS-AIS Inter-scenario Carbon Dioxide Emissions Mitigation Potential by Sector, 2000-2030



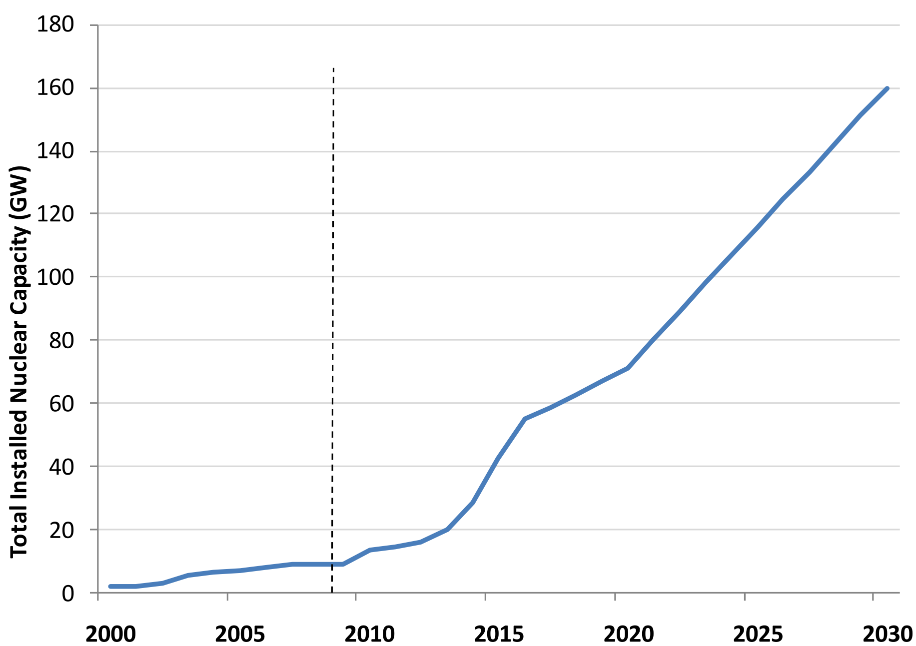
The power sector clearly has the largest potential for carbon dioxide emissions mitigation in China by 2030. However, there are a couple caveats for the picture painted by Figure 64

Namely, power sector decarbonization and transport electrification may be closely linked if electric vehicles can be used a form of energy storage to smooth and compensate for the intermittency of renewable electricity sources. On the other hand, the orange area may understate the importance of the power sector insofar as other sectors use more and more electricity.

5.3.2 Energy Security and Uranium Resource Implications of Nuclear Expansion

Although China has not increase its installed nuclear capacity in recent years and currently only has 11 nuclear plants in operation, capacity expansion is expected to ramp up significantly in the next two decades. Specifically, 20 nuclear plants with total expected capacity of 23 GW are currently under construction and expected to come online within the next four years while 37 more nuclear plants are planned.[69] In light of these planned capacity expansions and China's well publicized targets, both the CIS and AIS scenarios feature aggressive growth of nuclear electricity generation. Using estimations based on the expected capacity and operation date of nuclear plants under construction, planned and proposed, Figure 65 shows AIS scenario nuclear electricity capacity growth from less than 10 GW in 2009 to 160 GW in 2030. The rapid nuclear capacity expansion requires annual construction and commissioning of 3 to 13 GW of new capacity per year after 2010.

Figure 65 China AIS Nuclear Electricity Generation Capacity

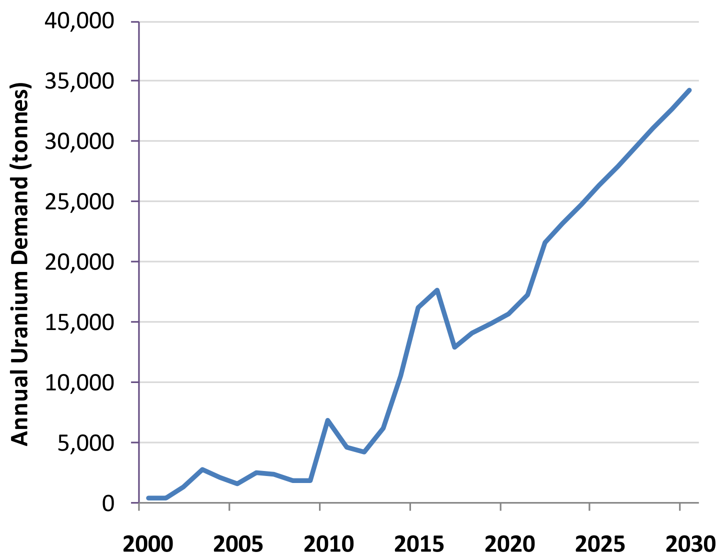


Source: Annual capacity additions estimated based on expected capacity of new plants under construction and planned.

[69] World Nuclear Association. 2010. "Nuclear Power in China." Available online at: http://www.world-nuclear.org/info/inf63.html

Assuming that each new one giga-watt pressurized water reactor requires 600 tons of natural uranium for its initial core and an annual additional 180 tons of natural uranium as burn-up fuel for generating 1 GW of electricity, China is likely to experience an acute uranium gap if it follows AIS-trajectory capacity expansion.[70] Figure 66 illustrates China's total uranium demand based on the capacity expansion shown above. Uranium demand has a large expected bump around 2015 due to the scheduling of several facilities coming on line that year. In 2006 China commenced operations of a 100-tonne per year nuclear fuel reprocessing plant in Lanzhou.[71] While expanded fuel reprocessing may help to reduce import dependence, it will not influence overall demand.

Figure 66 China AIS Uranium Demand, 2000-2030



Although the World Nuclear Association estimates China's known uranium resources to be 70,000 tons U, domestic production is not expected to exceed 2,000 tons per year before 2015. In fact, China already imports half of the uranium resources it uses as nuclear fuel.[72] If demand and supply grow according to scenario analysis, China will be importing more than two thirds of its uranium starting around 2012. Not only would high import dependence undermine China's energy security, but it would create displacement effects insofar as other countries may also seek to use nuclear electricity generation to decarbonize their power systems.

6. Comparison of Scenarios from Published Studies

A comparative analysis of this study’s model scenarios with other recent studies was conducted to examine similarities and divergences in key drivers and results of other recent studies. The

[70] Yang, G. and W. Huang. 2010. "The status quo of China's nuclear power and the uranium gap solution." *Energy Policy* 38: 966-975.
[71] *Ibid*.
[72] Yang and Huang. 2010.

studies included in the comparative analysis are: the *2050 China Energy and CO_2 Emissions Report (CEACER)*[73] published by China's Energy Research Institute, the *China's Green Revolution*[74] report published by McKinsey & Company, the *China's Energy Transition*[75] report published by the Sussex Energy Group and Tyndall Centre for Climate Change Research, and the China-specific section of the *World Energy Outlook (WEO) 2009*[76] published by the International Energy Agency. These reports were chosen because they represent some of the most recent work on Chinese energy and CO_2 emission scenarios or pathways to at least 2030, with WEO and Tyndall extending their scenario analysis as far as 2050. These studies also all included sectoral analysis of the industrial, transport and power sectors. Where comparable, our study was compared with these other four studies in terms of macroeconomic drivers and assumptions, aggregate energy and emission scenario results and sector-specific results.

6.1 Macroeconomic Drivers and Assumptions

A closer examination of two macroeconomic drivers, population growth and urbanization, used in the other four studies reaffirms the values used in this study. Specifically, LBNL's population for 2020 and 2030 as well as urbanization rates are all within the range of CEACER, McKinsey, WEO and Tyndall Centre's assumptions. As seen in Table 32, McKinsey's urbanization rates are lower than LBNL and CEACER's values while Tyndall study assumed a slightly lower population of 1.44 billion in 2030.

Table 32 Macroeconomic Drivers in Different Studies

	LBNL	CEACER 2009	McKinsey	WEO 2009	Tyndall
Population					
2020	1.42 Billion	1.44 Billion	1.4 Billion	1.429 Billion	
2030	1.46 Billion	1.47 Billion	1.5 Billion	1.461 Billion	1.44 Billion
Urbanization Rate					
2020	63%	63%	57%		N/A
2030	70%	70%	67%		N/A

A closely related driver to population and urbanization is the growth of residential buildings as measured by new construction area. Residential construction in turn is determined by per capita floorspace. As seen in Figure 67, there is a clustering of rural living area assumptions between ERI and LBNL, but a range of values for urban living area. ERI assumes a lower per capita urban

[73] China Energy Research Institute. 2009. *2050 China Energy and CO_2 Emissions Report (CEACER).* Beijing: Science Press, In Chinese.

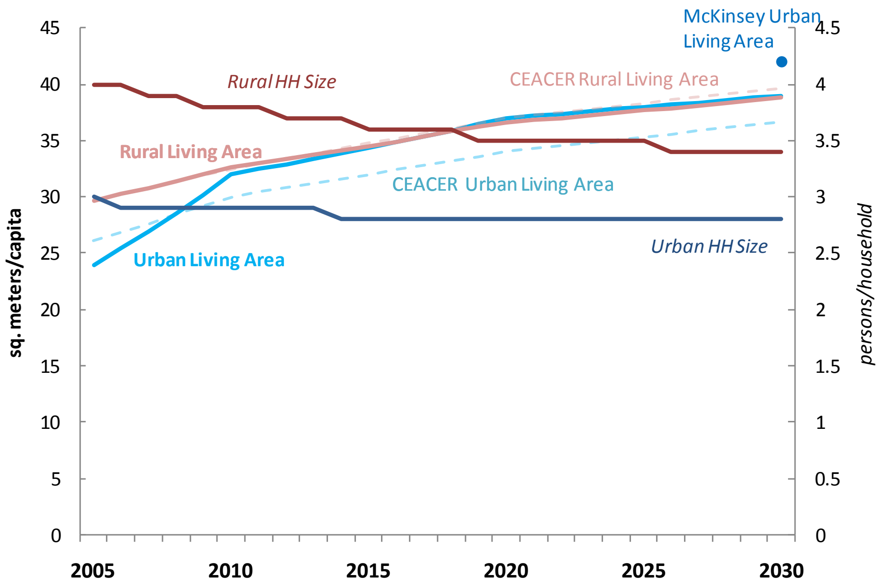
[74] McKinsey & Company. 2009. *China's Green Revolution: Prioritizing technologies to achieve energy and environmental sustainability*. Shanghai: McKinsey & Company.

[75] Wang, T. and J. Watson. 2009. *China's Energy Transition: Pathways for Low Carbon Development*. Available at: http://www.sussex.ac.uk/sussexenergygroup/documents/china_report_forweb.pdf. Brighton: University of Sussex Energy Group.

[76] International Energy Agency (IEA). 2009. *World Energy Outlook 2009*. Paris: OECD Publishing.

living area than LBNL, while McKinsey assumes a slightly higher per capita urban living area in 2030.

Figure 67 Comparison of Residential Living Space and Household Sizes



Consequently, the CEACER study has the lowest total residential construction as well as the lowest urban construction, while McKinsey has the highest floorspace assumptions in urban, rural and total residential construction. In fact, McKinsey's total new residential construction in 2030 is almost 10 billion square meters higher than the value in both LBNL and CEACER studies.

Table 33 Comparison of Residential Construction Area (million m²)

	2005	2010	2020	2030
CIS/AIS Urban	13,547	21,192	33,130	39,815
CIS/AIS Rural	22,231	22,470	19,247	16,973
CIS/AIS Total	*35,778*	*43,662*	*52,377*	*56,788*
CEACER Urban	14,670	19,580	27,810	33,337
CEACER Rural	22,140	22,980	22,830	21,310
CEACER Total	*36,810*	*42,560*	*50,640*	*54,647*
McKinsey Urban	15,000	-	-	42,000
McKinsey Rural	22,000	-	-	24,000
McKinsey Total	*37,000*	-	*55,000*	*66,000*

In terms of annual GDP growth, a key economic indicator and driver of energy demand, there are slight variations amongst the different studies. LBNL's assumed comparable but slightly lower GDP AAGRs after 2010 than CEACER and McKinsey. The Tyndall study, however, used a much lower GDP annual growth rate of 4.3% from 2015 to 2030 while the WEO 2009 annual growth rate of 6.1% from 2006 to 2030 is also on the low side compared to CEACER and McKinsey. Although the differences do not appear large, the compounded effect of annual economic growth actually result in more substantial divergences in economic activity related directly to GDP, such as industrial production and car ownership rates.

Table 34 Comparison of GDP Average Annual Growth Rates (AAGR) used in Different Studies

	LBNL CIS	LBNL AIS	CEACER Reference	CEACER Low Carbon	McKinsey	Tyndall (based on WEO 2006)	WEO 2009
2005-2010	9.58%	9.58%	9.67%	9.67%	9.90%	2004 -15: 7.3%	2006 - 2030: 6.1%
2010-2020	7.67%	7.67%	8.38%	8.38%	8.20%		
2020-2030	5.85%	5.85%	7.11%	7.11%	6.50%	2015-30: 4.3%	

In the production of key energy-intensive industrial products, for example, CEACER and McKinsey both assumed much higher levels of cement and ammonia production than this study in 2020 and 2030. Besides different rates of economic growth, this difference in assumed cement production may also be the result of a purely economic driver-based approach, rather than our physical-driver based approach of forecasting production levels. This may explain why McKinsey and ERI both used lower iron and steel production levels out to 2030 and why ERI used lower ethylene production levels.

Table 35 Comparison of Key Industrial Output Production Levels (Mt of product)

Study Source	2005			2020			2030		
Scenario	**LBNL** *CIS/AIS*	**ERI** *LC/ALC*	**McKinsey** *Base/Abatement*	**LBNL** *CIS/AIS*	**ERI** *LC/ALC*	**McKinsey** *Base/Abatement*	**LBNL** *CIS/AIS*	**ERI** *LC/ALC*	**McKinsey** *Base/Abatement*
Iron & Steel	353	355	355	978	610	596	940	570	776
Cement	1,069	1,060	1,069	1,282	1,600	1,752	1,013	1,600	1,627
Ammonia	41	46	-	43	50	-	43	50	75
Ethylene	8	8	-	40	34	-	52	36	-
Aluminum	8	9	-	16	16	-	17	16	-

Besides differing production levels, the assumed energy intensity of production may also vary depending on the technological outlook for a given industrial subsector under different scenarios. For most key industrial products, the AIS scenario had the lowest energy intensity amongst different LBNL and ERI scenarios while the energy intensity in ERI's Low Carbon and Accelerated Low Carbon scenarios are comparable or within the range of CIS scenario. However, ERI assumed a notably higher energy intensity for ethylene and also higher iron and steel energy intensity.

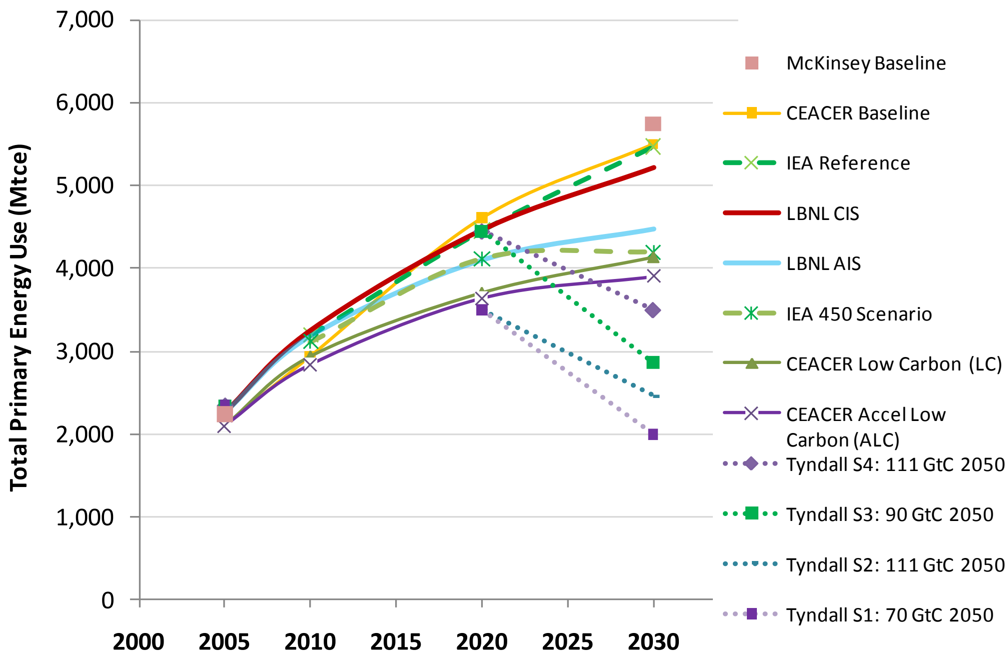
Table 36 Comparison of LBNL and ERI Energy Intensity of Key Industrial Products

Study Source		2005			2020			2030		
Scenario		**LBNL** *CIS*	**LBNL** *AIS*	**ERI** *LC/ALC*	**LBNL** *CIS*	**LBNL** *AIS*	**ERI** *LC/ALC*	**LBNL** *CIS*	**LBNL** *AIS*	**ERI** *LC/ALC*
Iron & Steel	(kgce/ton)	712	712	760	568	482	650	526	400	564
Cement	(kgce/ton)	125	125	132	110	99	101	105	89	86
Ammonia	(kgce/ton)	1,670	1,670	1,645	1,610	1,000	1,328	1,510	901	1,189
Ethylene	(kgce/ton)	700	700	1,092	650	534	796	600	478	713
Aluminum	(kWh/ton)	18,614	18,614	14,320	16,460	12,550	12,870	12,550	10,149	12,170

6.2 Comparison of Aggregate Energy and CO_2 Emission Results

Despite differing assumptions and methodologies, there was general clustering in total energy consumption of different sets of scenarios in the five studies reviewed. The only exception was the scenarios in the Tyndall study, which all resulted in significantly lower total primary energy use because each of the four scenarios had to meet a specific 2050 carbon budget. Thus, the Tyndall study differs from the other studies and may not be comparable as it followed a strictly pre-determined (in terms of total carbon budget) top-down rather than bottom-up modeling approach.

Figure 68 Comparison of Total Primary Energy Use in Different Scenarios



Note: ERI/CEACER numbers converted following IEA convention of using calorific value equivalent for primary electricity.

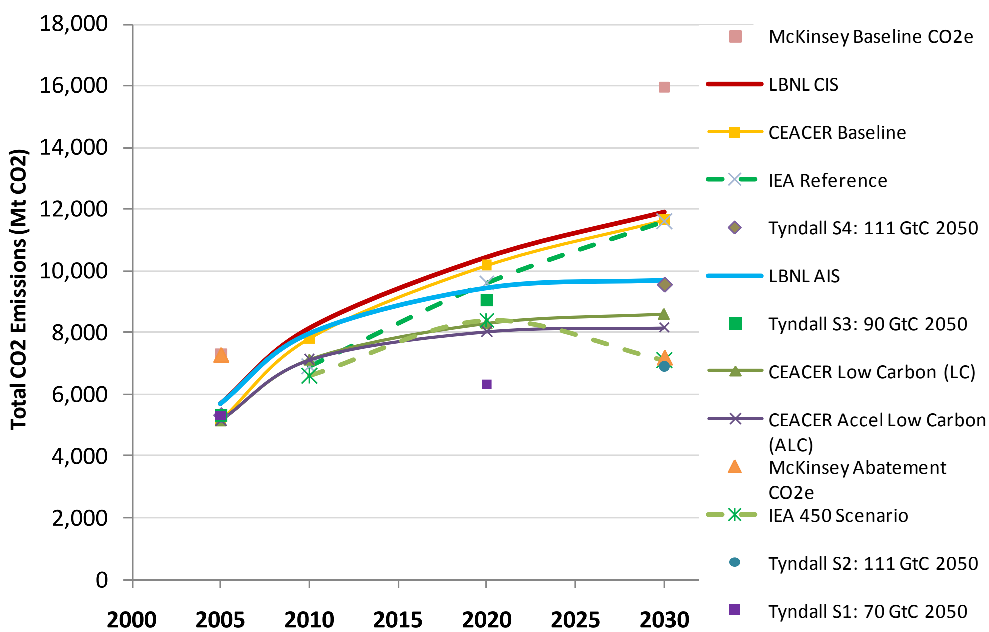
The McKinsey and CEACER baseline scenarios and IEA reference scenarios followed very similar total primary energy use trends with range of 5473 to 5750 Mtce by 2030. The CIS scenario results were also in this same range with 5213 Mtce in 2030, but likely lower because CIS is not business as usual or frozen baseline scenario, but rather represent continuing current and planned portfolio of programs, policies and technology deployment. For the alternative pathway, primary energy use results under AIS were also within the range of IEA 450 and CEACER Low Carbon and Accelerated Low Carbon scenarios. It is interesting to note that despite the very aggressive (e.g., current world best practice by 2020s) efficiency improvements and technology deployments assumed under AIS, its total energy demand was still slightly higher than the CEACER and IEA low carbon scenarios. It is not clear where the McKinsey abatement scenario would fall in terms of total primary energy use as all results for that scenario were given only in CO_2 equivalent terms.

Table 37 Total Primary Energy Use under Different Scenarios (Mtce)

	2005	2010	2020	2030
CEACER Baseline	2,099	2,940	4,608	5,504
CEACER Low Carbon (LC)	2,099	2,941	3,712	4,144
CEACER Accel Low Carbon (ALC)	2,099	2,839	3,643	3,905
LBNL CIS	2,246	3,243	4,459	5,213
LBNL AIS	2,246	3,176	4,097	4,475
Tyndall S1: 70 GtC 2050	2,343	-	3,504	2,000
Tyndall S2: 111 GtC 2050	2,343	-	3,504	2,457
Tyndall S3: 90 GtC 2050	2,343	-	4,452	2,867
Tyndall S4: 111 GtC 2050	2,343	-	4,451	3,500
McKinsey Baseline	2,245	-	-	5,750
McKinsey Abatement	2,245	-	-	Not Given
IEA Reference	-	3195	4457	5,473
IEA 450 Scenario	-	3116	4114	4,197

In terms of total CO_2 emissions, there is a much greater range in scenario results amongst the five different studies due to differing assumptions on mitigation potential and abatement technology deployment. Again, comparisons with the Tyndall scenarios are difficult due to its divergent modeling approach and lack of specific data points for 2030. For the other studies, however, the McKinsey baseline scenario had significantly higher total CO_2 emissions at 16 million tonnes of CO_2e by 2030, as opposed to the clustering around 11,700 million tonnes of CIS and CEACER and IEA baseline scenarios. McKinsey's baseline emissions may be higher partly because it includes other non-carbon greenhouse gases with a higher starting point in 2005, but is still notably higher between the other "baseline" scenarios.

Figure 69 Comparison of Total CO_2 Emissions in Different Scenarios



Comparing AIS with the other abatement scenarios in terms of carbon shows that the other studies relied heavily on CCS for carbon reduction as small differences in total primary energy demand under these scenarios translated into greater differences in CO_2 emissions. In spite of aggressive decarbonization, AIS still had the highest total carbon emissions at 9680 million tonnes of CO_2 in 2030 compared to ~8000 million tonnes under the two CEACER abatement scenarios and 7100 million tonnes under IEA 450. It is also interesting to note that while its baseline emissions were much higher in CO_2 equivalent terms, McKinsey's abatement scenario actually had one of the lowest total emissions by 2030 with comparable emissions to IEA 450 in CO_2 equivalent terms. This suggests that the McKinsey abatement scenario relies heavily on CCS and other non-traditional mitigation technologies to achieve its sizable abatement potential.

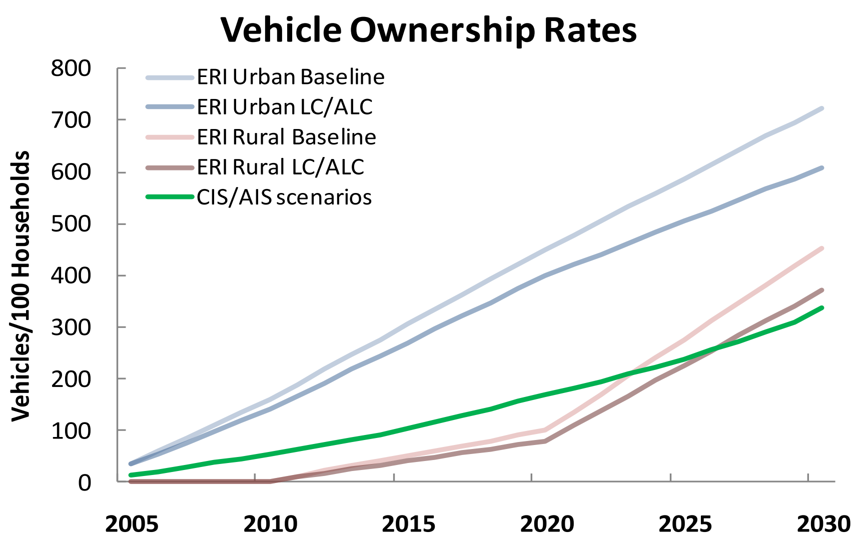
Table 38 Total CO_2 Emissions under Different Scenarios (Mt CO_2)

	2005	2010	2020	2030
CEACER Baseline	5,167	7,825	10,190	11,656
CEACER Low Carbon (LC)	5,167	7,124	8,294	8,598
CEACER Accel Low Carbon (ALC)	5,167	7,124	8,045	8,169
LBNL CIS	5,703	8,154	10,465	11,931
LBNL AIS	5,703	7,961	9,430	9,680
Tyndall S1: 70 GtC 2050	5,317	-	6,321	-
Tyndall S2: 111 GtC 2050	5,317	-	-	6,915
Tyndall S3: 90 GtC 2050	5,317	-	9,038	-
Tyndall S4: 111 GtC 2050	5,317	-	-	9,570
McKinsey Baseline CO2e	7,300	-	-	15,950
McKinsey Abatement CO2e	7,300	-	-	7,210
IEA Reference	-	6900	9600	11,600
IEA 450 Scenario	-	6600	8400	7,100

6.3 Comparison of Transport Sector Results

In understanding differences in scenario results in the transport sector, it is important to first acknowledge differences in methodology and key assumptions. CIS and AIS scenarios have lower implied vehicle ownership than both urban and rural ownership rates in the CEACER study because the total vehicle stock is projected using an econometric model based on income. As seen in Table 34, LBNL assumed slightly lower annual GDP growth rates and thus have lower per capita income levels that translate into lower implied vehicle ownership rates when compared to the CEACER scenarios. The CEACER study also included different urban and rural vehicle ownership rates for the baseline versus abatement scenarios, with urban ownership rates about double that of rural ownership rates.

Figure 70 Comparison of Private Passenger Vehicle Ownership Rates



Partly attributable to lower implied vehicle ownership rates, CIS and AIS also have a smaller fleet of light duty vehicles than the scenarios in other studies. The scenario differences in light duty vehicle fleets is more evident after 2020, with CIS and AIS having 100 million more vehicles in its fleet after 2020 whereas the ERI fleets experience jumps of 160 to 190 million vehicles from 2020 to 2030 and McKinsey study's fleet increases by 140 million vehicles.

Table 39 Comparison of Fleet of Light Duty Vehicles (million vehicles)

	CIS/AIS	ERI Ref	ERI LC/ALC	McKinsey	Ou et. al, 2010
2010	76	68	62	-	-
2020	164.2	195	186	152	-
2030	264.1	380	351	291	338

Note: Ou, X. and X. Zhang. 2010b. Supporting information for "Scenario Analysis on Alternative Fuel/Vehicle for China's Future Road Transport: Energy demand and GHG emissions." *Energy Policy* 38 (8): 3943-3956.

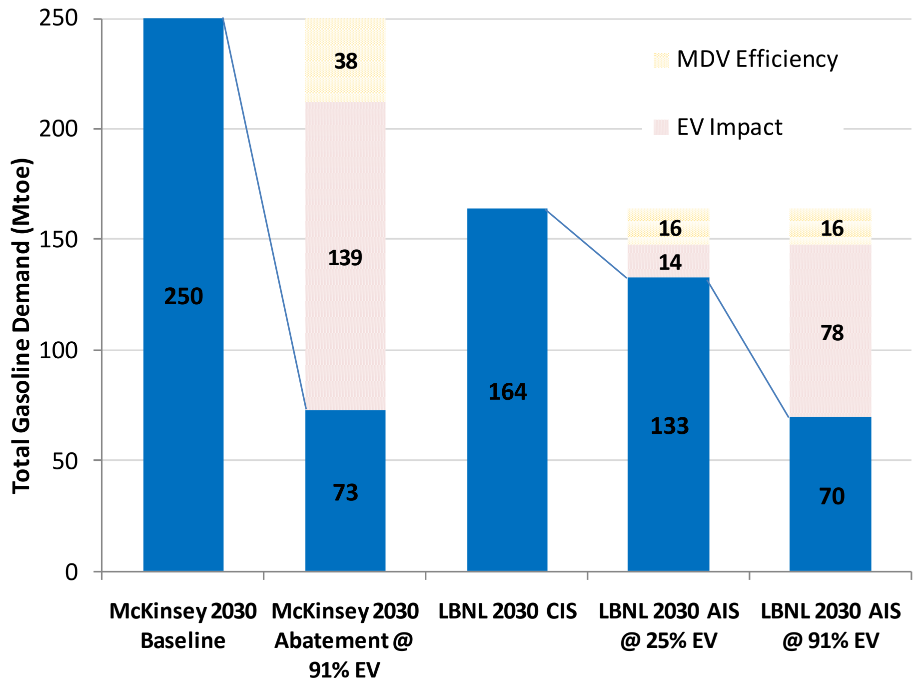
In terms of fuel economy, both LBNL and McKinsey studies assumed similar fuel economy levels for gasoline and diesel cars. McKinsey scenarios were based on slightly greater car efficiency improvements with 2005 levels that are higher than LBNL levels but 2030 levels that are lower than LBNL. For medium duty and heavy duty vehicles, however, LBNL assumes greater improvement on the order of 23% to 27% from 2005 to 2030 relative to McKinsey's improvements of 4% to 13%.

Table 40 Comparison of Fuel Economy Improvement Trends (MJ/km)

	McKinsey 2005	McKinsey 2030	LBNL 2005	LBNL 2030
Gasoline Powered Car	3.23	1.66-2.05	2.8	2.31
Diesel Powered Car	2.93	1.38-1.70	2.2	1.97
MDVs	-	8-13% improvement	-	23-27% improvement
HDVs	-	4-10% improvement	-	23-27% improvement

Despite similar size of light duty vehicle fleets and car fuel economy levels, total gasoline demand under the McKinsey baseline scenario was 90 Mtoe higher than the CIS scenario (Figure 71). The McKinsey scenario also included much greater abatement potential from switching to electric vehicles and efficiency improvements with additional reduction of almost 130 Mtoe of gasoline than AIS. The much higher reduction potential of the McKinsey abatement scenario is partly due to its higher assumed penetration of EVs, with 91% market share by 2030 as opposed to 25% share under AIS. However, even if AIS had a 91% market share of EVs by 2030, its reduction potential would still only be 78 Mtoe as opposed to 139 Mtoe, suggesting there are differences in other variables. Interestingly, though, an AIS scenario with 91% share of EV would have similar total gasoline demand as the McKinsey abatement scenario.

Figure 71 McKinsey and LBNL Transport Abatement Potential



In terms of transport energy demand by mode, CIS and AIS have similar 2050 shares for water and air transport as the Tyndall scenarios. However, Tyndall assumes much higher shares of transport energy consumption from railways in the range of 15% to 23% than either CIS or AIS at 5% and 6%, respectively (Figure 73). In contrast, road transport in all four Tyndall scenarios – including S4 which assumes large private road transport – have much smaller shares of transport energy demand than CIS and AIS.

Figure 72 CIS and AIS Transport Energy Use by Mode

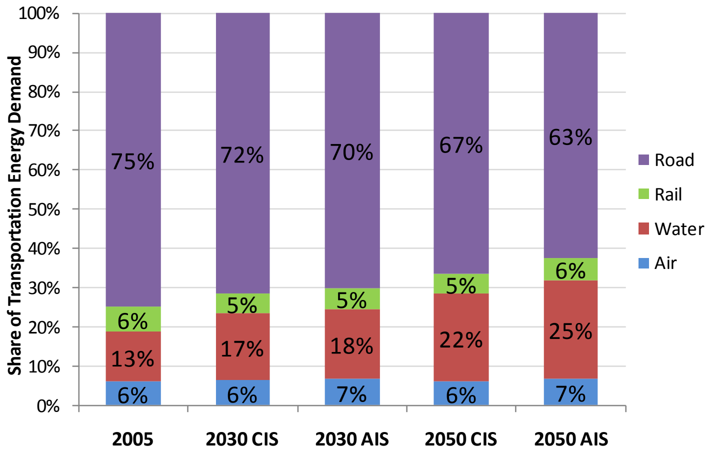
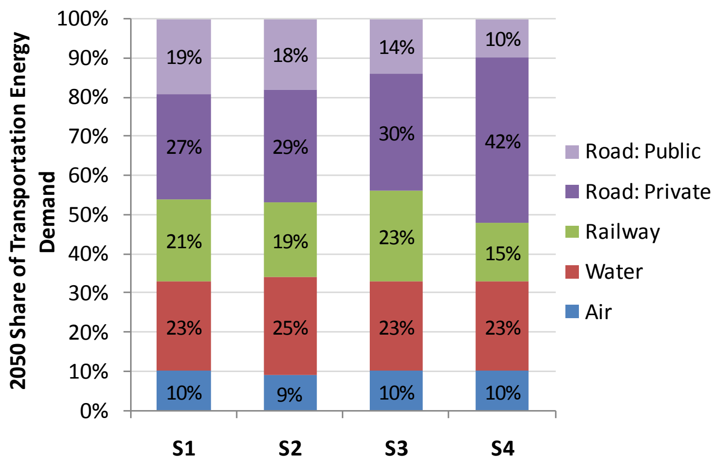


Figure 73 Tyndall Scenarios Transport Energy Use by Mode



S1	S2	S3	S4
High public road transport with residents in small cities and countryside	Similar to S1 but more private and public transport with highest mobility growth	Railways higher with few large and medium cities	Large private road transport, weak public transport

6.4 Comparison of Power Sector Results

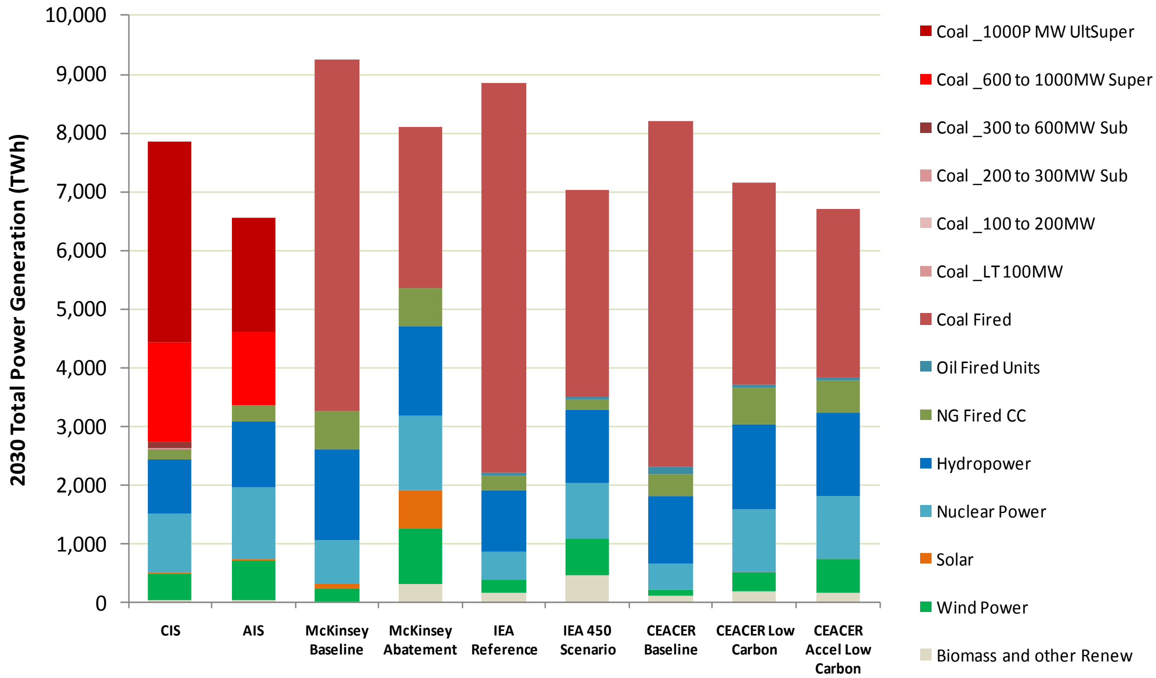
A major difference in the power sector scenario analysis between the different studies is the assumptions about carbon capture and sequestration (CCS) diffusion and utilization in the power sector. For all reference or baseline scenarios including CIS, CCS is not expected to play any roles in the power sector through 2030. However, different extent of CCS utilization is evident in the different abatement scenarios (Table 41). The CIS with CCS scenario in this study is consistent and aligned with the IEA 450 scenario, with CCS expected to be installed and utilized for 5% of fossil-fuel power capacity by 2030. For all their scenarios, ERI does not expect CCS to play a major role in the power sector as CCS will only be installed to IGCC plants after 2030 under the most aggressive accelerated low carbon scenario. In contrast, the McKinsey abatement scenario assumes a much higher CCS utilization rate of 25% of coal power capacity by 2030. The Tyndall study uses a range of assumptions about CCS utilization after 2020 in their four scenarios, ranging from 0% utilization in 2030 in S4 to 30% in 2030 in S3. The Tyndall study further differentiates the pace of CCS deployment after 2030 depending on the policy basis for a given scenario's carbon budget, with a low of 33% of capacity in S2 to a high of 80-90% in S3 and S4 by 2050. Finally, as a result of different CCS assumptions, the carbon mitigation impact of CCS varies between IEA/CIS and McKinsey. While the McKinsey abatement assumption about higher CCS deployment results in a much higher abatement potential of 1.4 Gt CO_2 emissions in 2030, both IEA 450 and CIS with CCS scenario assumptions abatement potential of only 230 Mt CO_2 emissions.

Table 41 Comparison of CCS Assumptions in Different Studies

	% of Coal Power Capacity	*Policy Basis for CCS Diffusion*	*CO_2 Impact*
CIS	None in 2030	-	
CIS with CCS	5% of coal power capacity in 2030	-	230 Mt CO_2 = set to IEA 450 level
AIS	None in 2030	-	-
McKinsey Baseline	None in 2030	-	-
McKinsey Abatement	25% of coal power capacity in 2030	CCS widespread application only after 2020	1.4 Gt CO2 total CO2 abatement in 2030; 120 Mt coal abatement in 2030
IEA Reference	None in 2030	-	
IEA 450	5% of coal and natural gaspower capacity in 2030	-	230 Mt CO2 saved from CCS
Tyndall S1	Not given	compulsory after 2020 and older plants retrofitted where feasible	-
Tyndall S2	33% of coal and gas fired power plants equipped with CCS by 2050	CCS diffuse slower than S1 and only gradually over time	-
Tyndall S3	30% of coal power plants in 2030; over 80% in 2050	Urgent and mandatory from 2020, retrofitted where feasible	-
Tyndall S4	Almonst none in 2030 to 90% in 2050	CCS rolled out quickly after 2030	-
Reference	None in 2030	-	-
LC	Not given	2050 begin CCS for IGCC	-
ALC	100% of IGCC Capacity after 2030	IGCC as main coal technology after 2020, all IGCC has CCS by 2030	-

In comparing the total power generation output of scenarios from different studies, CIS and AIS appear to be within the range of other results (Figure 74). Generation output under AIS is slightly lower than other abatement scenarios, but this is most likely due to more aggressive and detailed assumptions about end-use efficiency improvements like appliances and subsequent electricity demand reduction. Despite having similar installed capacity assumptions as other studies, however, CIS and AIS have different composition of power fuel mix than other studies with generally lower natural gas and hydropower generation, higher nuclear generation in 2030. Compared to other baseline scenarios, CIS also has much smaller coal generation in 2030.

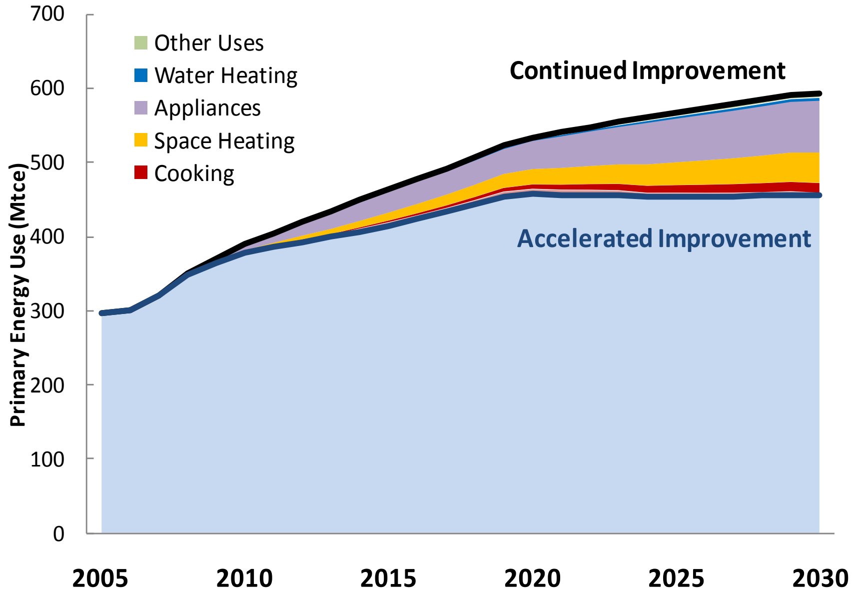
Figure 74 Comparison of Total Power Generation Output in 2030 by Scenario



6.5 Comparison of Other Sectoral Results

In the residential sector, AIS has high energy and emission reduction potential from more aggressive appliance efficiency improvements with savings of 71 Mtce in primary energy and 198 Mt of CO_2 emissions in 2030. As previously mentioned, the detailed assumptions about end-use efficiency improvements in this study can be linked to the high mitigation potential of end-uses like appliances, especially compared to McKinsey abatement scenario's low mitigation potential of 60 Mt CO_2e emissions for appliance efficiency improvements in 2030.

Figure 75 AIS Residential Energy Use Savings by End-Use



7. Conclusions

After a period of energy intensity reductions between 2005 to 2009 under concerted efficiency efforts and programs of the 11th FYP, China's rise in energy intensity in the first quarter of 2010 highlights the challenges of stabilizing total energy demand and emissions in the near future. While the industrial sector will continue to be an important energy consuming sector in a growing China, growth in the transport sector will follow ongoing urbanization and rising per capita income. Likewise, China's increasingly "electrified" economy will drive growth in the power sector, which is currently coal-dominated and very carbon-intensive. This study uses scenario analysis to understand the energy and emissions impact of macroeconomic and sector-specific drivers and analyze possible trajectories to 2030 in light of China's current and planned portfolio of programs and targets.

The results of this study show that China's energy and CO_2 emissions will not likely peak before 2030, although growth in both is expected to slow after 2020. Moreover, China will be able to meet its 2020 carbon intensity reduction target of 40 to 45% under both CIS and AIS, but only meet its 15% non-fossil fuel target by 2020 with more aggressive efficiency measures and deployment of EV and renewable in AIS. Meeting these intensity reduction targets will be possible only with continued efforts in efficiency improvements across sectors, which can result in equally significant emission reductions as electrification and fuel switching in the power sector. In the transport sector, electrification will be closely linked the degree of decarbonization in the power sector and EV deployment has little or no impact on China's crude oil import demand. The power sector has the largest sector potential for overall emission mitigation, with the greatest savings from efficiency improvements and electricity demand reduction while mine-mouth power generation and CCS have limited CO_2 mitigation potential.

Comparisons of this study's results with other published studies reveal that CIS and AIS are within the range of other national energy projections but alternative studies rely much more heavily on CCS for carbon reduction. The higher CCS deployment assumptions in the McKinsey abatement scenario, the IEA 450 scenario and ERI's low carbon and accelerated low carbon scenarios can be seen in the much lower carbon emission trajectories in these scenarios. Moreover, the McKinsey study has more optimistic assumptions for reductions in crude oil imports and coal demand in its abatement scenario, including much higher gasoline reduction potential for the same level of EV deployment. In the power sector, the McKinsey abatement scenario and ERI low carbon and accelerated low carbon scenarios also assume higher power generation output from hydropower and natural gas than AIS.

This study's scenario analysis and comparison of results with other studies all illustrate the necessity for aggressive power sector decarbonization and continued efficiency improvements in flattening China's CO_2 emissions. Achieving this decarbonization will be challenging for China given the remaining uncertainty of CCS technology and the expected but unclear resource constraints to alternative, low-carbon energy such as the uranium gap in nuclear power.

References

Aden, N.T., Fridley, D. and N. Zheng. 2009. *China's Coal Industry: Resources, Constraints, and Externalities*. Lawrence Berkeley National Laboratory Report (LBNL-2334E). Berkeley, CA: Lawrence Berkeley National Laboratory.

American Physical Society. 2010. "Energy Units." Available at: http://www.aps.org/policy/reports/popa-reports/energy/units.cfm

An, F. and A. Sauer. 2004. "Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards around the World." Pew Center on Global Climate Change Report. Available at: http://www.pewclimate.org/global-warming-in-depth/all_reports/fuel_economy

An, F. 2006. "The Chinese Fuel Economy Standards for Passenger Vehicles: How it Works, the Targets, the Effects." *Proceedings from 2006 European-Asian Policy Workshop on Cars, Climate and Energy*: Berlin, Germany.

Bradsher, K. 2009. "China Vies to be World's Leader in Electric Cars." *The New York Times*. April 2, 2009.

Brown, S. et. al. 2010. "Electric vehicles: the role and importance of standards in an emerging market." *Energy Policy* 38 (7): 3797-3806.

BYD Auto. 2010. http://www.byd.com

Cai, W., Wang, C. and J. Chen. 2010. "Revisiting CO2 mitigation potential and costs in China's electricity sector," *Energy Policy* 38 (8): 4209-4213.

Chen, Eadie and Aizhu Chen. "China's energy intensity rises 3.2 pct in Q1." *Reuters International* [Beijing] 6 May 2010. Available at: http://in.reuters.com/article/idINTOE64500C20100506

China Automotive Technology & Research Center (CATARC) and Chinese Automotive Manufacturers Association (CAAM). 2008. *China Automotive Industry Yearbook 2008* (in Chinese). Beijing: China Automotive Research Center.

China Daily. 2009. "China eyes 20% renewable energy by 2020." Available at: http://www.chinadaily.com.cn/china/2009-06/10/content_8268871.htm

China Daily. 2010. "BYD scales back electric-car plans: report." Available at: http://www.chinadaily.com.cn/bizchina/2010-03/16/content_9597028.htm

China Energy Research Institute (ERI). 2009. *2050 China Energy and CO2 Emissions Report (CEACER).* Beijing: Science Press, In Chinese.

China Electricity Council. 2010. "Smart Grid Snapshot: China Tops Stimulus Funding." Available at: http://www.zpryme.com/reports/smart_grid_snapshot_global_and_china%20federal_stimulus_funding_zpryme_jan27_2010.pdf

Energy Information Administration (EIA). 2009. *Annual Energy Review 2008*. Available at: http://www.eia.doe.gov/aer/ Washington, DC: Department of Energy.

Feng, et. al. 2009. "Thinking and Suggestions for Public Transport Development in Chinese Cities." Available online: http://www.vref.se/search.4.46d8812211a06b927e7800021054.html?query=beijing

Feron, P.H.M. 2009. "The potential for improvement of the energy performance of pulverized coal fired power stations with post-combustion capture of carbon dioxide," *Energy Procedia* 1 (1): 1073.

Göttlicher, G. and R. Pruschek. 1997. "Comparison of CO2 removal systems for fossil-fuelled power plant processes," *Energy Conversion and Management* 38, Supplement 1: S173-S178.

He, et. al. 2005. "Oil consumption and CO2 emissions in China's road transport: current status, future trends, and policy implications." *Energy Policy* 33 (12): 1499-1507.

House, K.Z., et al. 2009. "The energy penalty of post-combustion CO2 capture & storage and its implications for retrofitting the U.S. installed base."*Energy and Environmental Science* 2: 193-205.

Huo et. al. 2008. *Projection of Chinese Motor Vehicle Growth, Oil Demand and CO2 Emissions through 2050.* Report ANL/ESD/06-6. Argonne, IL: Argonne National Laboratory.

International Energy Agency (IEA). 2009. *World Energy Outlook 2009*. Paris: OECD Publishing.

Jinan Development and Reform Commission. 2009. "Economic Observer News: Railway Investment Starting to Expand Domestic Demand" (in Chinese). Published 27 May 2009. Available online: http://www.jndpc.gov.cn/E_ReadNews.asp?NewsID=5639

Kobos, P. et. al. 2003. "Scenario Analysis of Chinese Passenger Vehicle Growth." *Contemporary Economic Policy* 21 (2):200-217.

Levine, M.D., et.al. 2010. *Assessment of China's Energy Saving and Emission Reduction Accomplishments and Opportunities during the 11th Five Year Plan*. LBNL Report 3385-E. Berkeley, CA: Lawrence Berkeley National Laboratory.

Levine, M.D. and N. T. Aden. 2008. "Global Carbon Emissions in the Coming Decades: The Case of China." *Annual Review of Environment and Resources.* http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.environ.33.012507.172124.

McKinsey & Company. 2009. *China's Green Revolution: Prioritizing technologies to achieve energy and environmental sustainability*. Shanghai: McKinsey & Company.

Ministry of Industry and Information Technology of the People's Republic of China. 2010. "2009 National Closure of Small Thermal Power Plants Totaling 26.17 GW Capacity (in Chinese)." Available at: http://www.miit.gov.cn/n11293472/n11293832/n11294132/n12858387/12966802.html.

National Bureau of Statistics (NBS). Various years. *China Statistical Yearbooks*. Beijing: China Statistics Press.

National Bureau of Statistics (NBS). 2008. *China Energy Statistical Yearbook 2008*. Beijing: China Statistics Press.

National Bureau of Statistics (NBS). 2010. “2009 Provincial, Autonomous Regions and Municipalities GDP, Energy Consumption and Other Indicators Bulletin.” Published July 15, 2010. Available at: http://www.stats.gov.cn/was40/gjtjj_detail.jsp?channelid=4362&record=1

Ni, C. C. 2007. "China's Natural Gas Industry and Gas to Power Generation." IEEJ: July 2007.

OECD/IEA. 2010. *Energy Balances of OECD Countries (2009 edition).* Paris: OECD Publishing.

OECD/IEA. 2010*. Energy Balances of Non-OECD Countries (2009 edition)*. Paris: OECD Publishing.

Oliver, H.H. et. al. 2009. “China’s Fuel Economy Standards for Passenger Vehicles: Rationale, Policy Process and Impacts.” *Energy Policy* 37 (11): 4720-4729.

Ou,X. and X. Zhang. 2010a. “Scenario analysis on alternative fuel/vehicle for China’s future road transport: Life-cycle energy demand and GHG emissions.” *Energy Policy* 38 (8): 3943-3956.

Ou, X. and X. Zhang. 2010b. Supporting information for “Scenario Analysis on Alternative Fuel/Vehicle for China’s Future Road Transport: Energy demand and GHG emissions.” *Energy Policy* 38 (8).

Ou, et. al. 2009. “Analysis of future domestic EV energy consumption and life cycle greenhouse gas emissions.” *New Energy Vehicle* 1 (in Chinese).

Peeters et. al. 2005. *Fuel efficiency of commercial aircraft: an overview of historical and future trends.* Report NLR-CR-2005-669. Amsterdam: National Aerospace Laboratory.

Rutherford, D and M. Zeinali. 2009. “Efficiency trends for new commercial jet aircraft: 1960 – 2008.” International Council on Clean Transportation (ICCT) report. Washington, DC: ICCT.

Ruzzenenti, F. and R. Basosi. 2009. “Evaluation of the energy efficiency evolution in the European road freight transport sector.” *Energy Policy* 37 (10): 4079 – 4085.

Schuber and Fable. 2005. “Comparative Costs of 2010 Heavy-Duty Diesel and Natural Gas Technologies.” Final Report for California Natural Gas Vehicles Partnership.

Shanghai Government Legislative Information Network, 2007, “Notice of the Shanghai Municipal People’s Government on Approving and Transmitting the ‘Suggestions on Giving Priority to the Development of City Public Transport in Shanghai,’” http://www.shanghailaw.gov.cn/fzbEnglish/page/normative1820.htm

State Council Information Office. 2009. Transcript of Press Conference of the Results of the Second National Economic Census on 25 December 2009. Available online: http://www.china.com.cn/zhibo/2009-12/25/content_19120084.htm

State Electricity Regulatory Commission (SERC). 2009. "SERC Electricity Regulation Annual Report 2008." Translated by Jim Williams, Ding Jianhua, and Fredrich Kahrl; Energy and Environmental Economics, Inc. (E3)

U.S. Department of Energy National Energy Technology Laboratory (NETL). 2007. *Cost and Performance Baseline for Fossil Energy Plants*. DOE/NETL Report-2007/1281.

U.S. Department of Transportation. 2010. *National Transportation Statistics 2010.* Washington, DC. Available at: http://www.bts.gov/publications/national_transportation_statistics/

Wang, T. and J. Watson. 2009. *China's Energy Transition: Pathways for Low Carbon Development*. Available at: http://www.sussex.ac.uk/sussexenergygroup/documents/china_report_forweb.pdf. Brighton: University of Sussex Energy Group.

Weinert, et. al. 2008. "The future of electric two wheelers and electric vehicles in China." *Energy Policy* 36 (7): 2544-2555

World Bank. 2007. "An Overview of China's Transport Sector – 2007." Available at: http:// siteresources.worldbank.org/INTEAPREGTOPTRANSPORT/.../China-Transport-Overview-2007.pdf Washington, DC: World Bank.

World Nuclear Association. 2010. "Nuclear Power in China." Available online at: http://www.world-nuclear.org/info/inf63.html

World Resources Institute. 2007. "Beijing Gives Priority to Public Transportation", http://www.worldwatch.org/node/4895 Washington, DC: World Resources Institute.

Xinhua News. 2009. "China's Aviation Market to Expand 7.9% Annually in Next 20 Years." Available online: http://www.chinadaily.com.cn/bizchina/2009-09/21/content_8714453.htm

Yan and Crookes. 2009. "Reduction potentials of energy demand and greenhouse gas emissions in China's road transport sector." *Energy Policy* 37 (2): 658-668.

Yang, G. and W. Huang. 2010. "The status quo of China's nuclear power and the uranium gap solution." *Energy Policy* 38: 966-975.

Zhou, X., et al. 2009. "An overview of power transmission systems in China," *Energy* In Press, Corrected Proof.