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China Energy and Emissions Paths to 2030 (2nd Edition)

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Executive Summary

After over two decades of staggering economic growth and soaring energy demand, China has started taking serious actions to reduce its economic energy and carbon intensity by setting short and medium-term intensity reduction targets, renewable generation targets and various supporting policies and programs. In better understanding how further policies and actions can be taken to shape China's future energy and emissions trajectory, it is important to first identify where the largest opportunities for efficiency gains and emission reduction lie from sectoral and end-use perspectives. Besides contextualizing China's progress towards reaching the highest possible efficiency levels through the adoption of the most advanced technologies from a bottom-up perspective, the actual economic costs and benefits of adopting efficiency measures are also assessed in this study.

This study presents two modeling methodologies that evaluate both the technical and economic potential of raising China's efficiency levels to the technical maximum across sectors and the subsequent carbon and energy emission implications through 2030. The technical savings potential by efficiency measure and remaining gap for improvements are identified by comparing a reference scenario in which China continues the current pace of with a Max Tech scenario in which the highest technically feasible efficiencies and advanced technologies are adopted irrespective of costs. In addition, from an economic perspective, a cost analysis of selected measures in the key industries of cement and iron and steel help quantify the actual costs and benefits of achieving the highest efficiency levels through the development of cost of conserved energy curves for the sectors.

The results of this study show that total annual energy savings potential of over one billion tonne of coal equivalent exists beyond the expected reference pathway under Max Tech pathway in 2030. CO_2 emissions will also peak earlier under Max Tech, though the 2020s is a likely turning point for both emission trajectories. Both emission pathways must meet all announced and planned policies, targets and non-fossil generation targets, or an even wider efficiency gap will exist. The savings potential under Max Tech varies by sector, but the industrial sector appears to hold the largest energy savings and emission reduction potential. The primary source of savings is from electricity rather than fuel, and electricity savings are magnified by power sector decarbonization through increasing renewable generation and coal generation efficiency improvement. In order to achieve the maximum energy savings and emission reduction potential, efficiency improvements and technology switching must be undertaken across demand sectors as well as in the growing power sector.

Using the bottom-up conservation supply curve models for the cement industry, the cumulative cost-effective electricity savings potential for 2010-2030 is estimated to be 251 TWh, and the total technical electricity savings potential is 279 TWh. The cumulative cost-effective fuel savings potential is 4,326 PJ which is equivalent to the total technical potential. The CO_2 emission reductions associated with the total fuel saving potential is 406 Mt CO_2. For the steel industry, the cumulative cost-effective electricity savings potential for 2010-2030 is estimated to be 251 TWh, and the total technical electricity savings potential is 416 TWh. The cumulative cost-effective fuel savings potential is 11,999 PJ, and the total technical fuel saving potential is 12,139. The total potential savings from these measures confirm the magnitude of savings in the scenario models, and illustrate the remaining efficiency gap in the cement and iron and steel industries.

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1. Introduction

After over two decades of staggering economic growth and soaring energy demand, China began taking serious actions to reduce both its economic energy intensity (energy consumption per unit of gross domestic production) and carbon intensity (CO_2 emissions per unit of GDP). The 11th Five Year plan target of reducing economic energy intensity by 20% from 2006 to 2010 was followed by new and revitalized policies and programs to improve efficiency across all sectors. In November 2009, China also announced a commitment to reduce its carbon intensity by 40% to 45% below 2005 levels by 2020. Recent reports suggest that the 11th FYP target has been met, and that energy and carbon intensity targets will also be announced for the 12th FYP period of 2011-2015. Against this backdrop of short and medium-term targets for reducing energy demand and emissions, it is important to consider where the largest opportunities for efficiency gains and emission reduction lie from sectoral and end-use perspectives and how they may contribute to the achievement of these targets. At the same time, it is also important to contextualize the targets in terms of how far it will place China in attaining the highest possible efficiency levels and adopting the most advanced technologies.

In order to understand China's possible energy and emission pathways through 2030, this study uses a bottom-up, end-use model and two scenarios to represent energy supply and demand sectors. From a technical perspective, a reference scenario in which China continues the current pace of improvements is compared with a Max Tech scenario in which the highest technically feasible efficiencies and advanced technologies are adopted (irrespective of costs) to identify savings potential by measure and the remaining gap for improvements. In addition, from an economic perspective, a cost analysis of selected measures in the key industries of cement and iron and steel help quantify the actual costs and benefits of achieving the highest efficiency levels through the development of cost of conserved energy curves for the sectors.

This study presents two modeling methodologies that evaluate both the technical and economic potential of raising China's efficiency levels to the technical maximum across all sectors and the subsequent carbon and energy emission implications through 2030. After an in-depth review of the modeling methodologies and the two scenarios adopted for evaluating savings potential, the macroeconomic outlook on China's energy and emissions trajectories is analyzed. Next, detailed characterization of each economic sector (residential, commercial, industrial, transport) in terms of key energy drivers, technology and efficiency trends as well as key underlying parameters for the power sector are presented. The resulting sectoral energy and emissions trajectories to 2030 are then discussed, with particular focus on the energy savings and emission reduction potential from an end-use or subsector level. Finally, the cost analysis of measures in the three selected industrial subsectors provides economic grounding to the technical analysis of industrial efficiency gains.

2. Methodology

The basis for evaluating China's future energy and emissions trajectory and the span of cross-sectoral efficiency gains lies in a bottom-up, end-use model of the Chinese economy to 2030. By adopting an end-use approach to energy and emissions modeling, this study is able to separate out and decompose different magnitudes of potential efficiency gains by sector and by technology. At the same time, scenario analysis enables the modeling of a pathway where efficiency improvements are maximized across sectors to reach the highest technically feasible levels by 2030 in order to assess the combined effects of efficiency on energy and emissions reduction. In addition, a separate cost analysis of efficiency measures in the selected industrial sectors of cement, and iron and steel is conducted to provide a more in-depth look at the costs of conserved energy in industry. The China Energy End Use model, modeling scenarios adopted and cost analysis methodology is described in detail below.

2.1 China Energy End Use Model

Since 2005, the China Energy End Use Model has been continually extended and improved by the China Energy Group and used for various types of policy analysis. The foundation for the model is an accounting framework of China's energy and economic structure using the LEAP (Long-Range Energy Alternatives Planning) software platform developed by Stockholm Environmental Institute. Using LEAP, the China Energy End Use Model captures diffusion of end use technologies and macroeconomic and sector-specific drivers of energy demand as well as the energy required to extract fossil fuels and produce energy and a power sector with distinct generation dispatch algorithms. This model enables detailed consideration of technological development—industrial production, equipment efficiency, residential appliance usage, vehicle ownership, power sector efficiency, lighting and heating usage—as a way to evaluate China's energy and emission reduction development path below the level of its macro-relationship to economic development.

Within the energy demand module, the model is able to address sectoral patterns of energy consumption in terms of end-use, technology and fuel shares including trends in saturation and usage of energy-using equipment, technological change including efficiency improvements and complex linkages between economic growth, urban development and energy demand. For this study, refinements were made to the residential, commercial, industrial, and transport energy demand sectors, including calibrating energy data to 2008 or 2009 using newly revised national statistical data, incorporating newly reported targets for technical change such as equipment energy efficiency standards and rail electrification targets, and in-depth analysis of maximum technically feasible efficiency levels for each end-use. Detailed descriptions of the basis for sectoral energy demand drivers and future technology outlook trends by sector are provided in later sections.

From the supply side, the transformation sector in the model represents energy production subsectors such as oil refining, oil extraction, coking, coal mining, natural gas extraction and power generation. The energy production subsectors accounts for energy input to extracting different types of energy output, and is linked to the demand module. Similarly, following specified power sector module parameters, the model uses algorithms to calculate the amount and type of capacity required to be dispatched to meet the final electricity demand from the economic sectors. Specifically, the China Model uses an environmental dispatch order for generation, which favors non-fossil generation and reflects dispatch priority policies that are being considered in China. In the model, nuclear, wind, hydropower and other non-fossil generation are dispatched first, with coal generation dispatched last to meet all remaining electricity demand. Coal generation is further distinguished into six categories by size and efficiency, ranging from less than 100 MW generation units with average efficiency of 27% to greater than 1000 MW ultra-supercritical generation units with average efficiency of 44%. The model follows merit order dispatch for coal generation, where the largest and most efficient units are dispatched first to represent efficiency gains from structural shift to newer, larger-scale generation and mandated retirement of small, outdated generation units. China's announced targets for renewable generation and nuclear capacity expansion are used as the basis in setting the installed generation capacity.

2.2 Model Scenarios

In order to assess efficiency gains in terms of energy savings and CO_2 mitigation potential by measure and by sector, two key scenarios were developed, the Reference and Maximum Technology (Max Tech) scenarios. Both scenarios share the same demographic and macroeconomic characteristics in terms of population, urbanization and GDP growth as well as subsector drivers of energy demand such as building floorspace, car ownership and industrial production. They differ primarily in efficiency improvements as measured by terms such as equipment unit energy consumption (kWh/year) or energy intensity per ton of industrial product output, as well as technology mix (such as electric vehicles and more efficient electric arc furnaces for iron and steel) and fuel mix.

In particular, the reference scenario was developed to represent a pathway in which the Chinese economy continues a moderate pace of "market-based" improvement in all sectors and adopts all announced policies and goals related to efficiency improvement, such as continuing recent pace of appliance standard revisions and meeting the 2020 goal of 50% rail electrification. Unlike a frozen scenario, which is unrealistic given China's recent commitments to energy and carbon intensity reductions, the reference scenario reflects what is likely to happen and thus serves as the baseline for measuring savings from efficiency improvements.

The Max Tech scenario serves an alternative pathway for development in which efficiency improvements are maximized to the highest technical potential across end-uses in the residential, commercial, industrial, and transport sectors by 2030 as a result of aggressive policies and programs. By serving as the maximum technically feasible level of efficiency, the Max Tech scenario sheds light on the highest potential for efficiency gains from the reference scenario. The Max Tech scenario only takes technical feasibility into consideration and does not consider current economics of the technology such as high costs or commercial deployment barriers. For specific end-uses such as residential appliances, heating and cooling equipment and transport vehicles, the Max Tech scenario means adopting the best known efficiency level that is technically feasible or the saturation of cutting edge technology such as all electric vehicles or organic light-emitting diode televisions that are not yet commercially deployed by 2030. For other energy consuming processes such as the various industrial production processes, the Max Tech scenario embodies the adoption of current international best practice average energy intensity levels before 2030. For the power sector, the Max Tech scenario reflects a more aggressive, policy-driven approach to expanding renewable and non-fossil generation that is beyond the current pace.

The key similarities and differences between the two scenarios are highlighted in the table below. More detailed discussion of scenario assumptions, energy and CO_2 emissions outlook and savings potential are provided in later sections. In almost all instances, improvements in efficiency and technology mix in both scenarios are expected to occur linearly over time without time-specific changes in efficiency. For example, the strengthening of renewable and nuclear generation is expected to occur in a linear rather than stair-stepping fashion between 2010 and 2030. Consequently, the results of the scenario modeling should not be seen as providing short-term forecasts, as actual deployment of technology and efficiency gains will not likely occur in the smoothed path to 2030 employed in this study.

Table 1 Key Differences between Reference and Max Tech Scenarios

	Reference Scenario	**Max Tech Scenario**
Macroeconomic Parameters		
Population in 2030	1.46 Billion	1.46 Billion
Urbanization Rate in 2030	70%	70%
GDP Growth		
2010-2020	7.7%	7.7%
2020-2030	5.9%	5.9%
Residential Buildings		
Appliance Efficiency	Moderate efficiency improvements and Best Practice levels for new equipment are not reached until after 2030	Improvement of new equipment to Max Technology efficiency levels by 2030
Commercial Buildings		
Heating Efficiency	Moderate Efficiency Improvement by 2020	Current International Best Practice by 2020
Cooling Efficiency	Current International Best Practice is reached after 2030	Current International Best Practice by 2020
Water Heating, Lighting and Other Equipment Efficiency	Continuous improvement as a result of technology switching and technology efficiency improvements over time	More aggressive improvements in efficiency to meet highest technically feasible level of efficiency and greater technology switching
Transport Sector		
ICE Efficiency Improvements	Moderate efficiency improvements in fuel economy of aircrafts, buses, cars, and trucks through 2030	Accelerated efficiency improvements in fuel economy of aircrafts, buses, cars and trucks to 2030
Electric Vehicle Penetration	Moderate electric vehicle penetration to 10% by 2030	Accelerated electric vehicle penetration to 25% by 2030
Rail Electrification	Continued rail electrification from 60% in 2020 to 63% in 2030	Accelerated rail electrification from 60% in 2020 to 68% in 2030

Power Sector		
Thermal Efficiency Improvements	Coal heat rate drops from 320 to 257 grams coal equivalent per kilowatt-hour (gce/kWh) in 2030	Coal heat rate drops from 320 to 247 (gce/kWh) in 2030
Renewable Generation Growth	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 355 GW in 2030	Installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 441 GW in 2030
Demand Side Reduction through Efficiency	Total electricity demand reaches 6900 TWh in 2030	Total electricity demand reaches 5200 TWh in 2030
Industrial Sector		
Cement	Meet 2005 world best practice of 0.101 tce/ton cement for Portland cement by 2025.	Meet 2005 world best practice of 0.101 tce/ton cement for Portland cement by 2020.
Iron & Steel	19% production from EAF by 2030, with declining energy intensity in both EAF and BOF.	26% production from EAF by 2030, with faster decline in energy intensity in both EAF and BOF.
Aluminum	Reach current U.S. shares of 65% primary and 35% secondary production by 2030. Reaches final EI of 3.44 tce/ton for primary and 1.3 tce/ton for secondary production by 2030.	Reach target of 20% primary production and 80% secondary production by 2030. Reaches best practice final EI of 2.41 tce/ton for primary and 0.085 tce/ton for secondary production by 2030.
Paper	China reaches energy intensity (weighted by current production process and output shares) of 0.547 tce/ton by 2030	China reaches current world best practice energy intensity (weighted by current production process and output shares) of 0.426 tce/ton by 2030
Ammonia	China reaches energy intensity of 1.402 tce/ton output by 2030.	China achieves all targets set forth in 11th FYP through 2020, with continued decline in energy intensity to 0.901 tce/ton output by 2030.
Ethylene	China meets energy intensity targets through 2020 as set forth in 11th FYP, and reaches energy intensity of 0.559 tce/ton of output by 2030	China meets current world best practice energy intensity of 0.478 tce/ton of output by 2025.
Glass	China reaches a national average energy intensity of 0.298 tce/ton of output by 2030.	China reaches a national average equal to Shandong Top 1000 best practice energy intensity (~current US intensity of 0.262 tce/ton) by 2030.
Other Industry	~50% decline in other industry economic energy intensity (kgce/value added GDP) from current levels due to some efficiency gains and continued economic development (shift to higher value-added production) in trends consistent with other developed countries	Additional 20% efficiency gain by 2030 due to maximized technological improvements in motors for manufacturing industries and in balance of system (e.g., heat exchangers, condensers, pumps, etc.) in chemical and other industries

3. Macroeconomic Outlook

Besides sector specific drivers and technology trends, factors such as gross domestic product (GDP) growth rates, labor force structure, population growth and settlement patterns all have important linkages to China's future energy demand and CO_2 emissions. The compounded effects of these macroeconomic drivers on energy and CO_2 emissions are not directly apparent but rather, are manifested in the different sectoral outlooks. The macroeconomic parameters and drivers described below are assumed to be the same for both scenarios in this study.

3.1 Macroeconomic Drivers

As a key macroeconomic variable, GDP growth directly affects industrial production and trade as well as household income which in turn drive household energy usage, consumption patterns and transport demand. GDP growth also impacts China's labor market and structure, with the expansion of service-sector oriented employees driving commercial floorspace demand. In the model, the same growth rates are assumed for both scenarios but change over time to reflect China's maturing economy and shift away from industrialization. Specifically, fast economic growth is expected to continue from 2010 to 2020 at annual average growth rate of 7.7% before slowing down to 5.9% between 2020 and 2030.

Given China's significant population size, population growth and urbanization is the other major force shaping China's development and energy pathways. Using United Nation's World Population Prospects and published Chinese urbanization outlook, 360 million new residents will be added from now to 2030. China is expected to reach an urbanization rate of 50% within the next year with 70% of the population living in cities by 2030 (Figure 1). The influx of new urban residents will add new mega-cities and second-tier cities that require new infrastructure and buildings (Figure 2). In addition to the indirect energy use for producing building materials such as cement and steel to support infrastructure development, new cities will also drive commercial and residential demand for energy services and spur inter- and intra-city transport activity.

Figure 1. China's Population and Urbanization Outlook

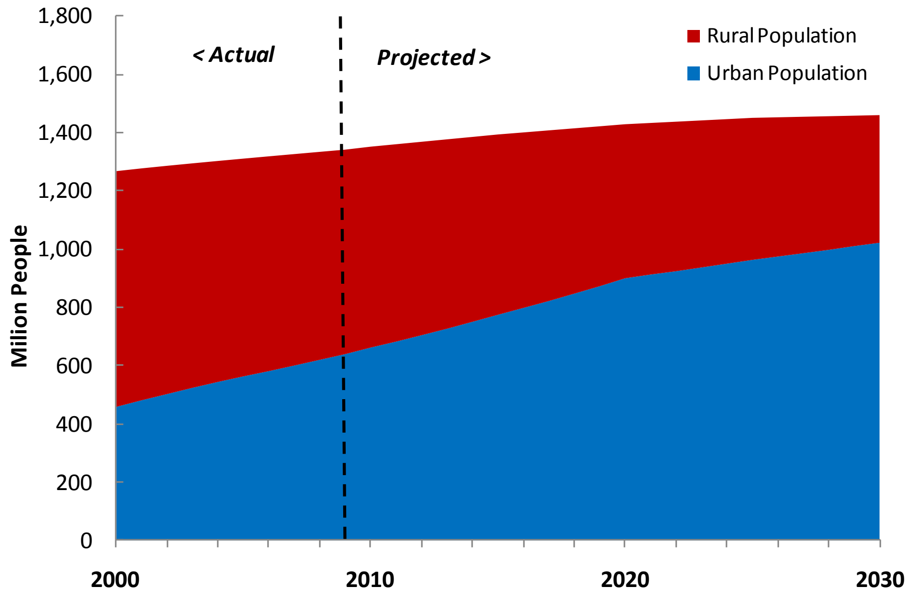
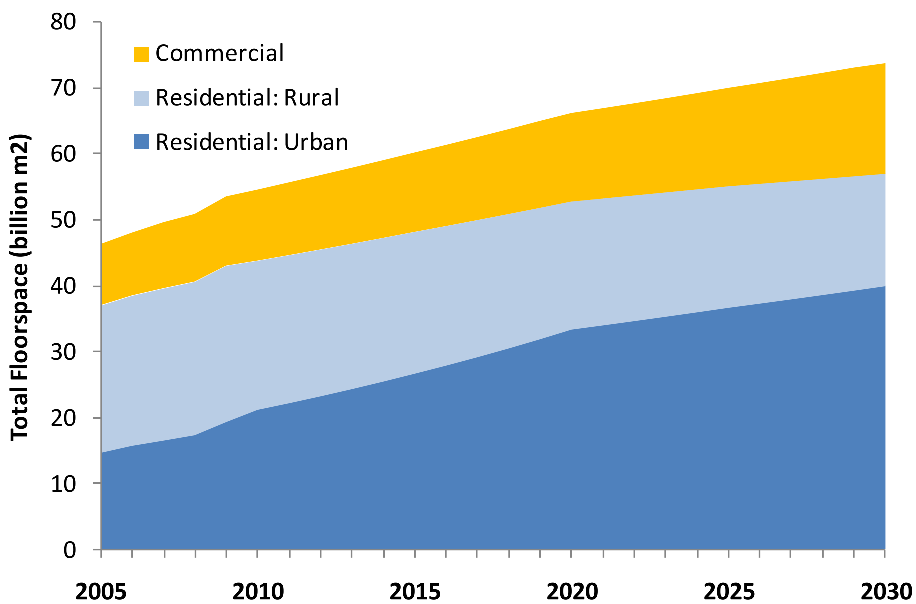


Figure 2. China's Commercial and Residential Building Floorspace Outlook

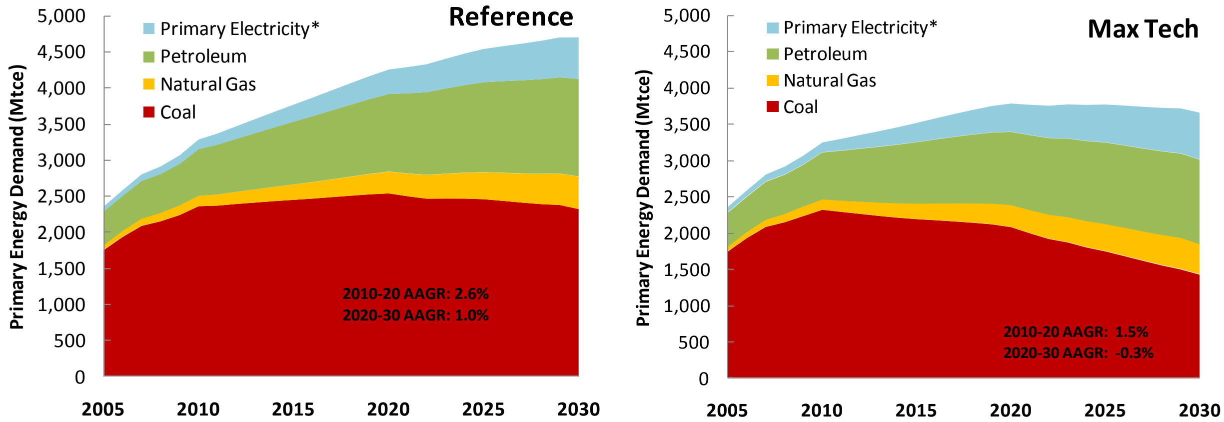


3.2 Macro-level Energy Findings

Total primary energy demand will rise from current levels under both scenarios, but at markedly different paces over the next twenty years. Under the reference scenario, total primary energy demand will continue growing at annual average rate of 2.6% from 2010 to 2020 before slowing to 1.0% annual growth after 2020 (Figure 3, left). The Max Tech scenario follows a very different trend with slower annual average growth of 1.4% to 2020, and then decline at an annual rate of -0.3% to 2030 (Figure 3, right). Unlike the reference scenario, total primary energy use under Max Tech reaches a peak before

2030 at 3790 Mtce. Primary energy savings from 2010 to 2030 under the Max Tech scenario total 10.5 billion tonnes of coal equivalent.

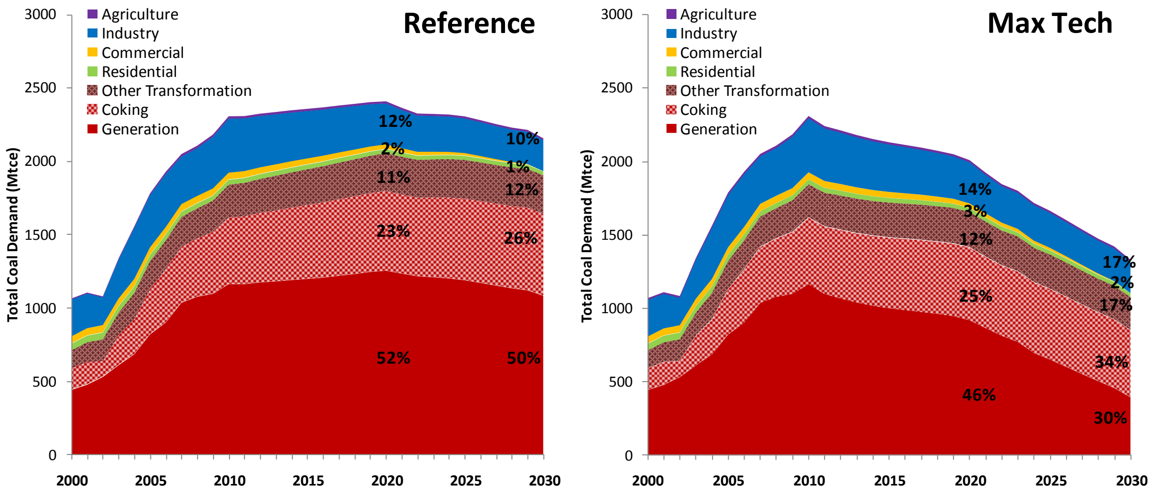
Figure 3. Total Primary Energy Demand Outlook by Fuel, Reference and Max Tech Scenarios



Note: *Primary electricity includes hydropower, wind, solar and other renewables at calorific equivalent for conversion from final to primary energy terms.

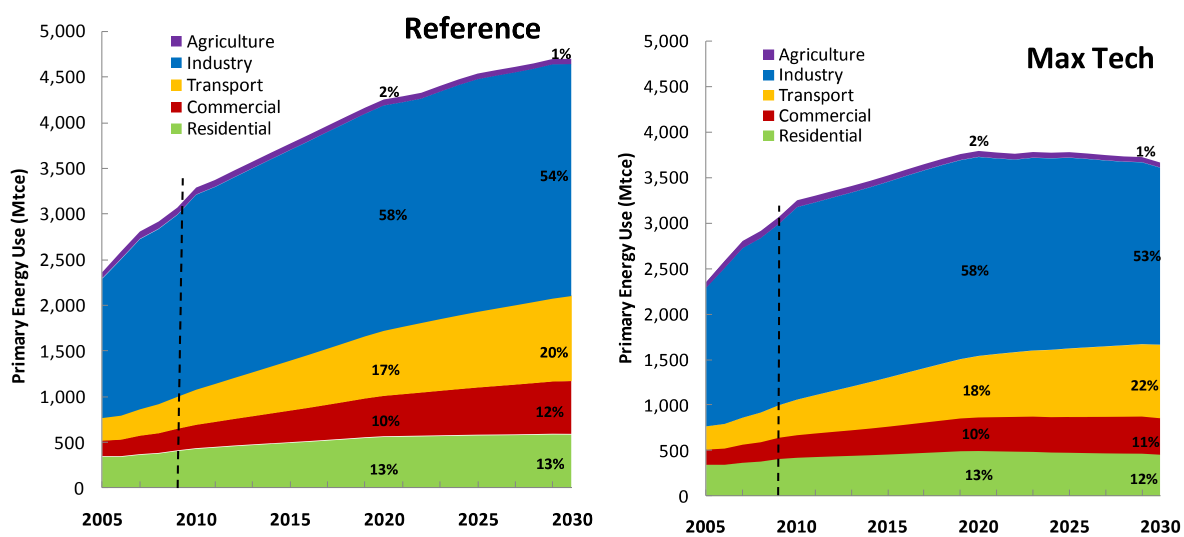
In terms of fuel consumed, the declining primary energy demand in the Max Tech scenario can be traced back to coal's decline as the major primary energy fuel. Coal as a primary energy fuel actually peaks early and contributes to only 39% of total energy demand by 2030 under Max Tech, but stays relatively constant under the reference scenario. In contrast, natural gas, petroleum and primary electricity all rise in absolute value and in shares of total primary energy demand in both scenarios. The decline in coal as a primary energy fuel can be attributed mostly to the transformation sector, since very little coal is used directly by end-use sectors such as agriculture, industry, commercial and residential sectors. Of the transformation end-uses, coal demand for electricity generation flattens under the Reference scenario but declines rapidly after peaking in the Max Tech scenario due to increased installed capacity and dispatch of low carbon and renewable generation as well as overall electricity demand reduction. By 2030, the annual reduction in coal used for electricity generation under the Max Tech scenario is as high as 691 Mtce.

Figure 4. Coal Demand by End-use, Reference and Max Tech Scenarios



From a sectoral perspective, the two scenarios are similar in the sectoral trends of primary energy consumption out to 2030, with industry declining after 2010 but still dominating the majority of energy use with greater than 50% share (Figure 5). In absolute terms, the Max Tech scenario achieves most of its primary energy reduction in the industrial sector, with annual reduction of 596 Mtce by 2030, followed by smaller reductions in commercial, residential and transport sectors. Additionally, commercial and transport are two sectors with rising primary energy use at an annual average rate of over 4% from 2010 to 2030.

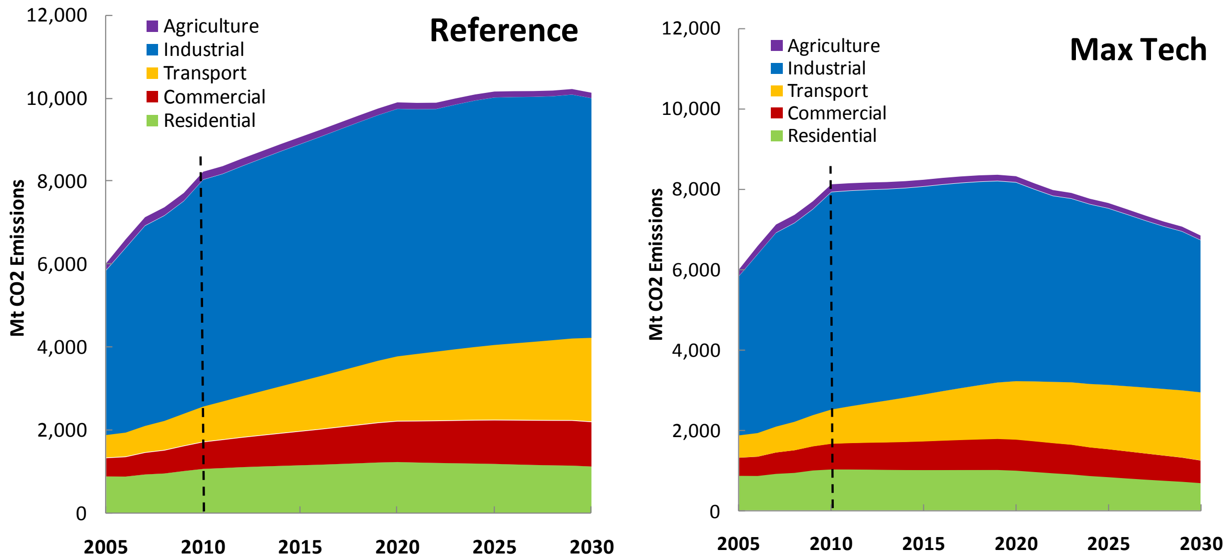
Figure 5. Total Primary Energy Demand Outlook by Sector, Reference and Max Tech Scenario



3.3 Macro-level CO_2 Emissions Findings

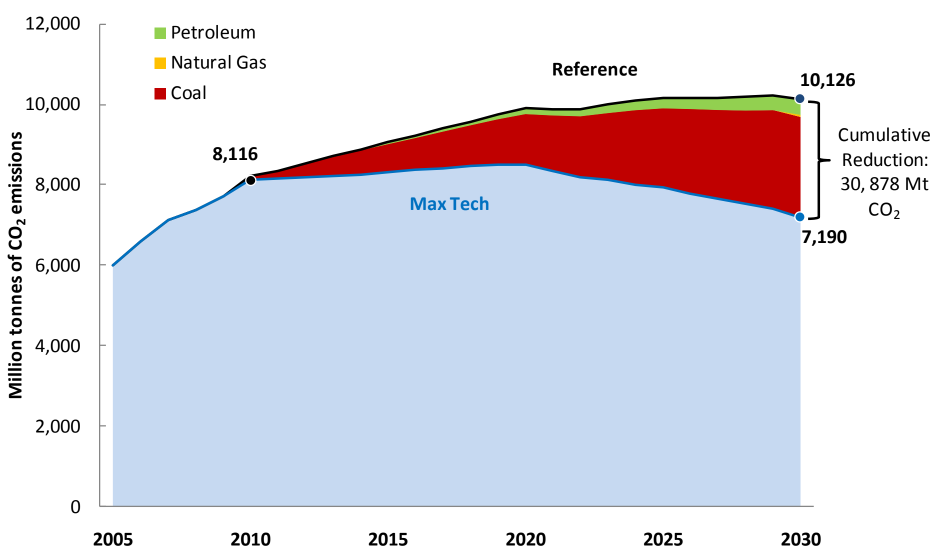
Under the Max Tech scenario, the emissions peak of 8504 million tonnes (Mt) of CO_2 is more accentuated with emissions declining rapidly at -2% per year peaking to a 2030 total that is lower than current emissions (Figure 6, right).This decline achieves annual reduction of 2.9 billion tonnes of CO_2 emissions by 2030, or one-third of total reference emissions in 2030. The Max Tech scenario's emission reduction relative to the reference scenario is possible in spite of growing emissions from the transport sector. As is the case with primary energy use, the industrial sector contributes 58% of the emission reductions under the Max Tech scenario, followed by commercial with 17%, residential with 13% and transport with 11% in 2030.

Figure 6. CO_2 Emissions Outlook by Sector, Reference and Max Tech Scenarios



In terms of fuel source, the vast majority of the emission reduction is in coal-related emissions, followed by a much smaller contribution from petroleum emissions (Figure 7). The cumulative CO_2 reduction under the Max Tech scenario from 2010 to 2030 is 30.9 billion tonnes of CO_2.

Figure 7. CO_2 Emissions Outlook and Max Tech Savings by Fuel



4. Residential Sector Outlook and Analysis

Residential energy demand is driven simultaneously by urbanization and growth in household incomes. Whereas urban households tend to consume more energy than rural households, particularly in non-biofuels, household income growth also affects the size of housing units and subsequent heating and cooling loads, and increase in ownership and use of energy-consuming equipment such as appliances, lighting and electronics.

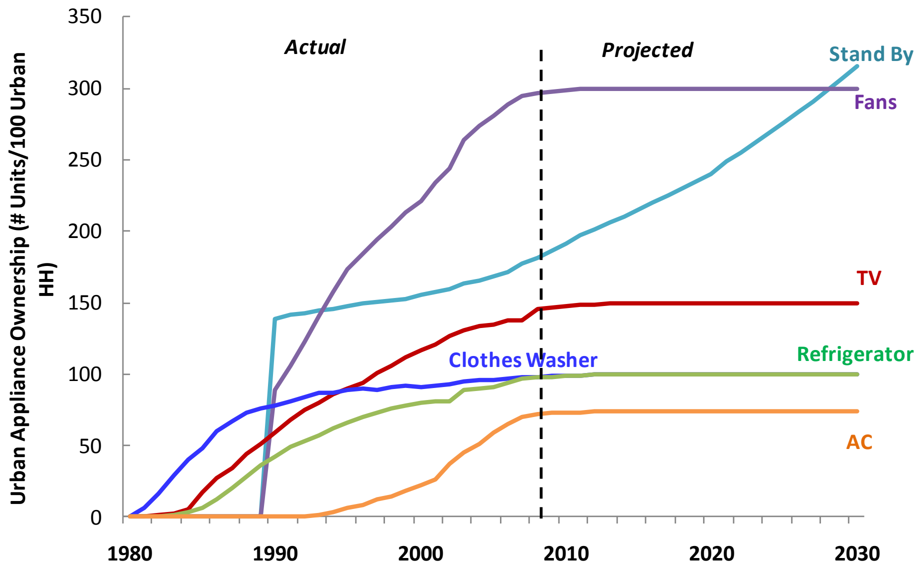
4.1 Key Assumptions and Technology Outlook

4.1.1 Basis for Residential Energy Demand Outlook

With respect to the basis for rising residential energy demand, key assumptions underlying the reference and max tech scenario include household size, residential floorspace per person, and ownership of key energy-consuming appliances. In terms of household size, international experience has shown that household size tends to decline with rising income and urbanization. Combined with China's "One Child Policy", the average urban household size is expected to decline from current levels of 3 persons per household to 2.8 in 2030 while rural households will decline from 4 persons per household to 3.5 in 2030. Following the path of gradual increases in per capita floorspace in developed countries since the 1970s, China's per capita floorspace is expected to continue rising from about 32 m^2/person in 2010 to 39 m^2/person in 2030 for both urban and rural residents. The decline in household size leads to an increase in the total number of households which, together with the increase in living area, will multiply the contribution of energy demand from households.

As seen in Figure 8, Chinese urban appliance ownership exploded in the early 1990s. In forecasting future ownership trends for the largest household energy-consuming appliances, an econometric model correlating historical ownership rates to incomes and using these to predict future trends is used. Significant growth in ownership, especially in the rural sector, is expected and saturation effects will become important in urban households in the near future. Once nearly every household owns a refrigerator, a washing machine, air conditioners and other appliances, growth in per household electricity consumption will slow. Some growth is assumed to continue as incomes continue to rise, resulting in increased usage (especially air conditioners), larger refrigerators, more lighting and more devices using standby power. Meanwhile, space heating intensity and usage also increases with dwelling area and wealth. In addition, the model takes into account prevailing trends in space heating equipment choice, such as an increase in the use of electric heat pumps in the Transition climate zone, and the phase-out of coal boilers.

Figure 8. Historical and Projected Urban Appliance Ownership



4.1.2 Efficiency Improvement and Technology Outlook

Opportunities for reducing energy consumption in households primarily fall in the improvement of equipment efficiency, which rises as the stock turns over and newer, more efficient units replace the retirement of old, inefficient units. In recent years, minimum energy performance standards (MEPS) and voluntary and mandatory energy labeling have driven equipment efficiency improvements in China and is expected to continue in the future. The current schedule of Chinese MEPS standards, with revisions occurring every 4 to 5 years, is taken into account explicitly in the development of the reference and max tech scenarios and is specific to each type of equipment.

Appliance Technology Outlook

Room Air Conditioners

Room air conditioner usage is expected to increase significantly with rising household incomes, as illustrated by the boom in ownership since the mid-1990s. In recognition of this, air conditioner MEPS were implemented in 1999 and revised in 2004 and 2010 in China. The reference scenario thus expects the current pace of revisions to continue, reaching an Energy Efficiency Ratio (EER) of 4 by 2030. Under the Max Tech scenario, MEPS revisions are expected to accelerate after 2010 and reach the maximum technically feasible EER of 6 by 2030.

Standby Power

For standby power, the assumed standby electricity consumption per plug-load is expected to decrease as more product MEPS begin to include maximum standby power consumption requirements for the regulated product. Under the reference scenario, per unit standby power consumption is reduced by 80% from the base level to 1 watt by 2030. The Max Tech scenario considers a much lower per unit standby power consumption of only 0.1 W by 2030.

Fans
As an alternative to room air conditioners, fans have already saturated in terms of ownership and relatively small incremental improvements in efficiency are expected as a result of further MEPS revisions. The reference scenario assumes unit energy consumption will drop from the base level of 10 kWh/year to 8.7 kWh/year by 2030, while Max Tech assumes greater reductions to 6.1 kWh/year by 2030.

Refrigerators
New MEPS were recently implemented for refrigerators and the expected efficiency gains are modeled in both the reference and Max Tech scenario, with an 11% and 15% improvement in unit energy consumption between 2010 and 2020, respectively. After 2020, the Max Tech scenario will reflect more aggressive efficiency improvements of 40% from 2020 level by 2030, compared to only 20% in the reference scenario. In both scenarios, the average size of refrigerators grows over time.

Televisions
Unlike other appliances, efficiency improvements in televisions are expected as a result of both MEPS and technology shift towards more efficient TVs illuminated by Light-Emitting Diodes (LED) instead of Cold Cathode Fluorescent Lamps (CCFL) used in most LCD televisions. Since China introduced flat panel television MEPS in December 2010, both scenarios assume the same pace of MEPS revisions. Specifically, televisions are expected to reach efficiency levels similar to U.S. EnergyStar version 3 specifications as a result of the 2010 standard and subsequent revisions (typically every four years) will achieve approximately half of the efficiency gains from EnergyStar version 4 and 5 specifications. By 2026, both scenarios will meet EnergyStar v.5 specifications with 35% efficiency gain. In addition to efficiency gains from MEPS, television efficiency is also expected to rise over time as a result of the technology shift towards LED and cutting-edge organic LED illuminated displays, which are 40% more efficient than CCFL-LCD TVs. Based on published market forecasts, the relative share of LCD televisions that are OLEDs is expected to reach 50% by 2030 since it will take a few years for the technology to be commercially deployed under the reference scenario, and 100% by 2030 under the Max Tech scenario.

Clothes Washers
Efficiency gains for clothes washers largely result from MEPS revisions, with 15% improvement from current levels by 2030 under reference and nearly 50% improvement by 2030 under the Max Tech scenario.

Residential Heating Technology Outlook
For residential space heating, three technologies are considered including gas boilers, heat pumps, and electric heaters. Gas boilers under the reference scenario is expected to reach 88% efficiency by 2030, with 88% efficiency accelerated to 2020 and the highest technically feasible efficiency of 99% by 2030 under Max Tech. For heat pumps, the coefficient of performance (COP) is expected to reach 2.6 by 2030 under the reference scenario and the highest known COP of 4 by 2030 under Max Tech. Lastly, small efficiency improvements of 5% and 14% are expected for electric heaters under the reference and Max Tech scenarios, respectively.

Residential Lighting Outlook

As with televisions, residential lighting efficiency improvements are also the product of technology shift to LED and advanced LED lighting technology, as well as incremental efficiency improvements within LED technology. Under both scenarios, the proposed phase-out of incandescent lighting will be implemented before 2030 and CFLs will dominate lighting in the short term. Over the long-term, LEDs are assumed to replace 50% of CFLs by 2030 under reference scenario, and 100% under Max Tech. In addition, within LEDs, the Max Tech scenario assumes growing technology shares of more efficient advanced LEDs that use 4.7 kWh/year instead of 7.6 kWh/year after 2015 to 100% advanced LEDs by 2030.

Residential Cooking Outlook

Both electric and gas stoves are assumed to improve by 18% from now to 2030 under reference scenario, and by a much higher 54% under the Max Technology scenario.

Residential Water Heating Technology Outlook

Residential water heating is comprised of electric and gas water heaters, both of which are expected to improve as a result of MEPS revisions. For gas water heaters, the energy factor is assumed to improve from 0.86 to 0.92 by 2030 under the reference scenario, a level comparable to the U.S. Department of Energy's assumed Best Available Technology in the most recent last water heating standard setting process. Under Max Tech, the energy factor increases to 0.96 by 2030, a maximum technically feasible level.

For electric water heaters, continued efficiency improvements as a result of efficiency standards and labeling programs are expected through 2020 under reference and Max Tech, with the energy factor rising from current level of 0.76 to 0.88 and 0.95 in 2020, respectively. From 2020 to 2030, a technology switch from electric water heaters to heat pump water heaters with energy factor of 2.5 is expected to bring significant energy savings in both scenarios.

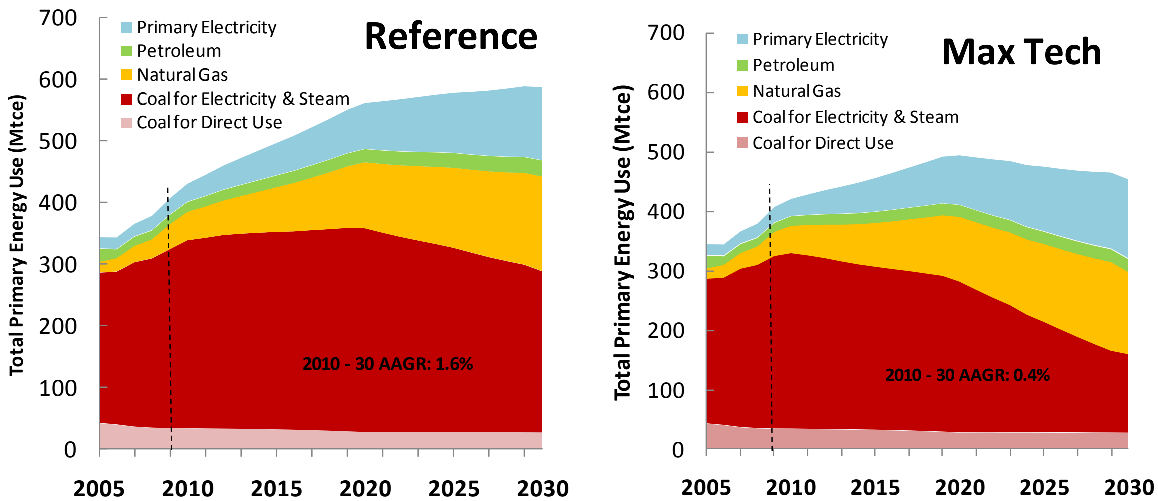
Household Other End-Use Energy Intensity Trends

In order to account for growing ownership and active use of miscellaneous end-uses such as hot water dispensers, entertainment electronics such as DVD players and stereo systems, rice cookers, microwaves, computers and printers, the "other end-use" category was created. Under both scenarios, other end-use energy intensity in urban households is expected to rise from 400 kWh per year per household to 730 kWh per year per household in 2030, or 2 kWh per day. Rural household other end-use energy intensity is expected to remain lower than urban households, with 50% lower growth through 2030.

4.2 Residential Sector Energy and CO_2 Emissions Findings

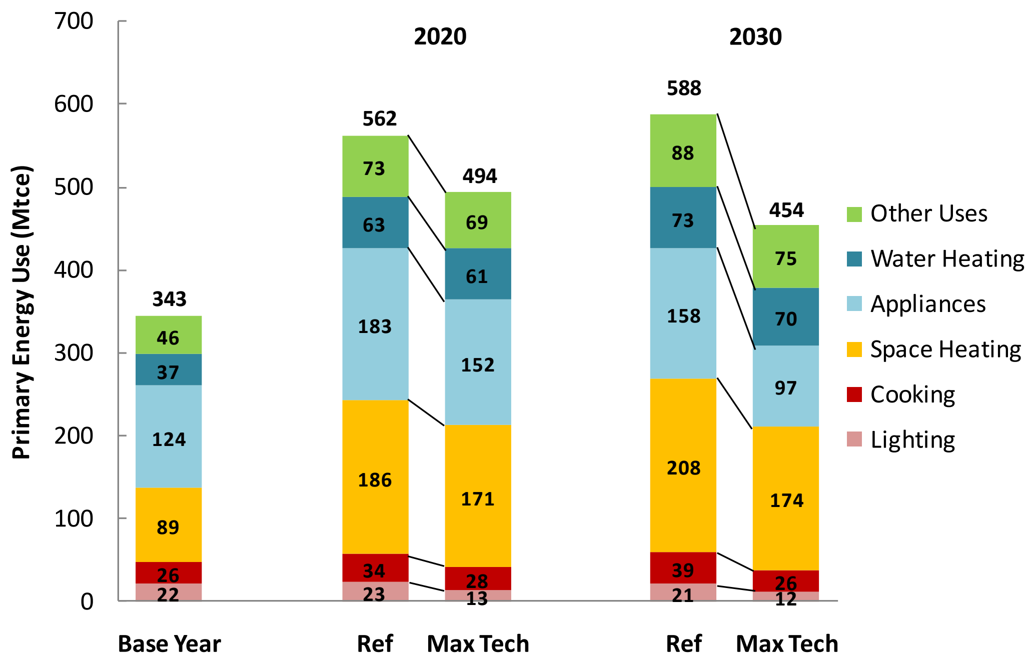
As Figure 9 shows, residential primary energy demand will not peak before 2030 under the reference scenario with rapid growth of 2.7% per year through 2020 and then slowing down to only 0.5% per year by 2030. This slowing of growth is largely due to saturation effects, as the process of urbanization will be largely complete and most households will own all major appliances by 2030. The impact of the aggressive efficiency improvements under the Max Tech scenario is to both cap demand growth in the residential sector and to achieve a reduction in total energy demand after 2020. Under Max Tech, residential primary energy demand peaks after growing at 1.6% per year and reaches a significantly lower level of 23% lower than the reference case by 2030, after declining at nearly 1% per year after 2020. Effects of this magnitude in any sector are significant, and show that policy actions taken now to cap energy intensity in non-industrial sectors can contribute greatly to China's ability to cap energy demand in the long term. In terms of primary fuel, coal for electricity and steam is increasingly replaced by primary electricity and natural gas with only 35% coal share of primary energy under the decarbonized and more efficient Max Tech scenario.

Figure 9. Residential Primary Energy Consumption by Fuel, Reference and Max Tech Scenario



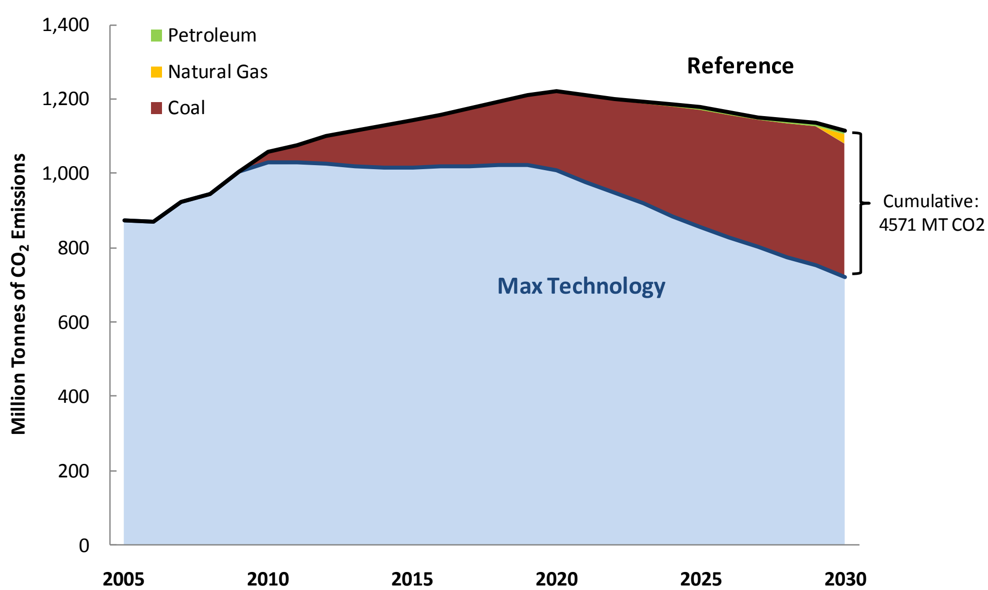
Within the residential sector, primary energy demand growth is driven primarily by space heating and appliances, which together comprise of 60% to 62% of total demand under the two scenarios (Figure 10). Under the reference scenario, space heating energy use grows at 3% from 2005 to 2030 while appliances grow at a slower 1.6% through 2030 due to more efficiency improvements and increased equipment saturation. While space heating grows at a slightly lower annual average rate of 2.6% in Max Tech relative to reference, the growth of energy use from appliances is much slower with only 0.8% due to more aggressive efficiency improvements and technology switching. After initial growth between 2010 and 2020, energy use from water heating, cooking, and other uses are relatively constant after 2020.

Figure 10. Residential Primary Energy Consumption by End-Use



As a result of the significant decline in coal primary energy demand under Max Tech, residential CO_2 emissions actually plateaus after 2010 and declines rapidly after 2020 (Figure 11). In contrast, reference residential CO_2 emissions continue rising at annual average rate of 1.5% before peaking at 1.2 billion tonnes and then declining slowly through 2030. Because CO_2 emissions growth is capped after 2010 under Max Tech, the 2030 annual residential emissions under Max Tech is 35% lower than under reference with cumulative reduction of 4.6 billion tonnes of CO_2.

Figure 11. Residential CO_2 Emission Trajectories of Reference and Max Tech Scenarios



4.3 Analysis of Residential Savings Potential

The energy savings opportunity in the residential sector varies across end-uses, with appliances having the largest savings potential followed by space heating and cooking over time (Figure 12). The high savings potential for appliances in 2030 can be traced back to major residential energy consuming end-uses including refrigerators and air conditioners, as well as aggressive efficiency improvements such as in OLED televisions and standby power (Figure 13).

Although appliances do not have the largest share of residential energy consumption, they continue to be responsible for nearly half of all savings through 2030. Of all the appliances included in the model, refrigerators have the greatest electricity savings potential with a 37% share of total savings in 2030, followed by air conditioners at 24% and clothes washers at 22% (Figure 14). Refrigerators and air conditioners have the largest energy savings potential because they are the two largest energy consuming appliances within households so small relative efficiency gains can translate into large absolute energy savings. In contrast, televisions have smaller savings potential because their unit energy consumption is lower and they are already relatively efficient under the reference case with 50% of all televisions being OLEDs by 2030.

Space heating is responsible for the most energy use but has the second highest energy savings potential, with a 26% share in 2030. This is due to the smaller incremental efficiency gain between reference and Max Tech scenario, with gas boiler efficiency increasing from 88% by 2030 to 99% under Max Tech and heat pump energy factor increasing from 2.4 to 4 from reference to Max Tech. Cooking, lighting and other uses have the next three largest efficiency savings potential, with water heating having the smallest savings potential in the residential sector.

Figure 12. Residential Primary Energy Use Savings Potential by End-Use

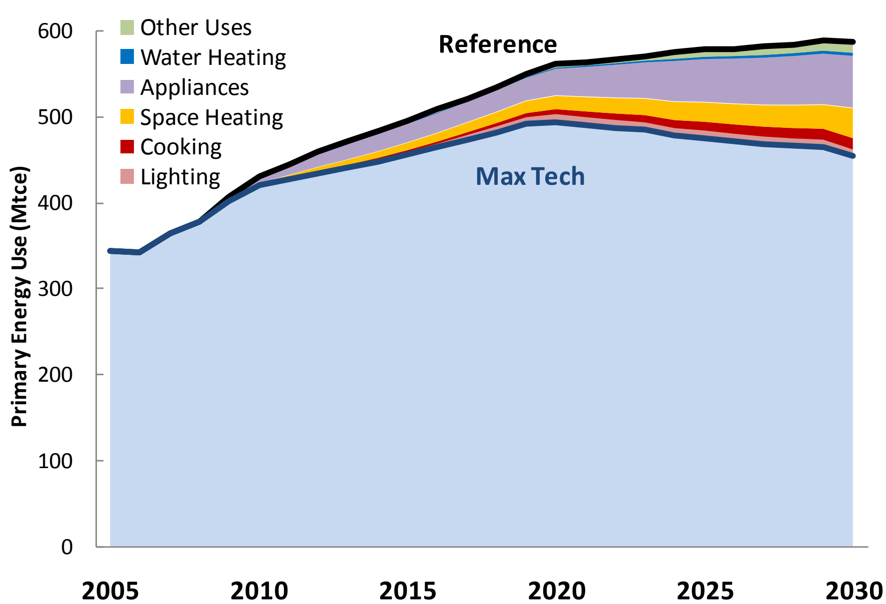
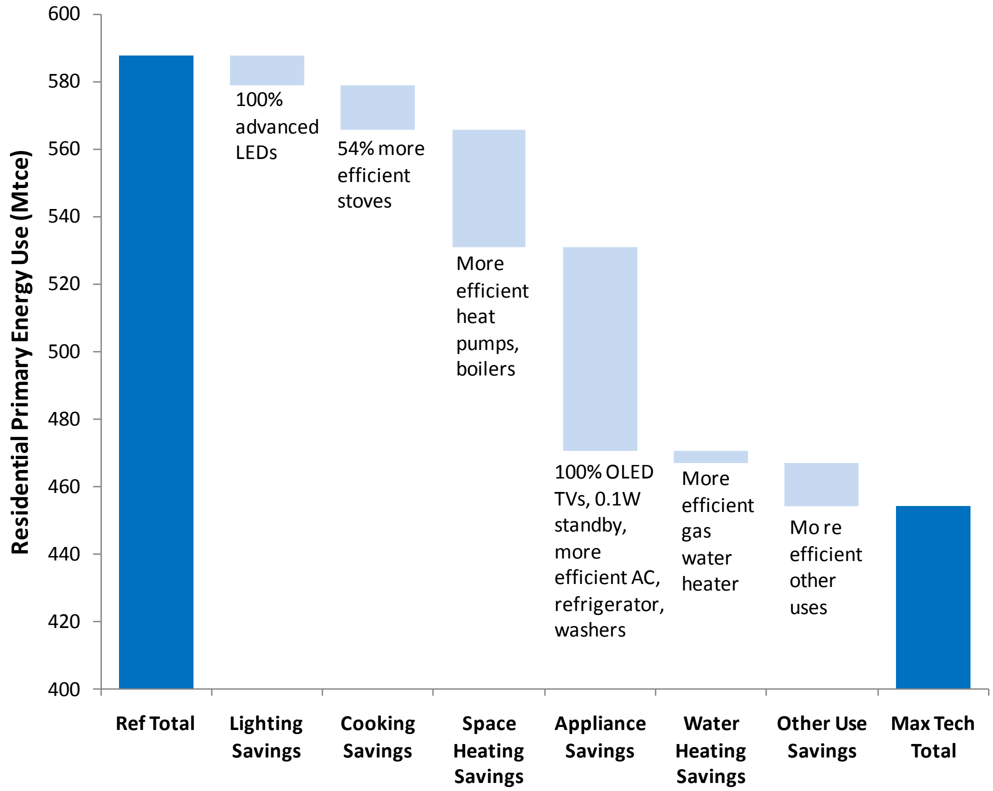
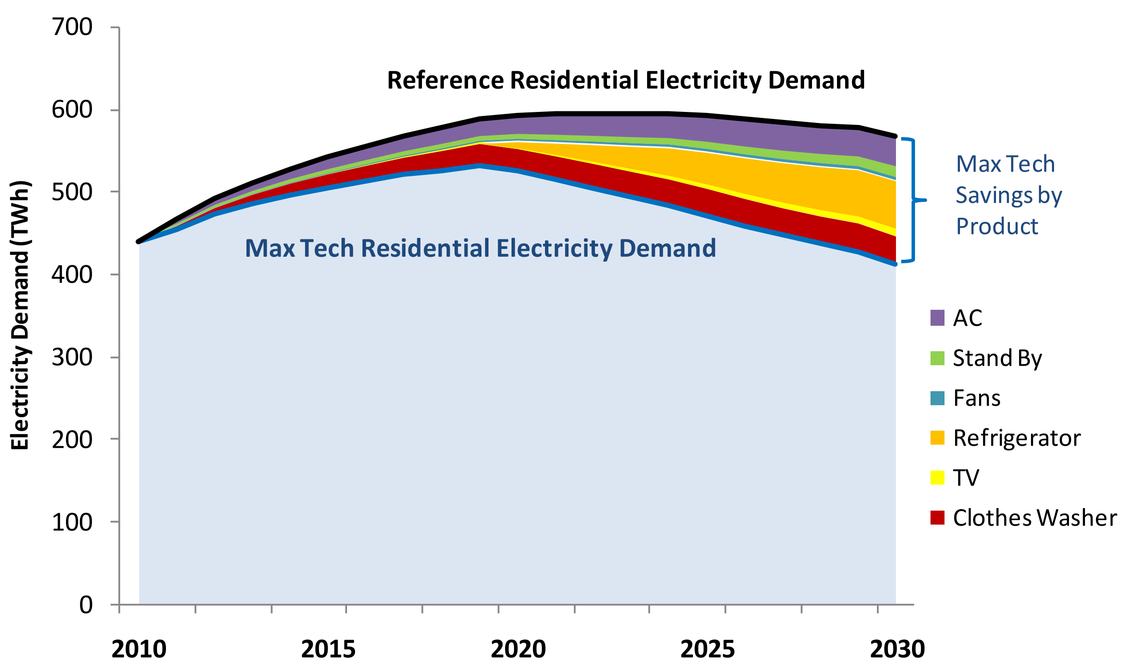


Figure 13. 2030 Residential Primary Energy Savings by End-Use



Note: Y-axis not scaled to zero.

Figure 14. Max Tech Appliance Electricity Savings by Product



5. Commercial Sector Outlook and Analysis

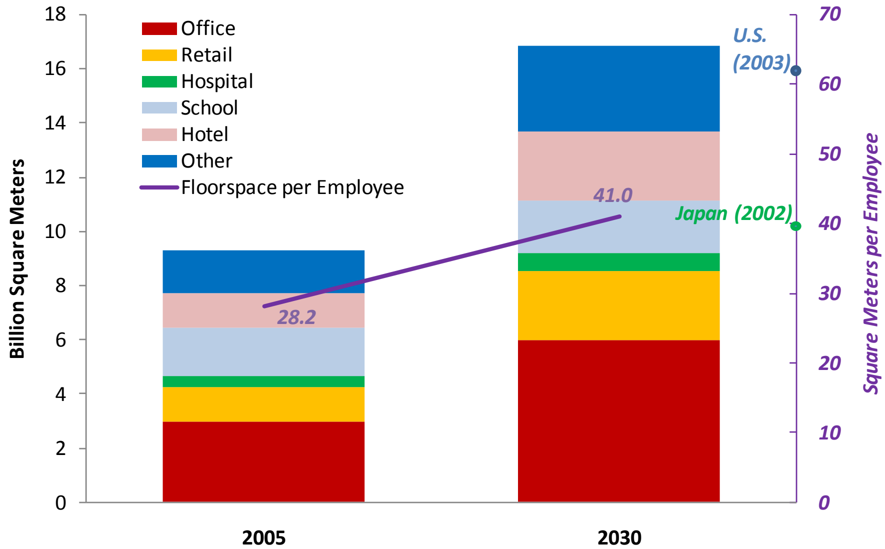
As China continues on its economic development path and the structural shift away from heavy industry towards service-oriented economy quickens, the commercial sector will become an increasingly important sector and a larger energy consumer than today.

5.1 Key Assumptions and Technology Outlook

5.1.1 Basis for Commercial Energy Outlook

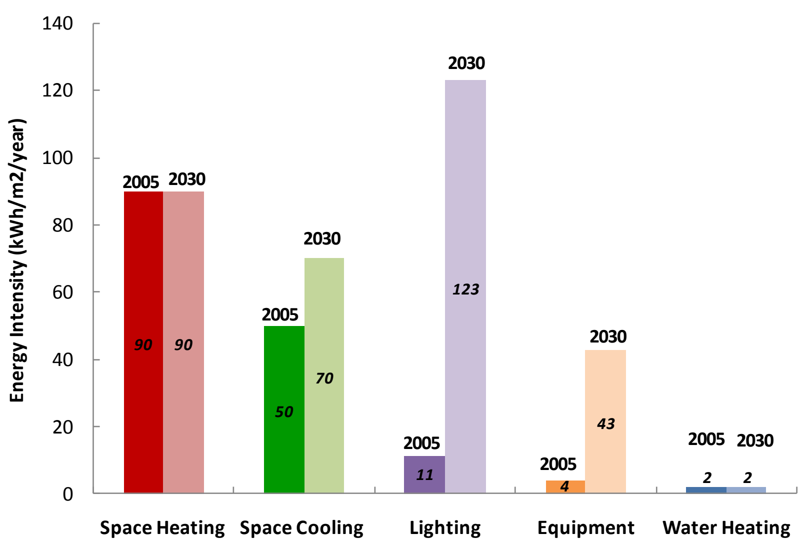
Commercial building energy demand is the product of two factors: building area (floor space) and end use intensity (MJ per m^2). Forecasting commercial building floor space requires an understanding of the drivers underlying the sector's recent growth and where these trends are likely to be heading. In our analysis, commercial floor space is determined by the total number of service sector employees, and the area of built space per employee. This approach differs from the conventional assumption that commercial floor space grows with GDP, which we consider to be unrealistic. According to national statistics, the fraction of Chinese workers employed in the tertiary sector increased from 27% in 2000 to 32% in 2006, an increase of 19% in just 6 years. When these numbers are corrected to include the number of unregistered workers likely to be working in urban service sector businesses, the current fraction is estimated to be 43%. As a general rule, as economies develop, employment shifts away from agriculture and industry toward the service sector, and this trend is expected to continue in China leading to further increases in commercial building floor space. The potential for growth is not unlimited, however. Chinese population is expected to peak by about 2030. Furthermore, the population is aging, so that the number of employees will peak closer to 2015. By comparing Chinese GDP per capita to that of other countries, we estimate that the tertiary sector share of workers will reach 52% by 2030. Under these assumptions, the total number of tertiary sector employees will increase by only about 33% by 2030 compared to 2005. Floor space per employee has some room to grow: we forecast an increase of about 25% by 2030. Overall commercial floor space may likely only double by 2050, and construction in this sector may already be approaching its peak (Figure 15).

Figure 15. Change in Commercial Floorspace



Commercial sector energy demand growth is therefore likely to arise much more from intensity increases than overall floor area growth. Chinese energy use per square meter is still relatively low. Due to the presence of (often unmetered) district heat, space heating intensity in cold climates in China is already comparable to that in Japan so space heating usage is not expected to increase. However, space cooling, lighting and equipment energy is only a fraction of the Japanese level so growth will continue. As an example, the forecasted energy intensity per square meter for office buildings from 2005 to 2030 is illustrated in Figure 16.

Figure 16. Office Buildings Energy Intensity by End-Use



5.1.2 Efficiency Improvement and Technology Outlook

Similar to the residential sector, opportunities for energy efficiency gains in the commercial sector also center on improving the end-use efficiency of heating, cooling, lighting, water heating, and other equipment. By increasing the efficiency of each end-use through policies such as standards, the energy needed to meet the end-use energy intensity demands for a given type of commercial building is lowered. For example, the rising use of more efficient lighting in office buildings will lower the total energy needed to provide the 2030 lighting energy intensity of 123 kWh/m^2/year. Specific assumptions about efficiency improvement and technology outlook in the commercial sector are described below.

Space Heating

Space heating efficiency gains under the Max Tech scenario arise from both technology switching and technology-specific efficiency improvements. The most notable change is in the greater floorspace share of gas boiler space heating across building types, with particularly significant technology switching from coal boilers to gas boilers in hospitals, schools, hotels and other commercial buildings (Table 2). Similarly, heat pump is also expected to double in shares from 2010 to 2030 in most building types, albeit it is still a relatively small share of total space heating. The technology switching in turn drives efficiency gains, as gas boilers are more efficient than coal boilers and heat pumps have the highest efficiency of all heating technology types (Table 3).

Table 2. 2010 and 2030 Commercial Space Heating Technology Shares

	2010 Technology Shares						2030 Technology Shares					
	Office	Retail	Hospital	School	Hotel	Other	Office	Retail	Hospital	School	Hotel	Other
District Heating	27%	30%	18%	20%	29%	27%	26%	30%	22%	26%	30%	26%
Boiler	0%	0%	44%	46%	35%	35%	0%	0%	0%	0%	0%	0%
Gas Boiler	35%	34%	20%	15%	20%	20%	48%	48%	54%	50%	48%	48%
Small Cogen	20%	20%	12%	12%	12%	12%	14%	14%	14%	14%	14%	14%
Electric Heater	12%	12%	2%	2%	0%	2%	4%	0%	4%	4%	0%	4%
Heat Pump	4%	4%	4%	3%	4%	4%	8%	8%	6%	6%	8%	8%

Moreover, Table 3 also illustrates the efficiency improvements over time for all space heating technologies, with more aggressive improvements for most technologies under the Max Tech scenario.

Table 3. Commercial Space Heating Technology Efficiencies over Time

	Reference Scenario			Max Tech Scenario		
	2010	2020	2030	2010	2020	2030
District Heating	75	81	81	75	81	81
Boiler	63	68	68	63	68	68
Gas Boiler	81	87	87	81	95	95
Small Cogen	69	75	79	69	75	80
Electric Heater	94	98	98	94	98	98
Heat Pump	280	290	300	300	400	500

Cooling

For commercial cooling, there is some but much less technology switching with generally increasing shares of geothermal heat pump and centralized air conditioning by natural gas across building types between 2010 and 2030 (Table 4). However, the efficiency of geothermal heat pump and centralized AC by natural gas are relatively close to the other two technology types, suggesting limited efficiency gains from technology switching alone.

Table 4. 2010 and 2030 Commercial Cooling Technology Shares

	2010 Technology Shares						2030 Technology Shares					
	Office	Retail	Hospital	School	Hotel	Other	Office	Retail	Hospital	School	Hotel	Other
Centralized AC	59%	59%	59%	59%	59%	59%	58%	58%	57%	58%	58%	58%
Room AC	34%	34%	35%	34%	34%	34%	28%	25%	31%	28%	25%	28%
Geothermal Heat Pump	3%	3%	3%	3%	3%	3%	6%	7%	6%	6%	7%	6%
Centralized AC by NG	4%	4%	3%	4%	4%	4%	8%	10%	6%	8%	10%	8%

Rather, there are much greater efficiency gains from efficiency improvements over time within each technology and especially in the Max Tech scenario (Table 5). While the efficiencies of the four cooling technologies only increase by 10 to 20% every decade under the reference scenario, they increase by 70% to 100% per decade to meet the highest technically feasible efficiency level by 2030 under Max Tech.

Table 5. Commercial Cooling Technology Efficiencies (COP) over Time

	Reference Scenario			Max Tech Scenario		
	2010	2020	2030	2010	2020	2030
Centralized AC	2.8	2.9	3.0	3.0	4.0	5.0
Room AC	2.6	2.8	3.2	2.6	4.0	4.7
Geothermal Heat Pump	2.8	2.9	3.0	3.0	4.0	5.0
Centralized AC by NG	2.8	2.9	3.0	3.0	4.0	5.0

Water Heating

Unlike space heating and cooling, water heating technology shares are not affected by the commercial building type and the same shares are assumed for all commercial buildings. All commercial buildings thus achieve efficiency gains from technology switching with the phase-out of less efficient coal boilers and significant increase in the use of more efficient gas boilers for water heating (Table 6). Electric water heaters, which has the highest efficiency, also doubles in shares in 2030 but is still very small portion of total water heating with only 4% share. In terms of efficiency improvements under the two scenarios, gas boilers, electric water heaters and oil water heaters experience much greater efficiency improvements from 2010 to 2020 under Max Tech scenario, with a range of 3% to 8% additional efficiency improvements.

Table 6. Commercial Water Heating Technology Shares and Efficiencies, 2010 to 2030

	2010 Shares (all types)	2030 Shares (all types)	Reference Scenario			Max Tech Scenario		
			2010	2020	2030	2010	2020	2030
Boiler	53%	0%	63	68	68	63	68	68
Gas Boiler	20%	75%	81	87	87	81	95	95
Small Cogen	12%	14%	69	75	79	69	75	80
Electric Water Heater	2%	4%	93	95	95	94	98	98
Oil	13%	7%	81	87	87	81	95	95

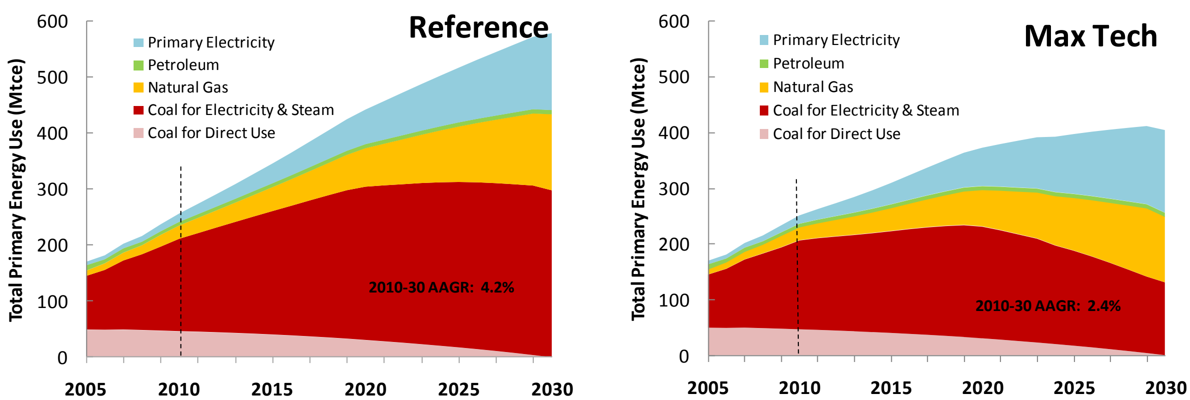
Lighting and Other Equipment

For lighting and other equipment, the expected efficiency gains under the two scenarios are expressed not by technology types, but by reducing the total lighting and total other equipment energy intensity per square meter. Under a hypothetical frozen scenario where there are no efficiency gains from technology switching or technology efficiency improvements, lighting and other equipment energy intensity per square meter will rise from 2010 through 2030 since it is currently very low compared to international levels. However, for the reference and Max Tech scenarios, this increase in energy intensity is expected to be partially offset by efficiency gains. Specifically, the reference scenario is expected to have 18% reduction in lighting and in other equipment energy intensity as a result of efficiency gains relative to the frozen scenario. At the same time, the Max Tech scenario is assumed to reach 85% penetration of high efficiency lighting and high efficiency equipment with an energy intensity of 50% of today's level by 2030. With more aggressive technology switching and incremental efficiency improvements under Max Tech, this translates into a 30% greater reduction in lighting and other equipment energy intensity relative to the reference scenario.

5.2 Commercial Sector Energy and CO_2 Emissions Findings

While building energy demand in the commercial sector is driven by different variables than that of the residential sector, the patterns expected over the short and medium term are similar. Specifically, energy demand in this sector is still growing rapidly at annual average rates of 5.6% between 2010 and 2020 but there will be a slowing of growth with the annual growth rate halved to 2.7% after 2020 in the reference scenario (Figure 17). Nevertheless, the 2030 level of commercial primary energy demand will be more than doubled the current level. Under Max Tech, growth through 2020 will be slightly lower at 4% annually but differs significantly from the reference scenario in that it approaches a plateau after 2020 with annual growth of less than 1%.

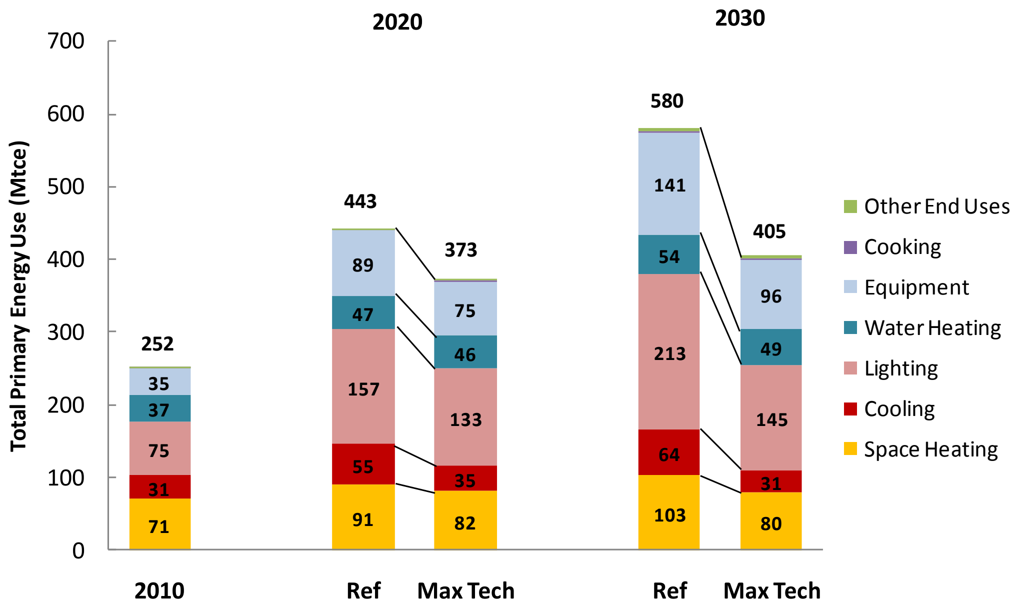
Figure 17. Commercial Primary Energy Consumption by Fuel



Total commercial building floorspace may saturate in the short term, but end uses of energy have much room to grow before reaching current levels in industrialized countries. In particular, lighting, office equipment and other end uses in these buildings is expected to grow dramatically through 2030 as seen in Figure 18. Lighting will triple from current levels under reference and double under Max Tech, while growth in office equipment energy consumption is even greater with quadrupling and tripling of 2010 levels by 2030 under the two scenarios.

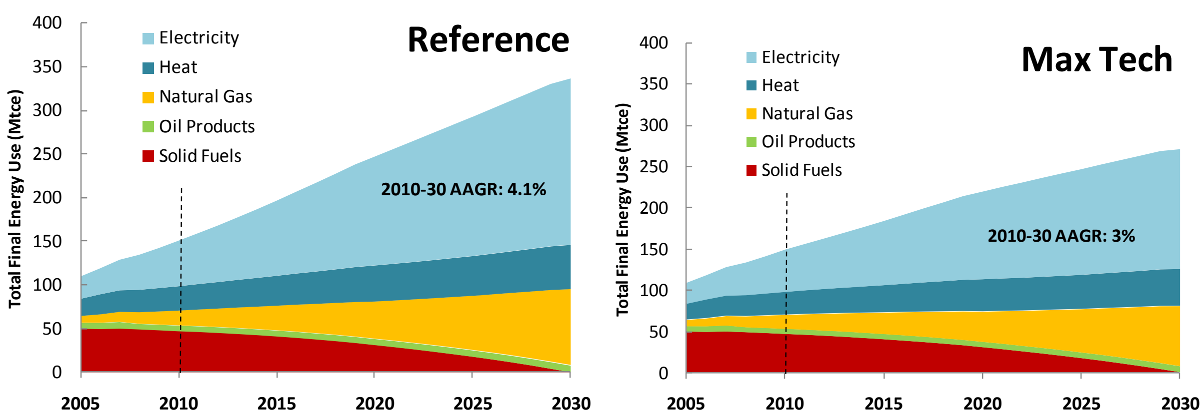
The main dynamic of energy consumption in commercial sector buildings revealed by this study is that energy growth will be largely dominated by intensity increases, rather than overall increases in commercial floor area. As noted above, increases in commercial building space will be limited by the number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

Figure 18. Commercial Primary Energy Use by End-use for Selected Years



In final energy terms, neither the Reference nor Max Tech scenario actually peaks before 2030, albeit both grow at a slightly slower annual rate than primary energy as a result of efficiency improvements in the energy transformation processes (e.g., power generation). The majority of the final energy savings between Reference and Max Tech is in the form of electricity, with annual savings of 45 Mtce, followed by 13.6 Mtce of natural gas in 2030 (Figure 19).

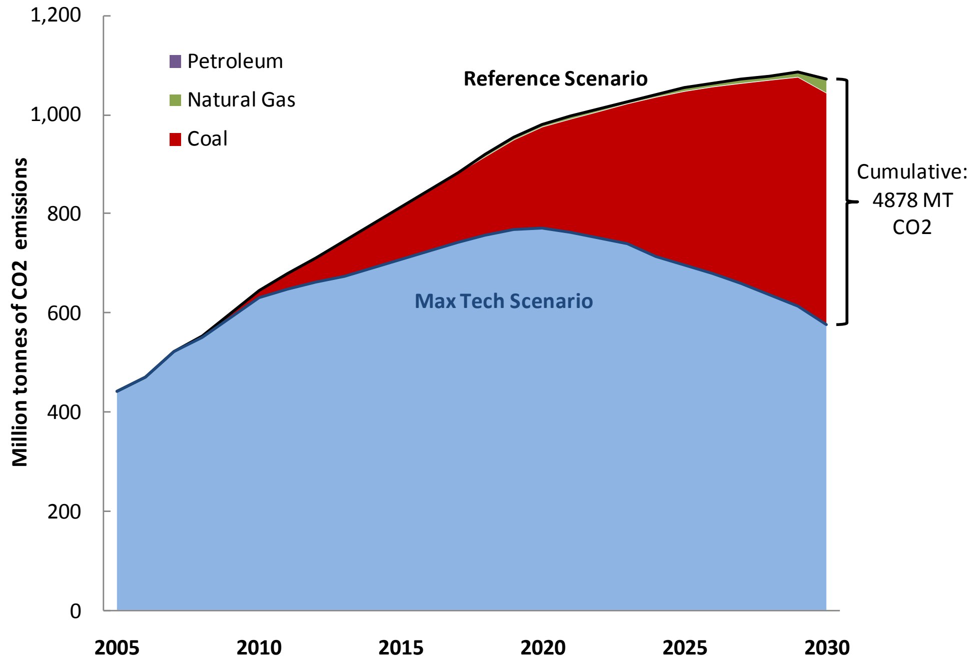
Figure 19. Commercial Sector Final Energy Use by Fuel



Unlike primary energy, CO_2 emissions trends differ from the residential sector in that the commercial sector emissions peak much later at 1085 Mt of CO_2 under the reference scenario (Figure 20). Under Max Tech, commercial sector CO_2 emissions peaks earlier reference, but only returns to current levels of

580 Mt CO_2 by 2030 rather than declining to below today's levels as in the case for the residential sector. Since emissions are reduced by nearly half under the Max Tech scenario, cumulative CO_2 reductions from the aggressive efficiency improvements and power sector decarbonization reach nearly 4.9 billion tonnes by 2030.

Figure 20. Commercial Sector CO_2 Emissions Outlook and Reduction



5.3 Analysis of Commercial Savings Potential

Within the commercial sector, the greatest energy savings and emission reduction potential lays with the two fastest growing end-uses of equipment and lighting, which together comprise of 65% of Max Tech energy savings in 2030 (Figure 21). Despite significant efficiency gains on the order of 40% for cooling, primary energy savings in commercial space heating and cooling combined is still less than that of lighting (Figure 22). Technical improvements that lead to 30% efficiency gains in lighting and equipment and technology switching, in contrast, can achieve cumulative energy savings of 1020 Mtce or nearly 2200 TWh between 2010 and 2030. Since both lighting and equipment use electricity exclusively, the CO_2 emission reduction associated with Max Tech electricity savings will depend on the fuel mix of the electricity generation and its carbon intensity.

Figure 21. Max Tech Scenario Commercial Energy Savings by End-Use

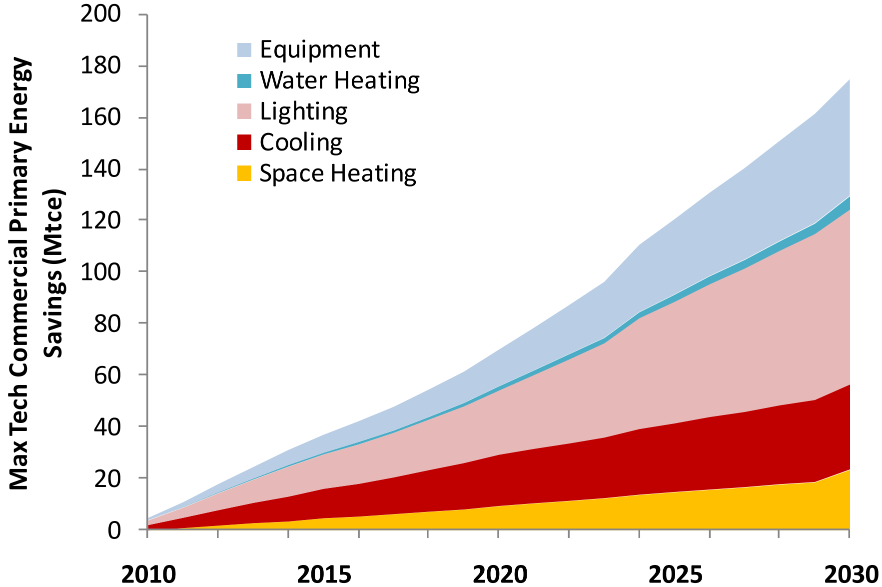
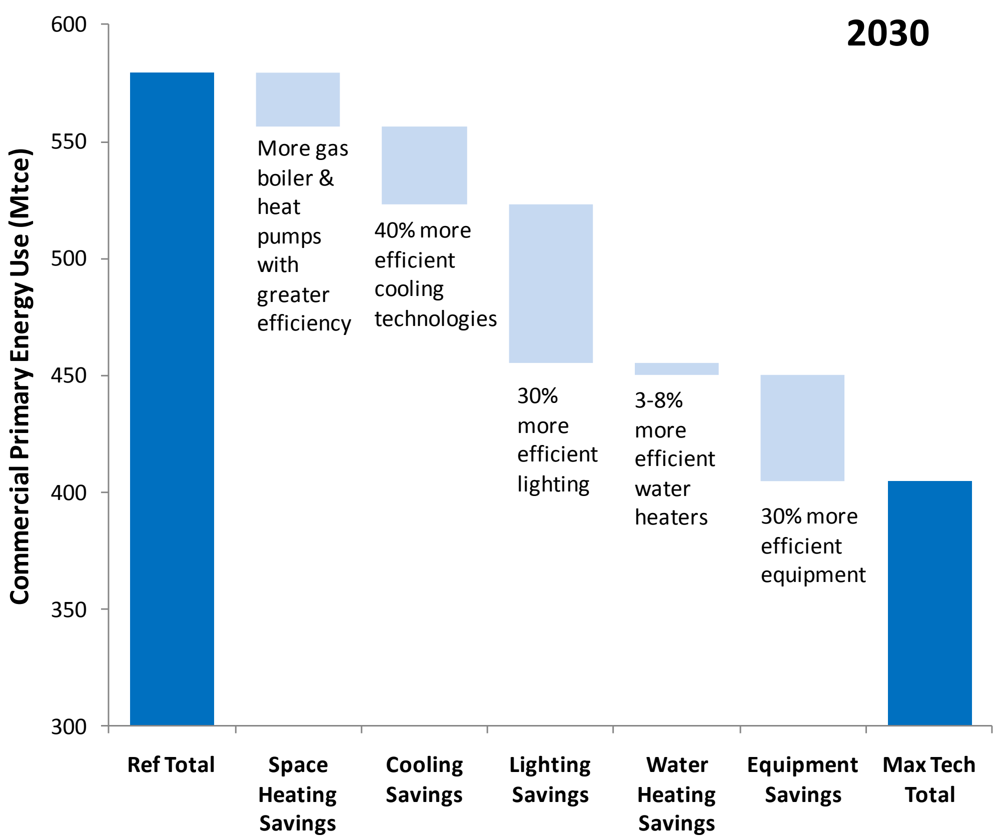


Figure 22. 2030 Commercial Primary Energy Savings by End-Use



Note: Y-axis not scaled to zero.

6. Industrial Sector Outlook and Analysis

The industrial sector has been a major driver of China's economic boom since its ascension to the World Trade Organization, and is thus responsible for a vast majority of total primary energy demand. While the industrial share of energy demand will likely decrease with continued economic development and structural change, industrial sector will continue to have important implications for China's energy and carbon pathways. In order to analyze the energy savings and emission reduction potential of the industrial sector, seven of the largest energy-consuming industries are singled out for in-depth analysis, including cement, iron and steel, aluminum, paper, glass, ammonia and ethylene in addition to an "other industry" subsector to capture other industries such as the various manufacturing and processing industries.

6.1 Key Assumptions and Technology Outlook

6.1.1 Basis for Industrial Energy Outlook

In the model, industrial energy consumption is a function of total production output (by process if applicable) and the specific energy intensity of the production processes and thus the key drivers differ by industrial subsector. In general, for cement, steel and aluminum, the scenarios were based on floor space construction area and infrastructure construction as a proxy for production output. Ammonia production, in contrast, was modeled as a function of sown area and fertilizer intensity while ethylene production was based on population and per capita demand for plastics. The exports (or imports) of energy-intensive industrial products from these subsectors were also assumed to be frozen at current levels through 2030.

Cement

In the model, cement production is modeled as a function of 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. The specific formula for modeling cement production is:

$$P_c = [(CFSu + CFSr) \times CI1 + (RFSu \times CI2) + (RFSr \times CI3)] + (PA \times CI4) + (H \times CI5) + (R \times CI6) + Ex$$

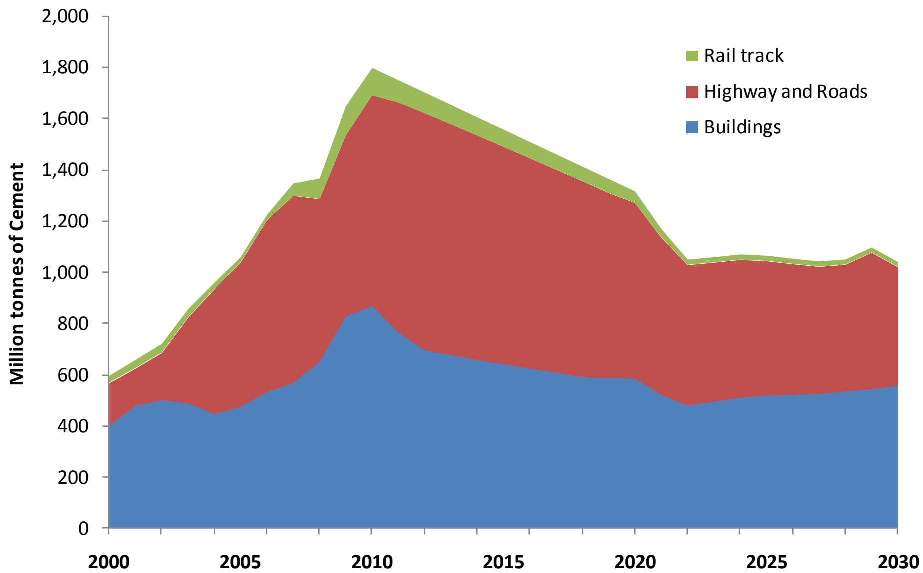
Where:

P_c	= Annual cement production
CFSu	= Urban commercial floorspace (3 year rolling average)
CFSr	= Rural commercial floorspace (3 year rolling average)
RFSu	= Urban residential floorspace (3 year rolling average)
RSFr	= Rural residential floorspace (3 year rolling average)
CI1	= Commercial building cement material intensity
CI2	= Urban residential building cement material intensity
CI3	= Rural residential building cement material intensity
PA	= Urban paved area
CI4	= Paved area cement material intensity
H	= Highways, specifically expressways, and Class 1 and 2 highways (3 year rolling average)
CI5	= Highway cement material intensity
R	= Railroad track length, 3 year rolling average
CI6	= Railroad track cement material intensity

Ex = Net exports of cement

This approach explicitly accounts for the effect of growing commercial and residential building construction and targeted expansion of urban paved areas, highways and rail tracks on cement production. In particular, the expansion of urban paved areas and highways are modeled after Japanese experience of infrastructural development while the railway track forecast assumes meeting the 2020 targets set forth in the railway development plan. Based on these assumptions, cement production is expected to have peaked around 2010 after the stimulus-driven infrastructure boom and declines to 2020 (Figure 23). After 2020, buildings demand for cement rises slightly as a result of the short 30-year lifetime of buildings. Buildings and highways and roads are expected to remain the key drivers of cement demand, with 54% and 45% share, respectively, in 2030.

Figure 23. Cement Production by End-Use



Iron and Steel

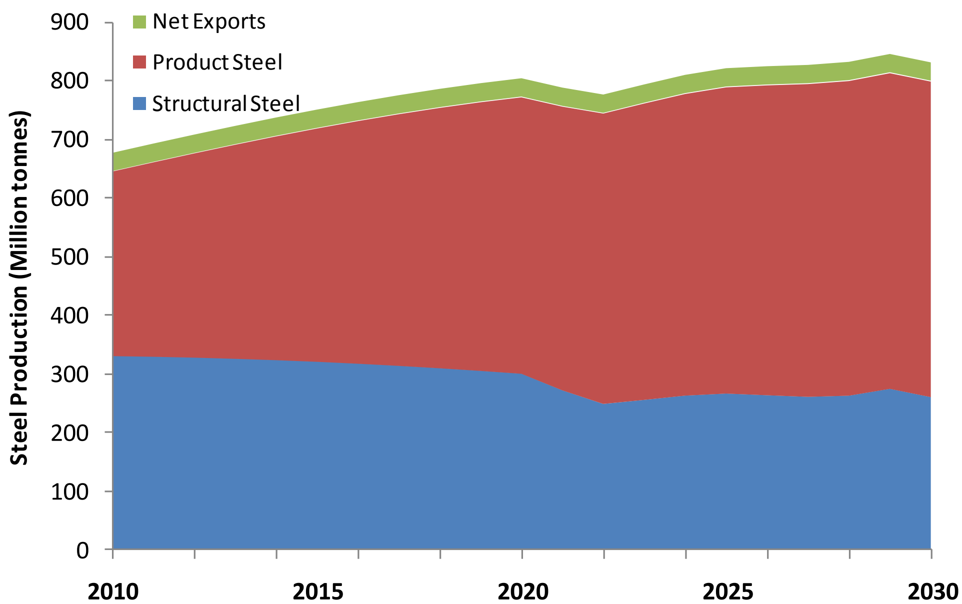
As another leading industry and a major component of buildings, iron and steel production is also largely driven by infrastructural and construction demand (i.e., structural steel) in addition to product steel used in appliances, machinery, and other products for final consumption. On one hand, structural steel has the same drivers as cement consumption and is therefore projected using a ratio to cement consumption of 0.18 kg steel per kg of cement in 2010 to 0.25 kg steel per kg of cement in 2030. For product steel, a ratio to "Other Industry" value-added of 198 tons of product steel per million US$ of "Other Industry" value-added is used for 2010. Following Japan's trend of declining steel to manufacturing GDP from 1970 to 1988, we assume that the 2010 ratio will be lowered by 40% to 119 in 2030 as production shifts to higher value-added steel products. The projected steel production is illustrated in Figure 24, and shows product steel rising as a proportion of total steel demand, from 47% share of total steel demand in 2010 to 65% in 2030.

$P_S = (SSR \times Pc) + (PSR \times OI\,VAGDP) + Ex$

Where:

P_S	= Annual steel production
SSR	=Structural steel ratio to cement, kg steel per kg cement
Pc	= total cement production
PSR	= Product steel ratio to other industry value added GDP, ton steel per million $
OI VAGDP	= Other Industry Value-Added GDP, US$
Ex	= Net exports

Figure 24. Steel Production by End-Use



Aluminum

Aluminum comprises the largest share of China's non-ferrous metals industry in terms of both annual production and energy use, with a 52% share of all non-ferrous metals production in 2008. As an important building material, building and construction use constitutes the highest fraction of aluminum consumption, which differs from the manufacturing and transport dominated demand for aluminum in the U.S. With continued economic development and a slowdown in construction, construction-driven aluminum production is expected to drop from 35% share in 2007 to 30% in 2025 and thereafter as a result of increasing manufacturing and transport use. Net exports are assumed to stay constant at current levels through 2030. As with cement and iron and steel industries, aluminum production forecast is also based off its relationship with the physical driver of building construction, as expressed by:

$P_A = [(CFSu + CFSr + RFSu + RFSr) \times AI1)]/CSA + Ex$

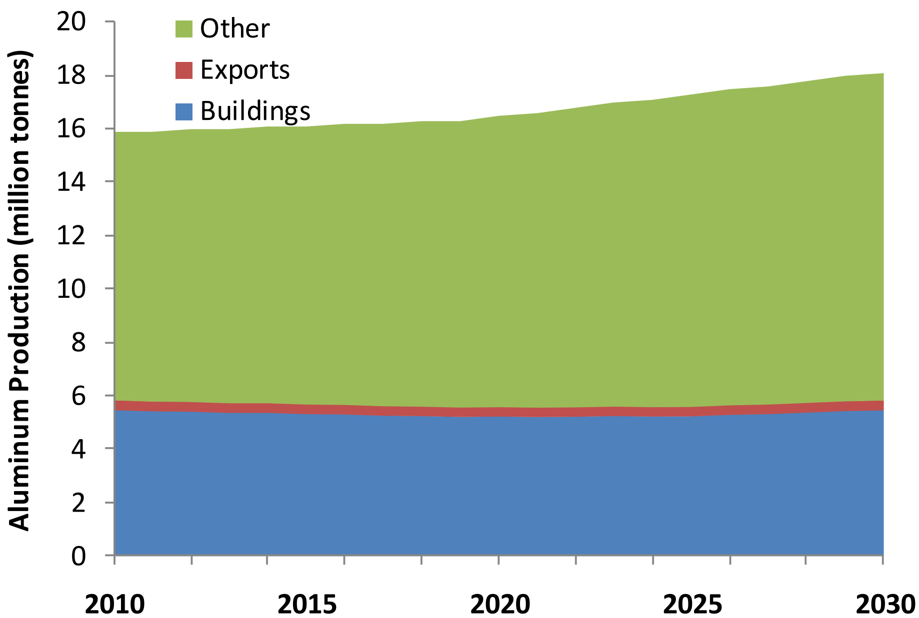
Where:

P_A	= Annual aluminum production
CFSu	= Urban commercial floorspace
CFSr	= Rural commercial floorspace

RFSu = Urban residential floorspace
RSFr = Rural residential floorspace
Al1 = Aluminum material intensity of building construction
CSA = Construction share of aluminum production
Ex = Net exports

Based on the above relationship, China's projected aluminum production by end-use is shown in the figure below.

Figure 25. China's Forecasted Aluminum Production by End-use



Paper

China is currently the world's largest producer of paper, providing over 17% of world's paper supply in 2009. Although the current per capita paper consumption is lower than international levels, China's domestic markets are already relatively saturated with industry, particularly light industry, responsible for the bulk of domestic demand. Specifically, the domestic demand for paper can be broken down into 17% for food, 14% for drinks, 12% for shoes, 11% for electronics and electrical appliances, 7% for chemicals, 6% for medicine and hygiene, 2% for toys, 2% for cigarettes and 16% for others (Haley, 2010). Given these diverse demand drivers for paper consumption, it is not possible to derive a physical driver based relationship for forecasting paper production. Instead, China's own projections of total production output in the Energy Research Institute's 2009 modeling study is used (ERI, 2009) along with our own in-depth analysis of paper production processes. Net paper exports are assumed to stay constant at current levels through 2030. Total production of paper is expected to grow at an average annual rate of 2.5% between 2010 and 2030, with much slower growth after 2020 due to a shift away from energy-intensive industrial activity (Figure 26). Based on United Nations FAOSTAT data, we assume that China's current production output mix of paper products as illustrated in Figure 27 below will remain relatively constant through 2030.

Figure 26. Forecasted China Paper Production Output

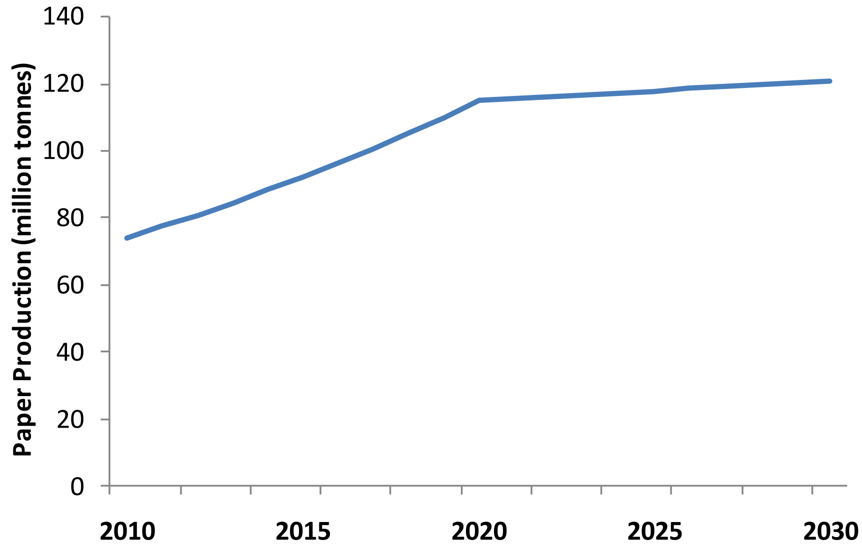
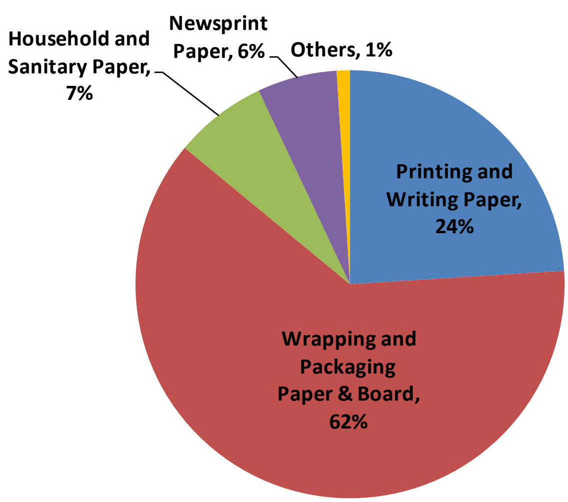


Figure 27. China 2009 Paper Production Output by Product Type



Source: United Nations, 2010, FAOSTAT ForesStat Database. Available at: http://faostat.fao.org/

Glass

Glass is another important building material in China, and the glass industry is dominated by the production of flat glass with relatively negligible production of container glass. Historical and recent data indicate that flat glass is primarily driven by commercial and residential construction, with the construction sector responsible for 80 to 87% of all flat glass consumption (Haley, 2009 and Lee, 2009). This is followed by the second largest consumer, the automobile industry, which is ignored in our analysis because it consumed less than 10% of total flat glass production in 2009. Since glass use in the construction sector varies significantly and is not dictated by building codes as is the case for cement and steel, a multiple regression was ran using historical data for domestic glass consumption and residential and commercial construction to determine the relationship between glass use and new commercial and residential floorspace. The regression results had a relatively strong fit, and the following relationship was used to determine domestic demand for flat glass:

Y = -49753638.708 + 0.027*(new commercial floorspace) + 0.030*(new residential floorspace)

Where:

Y = *domestic consumption of flat glass, in tonnes*
0.027 = *tonne flat glass/m2 commercial floorspace*
0.030 = *tonne flat glass/m2 residential floorspace*

Total glass production is thus domestic demand plus net exports, which is assumed to stay constant at 2000 to 2008 average level through 2030. Our forecast suggests that total glass production will grow relatively slowly at an annual average rate of 0.5% from 28.5 million tonnes in 2010 to 31.8 million tonnes in 2030.

Ammonia

China's important role in the production of key fertilizers is reflected in its rising production of nitrogen-based nutrients as the world's largest producer. Ammonia production is driven by rapid urbanization in two specific ways. First, rising incomes in urban households and correspondingly greater demand for meat-based diet has increased the demand for animal feed from maize and soybean production. Second, growing urban demand and a readily available labor supply has driven up the labor-intensive production of fruits and vegetables in China, which require double the amount of fertilizer application as cereal production. Given these drivers, China's future ammonia production is forecasted as a function of rising application intensity of nitrogenous fertilizers for decreasing levels of sown area and net exports. The application intensity of nitrogenous fertilizer is expected to rise to Korea's 2005 level of 225 kg nitrogen nutrients per hectare by 2030 from the current level of 200 kg N/ha, while total sown area is expected to decrease by 2% by 2030 based on historical trends and recent projections. Exports are expected to remain at 2005 levels through 2030. Total ammonia production can be expressed as:

$$P_{AM} = (SA \times AI) + Ex$$

Where:

P_{AM} = Annual ammonia production
SA = Sown area
AI = Application intensity of nitrogenous fertilizers to sown area
Ex = Net exports

As a result of the offsetting effect of rising application intensity but declining total sown area, ammonia production increases very slowly at an annual rate of only 0.2% from 41 million tonnes in 2010 to 43 million tonnes in 2030.

Ethylene

Ethylene is a major petrochemical product that has experienced rapid growth in production in China, driven primarily by rising demand for its polymers such as high and low-density polyethylene, polypropylene and styrene. For example, high demand for polyethylene is likely with continued urbanization given their applicability to be substituted for non-synthetic, nondurable goods like grocery and garbage bags, food packing and shipping containers. Polypropylene will also continue to be in high demand due to its applications in the production of mechanical parts, containers, fibers and films and as a popular substitute for non-plastic materials such as paper, concrete and steel. Lastly, styrene and polystyrene demand will grow with the use of styrene monomer and derivatives in the construction sector to substitute out other chemicals. The ethylene industry is also unique in that China is currently a net importer, not exporter of ethylene. In light of these demand drivers, ethylene production is modeled as a function of per capita demand for ethylene, calculated from its share of per capita plastics demand, and net imports. China's per capita demand of primary plastic is assumed to reach levels comparable to Japan's 2007 level of 108 kg per person by 2030 while the per capita ethylene demand is derived off of the historical shares of ethylene in the production of primary plastics, specifically:

$$P_E = (PDpc \times Pop \times PER) + Im$$

Where:

P_E	= Annual ethylene production
PD_{pc}	= Per capita primary plastic demand
Pop	= Total population
PER	= Primary plastic demand to ethylene demand ratio
Im	= Net ethylene imports

Since the current per capita plastic demand in China of 50 kg per person is very low compared to international levels, per capita plastic demand will grow rapidly between 2010 and 2030. Coupled with continually growing total population, ethylene production is expected to increase rapidly at 5% per year from 19 to 52 million tonnes between 2010 and 2030.

Other Industry

In addition to the seven selected industrial subsectors, the model also includes an "Other Industry" subsector that covers the other remaining energy-consuming industries. As seen in Table 7, there are many smaller energy-consuming industries beyond the seven selected subsectors.

Table 7. Energy Consumption by Industrial Subsector (2008)

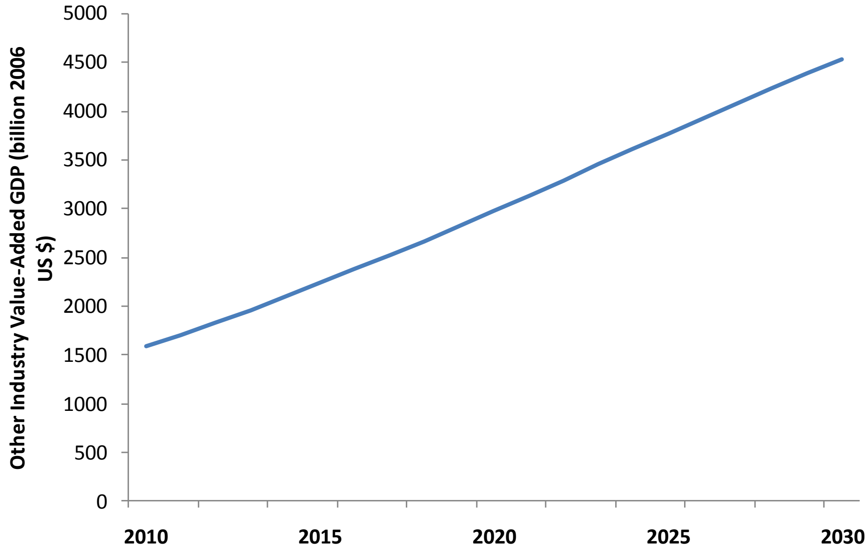
Sector	Total Energy Consumption (Mtce)
Total Consumption	**2,914.5**
Industry Total	**2,093.0**
Partially included in model subsectors:	
Smelting and Pressing of Non-ferrous Metals (Aluminum)	112.9
Manufacture of Raw Chemical Materials and Chemical Products (Ammonia)	289.6
Manufacture of Non-metallic Mineral Products (Cement & Glass)	254.6
Not in Model Subsectors	
Manufacture of Textile	64.0
Manufacture of Metal Products	30.2

Manufacture of General Purpose Machinery	27.6
Manufacture of Transport Equipment	27.3
Processing of Food from Agricultural Products	27.3
Manufacture of Communication Equipment, Computers and	22.0
Manufacture of Electrical Machinery and Equipment	17.9
Manufacture of Special Purpose Machinery	16.3
Manufacture of Foods	15.4
Manufacture of Chemical Fibres	14.5
Mining and Processing of Ferrous Metal Ores	14.1
Manufacture of Artwork and Other Manufacturing	14.0
Manufacture of Medicines	13.6
Manufacture of Rubber	13.4
Manufacture of Beverages	11.6
Mining and Processing of Non-metal Ores	10.3
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm,	9.8
Mining and Processing of Non-Ferrous Metal Ores	8.6
Manufacture of Textile Wearing Apparel, Footware and Caps	7.3
Manufacture of Leather, Fur, Feather and Related Products	3.9
Printing, Reproduction of Recording Media	3.5
Manufacture of Measuring Instruments and Machinery for Cultural Activity	2.8
Manufacture of Tobacco	2.3
Manufacture of Articles For Culture, Education and Sport Activities	2.2
Mining of Other Ores	1.8
Manufacture of Furniture	1.8
Recycling and Disposal of Waste	0.6

Source: NBS, 2010.

These other industries include: mining and processing of metal and non-metal ores; manufacture of textiles, machinery, various types of equipment, food and beverages, artwork and furniture; processing of food, timber; and manufacture of chemicals other than ammonia and non-metallic mineral products other than cement and glass. Since there is a significant range in the output of other industries and in demand drivers, it is not possible to base production forecasts on physical drivers. Rather, because most of the other industry outputs involve manufacturing and processing, the model uses the common unit of value-added GDP to quantify activity in this subsector. Under both scenarios, the value-added GDP of Other Industry is expected to continue growing at recent high annual rates of 6% for the next five years and then slow down to 4% annually through 2025 and to only 2% after 2025 as China shifts away from industrial-driven to commercial and service-oriented economy (Figure 28). By 2030, the Other Industry value-added GDP will be three times higher than current levels at $4.5 trillion US dollars.

Figure 28. Projected Other Industry Value-Added GDP, 2010-2030

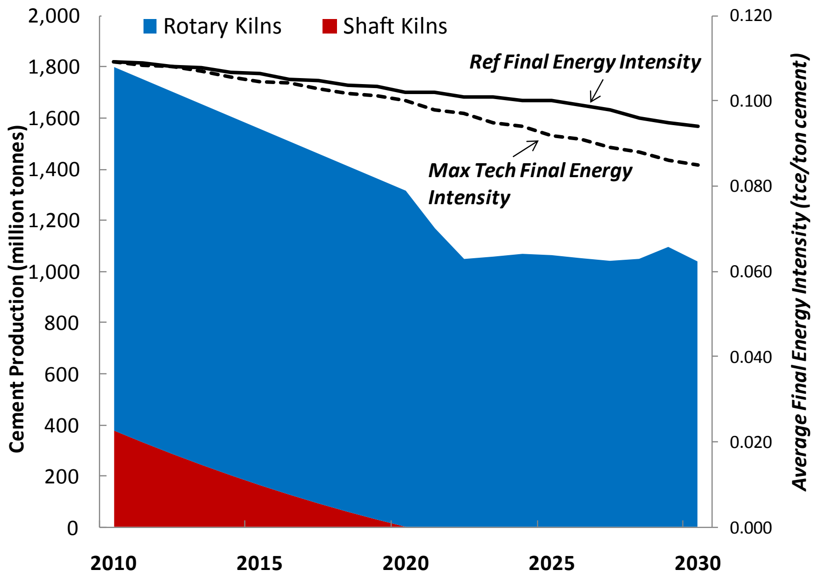


6.1.2 Efficiency Improvement and Technology Outlook

Cement

China's cement industry is steadily transitioning from using less-efficient vertical-shaft-kiln to new-suspension-pre-heater (NSP) technology for making clinker—the key ingredient for cement production. New cement production capacity employs NSP and high-efficiency technology, with overall shift further accelerated by industry consolidation and closure of small and inefficient kilns. In terms of modeling the cement industry's energy consumption, the recent technology and efficiency trends of shutting down plants with backward 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 reference and Max Tech scenarios as part of China's committed efforts to reduce its industrial energy intensity (Figure 29). The Max Tech scenario further differs from reference scenario in that the 2030 final energy intensity of rotary kilns will be slightly lower as it achieves the current world best practice efficiency level of 0.101 tce/ton cement for Portland cement five years earlier. Detailed measures that can be taken by the cement sector to reach this level of intensity are discussed in greater detail in Section 10.3.1.

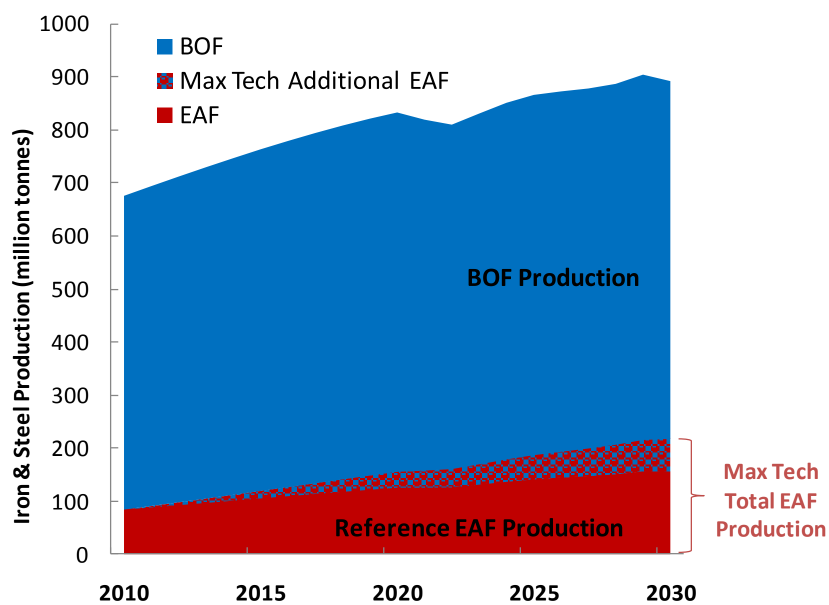
Figure 29. Projected Technology and Energy Intensity Trends in Cement Production



Iron & Steel

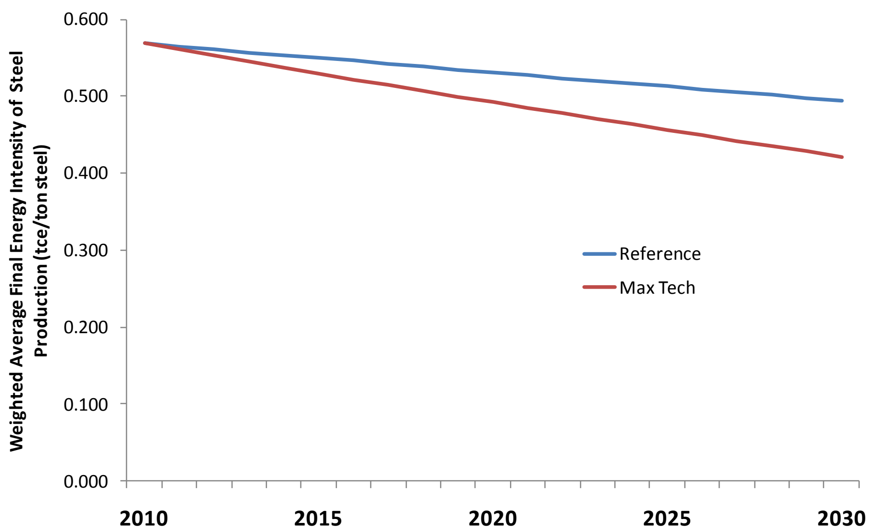
The two primary crude steel-making routes include using basic oxygen furnace (BOF) or the more efficient electric arc furnaces (EAF). In 2008, 87% of crude steel in China was produced using the BOF route and only 13% using the EAF route, which is more efficient and can use steel scrap or sponge iron as raw materials. Compared to the world crude steel average share of 34% for EAF production, China's EAF utilization is much lower and suggests more room for efficiency improvements although the technology shift is constrained by the supply of scrap steel. In the model, 19% of steel production is expected to be from EAF by 2030 under the reference scenario, compared to 26% under the Max Tech scenario (Figure 30).

Figure 30. Projected Steel Production Technology Trends in Reference and Max Tech Scenarios



Another efficiency improvement in the steelmaking process is the use of continuous casting, which reduces the consumption of energy and other materials by eliminating the reheating step for semi-finished steel prior to being cast. Continuous casting has additional benefits in improved yield from liquid to finished steel and better steel quality. With continuous casting expected to play a bigger role in Chinese steel production and the advent of other technical improvements, the final energy intensity of BOF and EAF production declines under the reference scenario. The decline in energy intensity for both BOF and EAF production is accelerated under Max Tech with greater efficiency improvements. As a result of faster improvements in BOF and EAF as well as faster adoption of EAF, steel production under Max Tech has a 15% lower average final energy intensity of production than the reference scenario (Figure 31). Detailed measures that can be taken by the iron and steel sector to reach this level of intensity are discussed in greater detail in Section 10.4.2.

Figure 31. Process-weighted Average Final Energy Intensity of Steel Production



Aluminum

China has been active in both the primary and secondary production of aluminum, with 80% primary aluminum production and 20% secondary aluminum production in 2006. Primary production of aluminum includes bauxite ore mining, alumina refining, ore precipitation and calcination, electrochemical conversion from alumina to aluminum and smelting. Secondary production of aluminum is much less energy-intensive, typically requiring only 5% of the electricity used in primary production, because it directly extracts aluminum from recycled materials. However, secondary aluminum production is limited by the availability of metal scrap material. Taking these constraints into consideration, China is expected to meet its 2010 goal of 25% secondary production under both scenarios with the secondary share rising to US 2008 equivalent levels of 36% by 2030 under the reference scenario and the 2030 Chinese target of 80% under the Max Tech scenario (Figure 32). Overall, total energy intensity of primary and secondary aluminum production declines under both scenarios as a result of technical improvements. Under the Max Tech scenario, for instance, both primary and secondary production are assumed to meet the current world best practice energy intensity of 2.41 tce/ton aluminum and 0.085 tce/ton, respectively, by 2030 (Worrell et. al., 2007).

The decline in overall final energy intensity is especially significant under the Max Tech scenario because of the aggressive switch to secondary production after 2010, with as much as 80% reduction in the average energy consumption per ton of aluminum relative to the reference scenario by 2030 (Figure 33).

Figure 32. Aluminum Production Technology Trends in Reference and Max Tech Scenarios

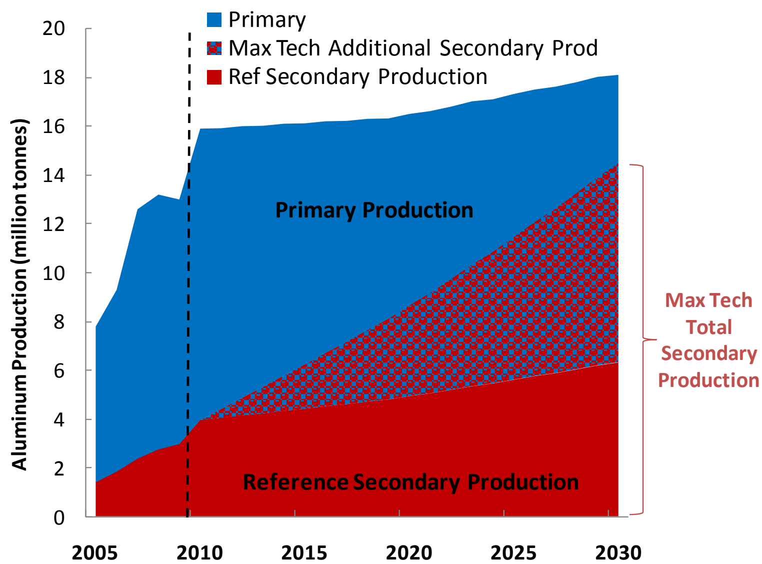
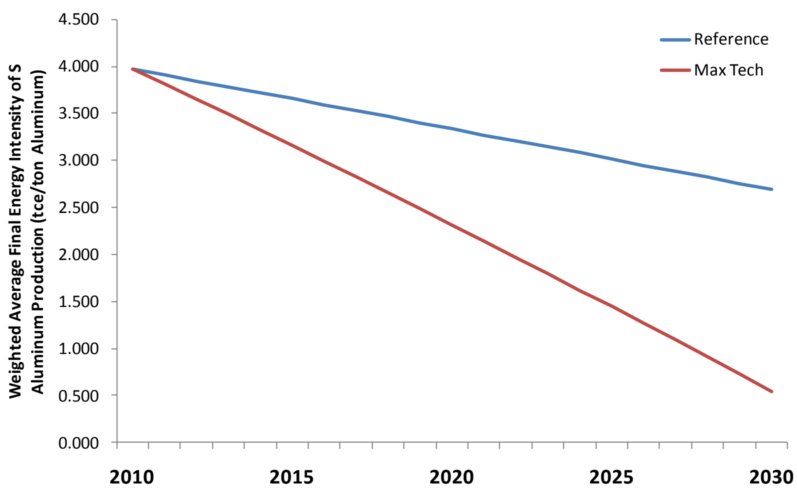


Figure 33. Process-weighted Average Final Energy Intensity of Aluminum Production



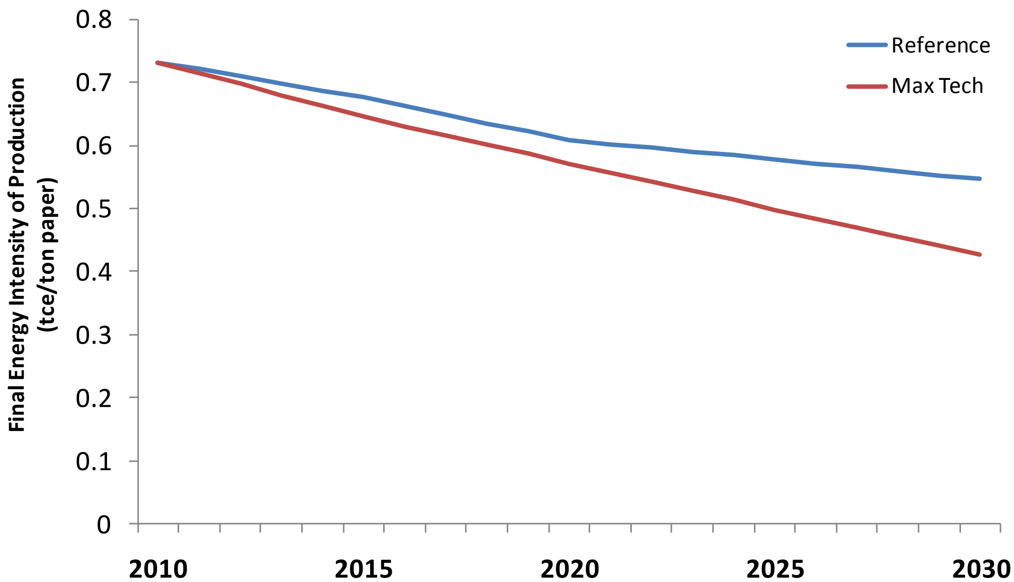
Paper

Energy consumption for the paper industry occurs in two stages: pulping and paper-making. Since China is a major importer of waste paper and non-wood fiber, the pulping share of the industry's total energy consumption is actually relatively low. Specifically, China's paper production only uses 7% wood market pulp and 23% non-wood market pulp (UN FAOSTAT, 2010). The imported and domestically recycled pulp, which makes up the remaining 70% of paper pulp, only requires 15% to 20% of the energy needed for wood and non-wood pulping (Worrell, et. al., 2007). In determining the lowest possible final energy intensity of pulping, the Chinese shares of pulp are multiplied by the world best practice energy intensity given in Worrell, et. al. for each type of pulp to determine the pulp-weighted average energy intensity for the industry.

In the papermaking stage, the process energy consumption varies by paper product type, with coated print and writing paper and household and sanitary paper production requiring the most energy and newsprint requiring the least energy. Given the Chinese paper industry's current production mix, the lowest possible product-weighted average energy consumption can be derived for papermaking using best practice values given in Worrell et. al.

Under Max Tech, China is assumed to reach the lowest energy intensity of 123 kgce per ton of pulp and 304 kgce per ton of paper given its production mix by 2030 as a result of aggressive efficiency improvements in both pulping and papermaking processes. The maximum technically feasible level of pulping and papermaking efficiency is not reached under the reference scenario until at least 2050, resulting in 28% higher energy consumption per ton of paper than the Max Tech scenario in 2030 (Figure 34).

Figure 34. Average Final Energy Intensity of Paper Production



Glass

The Chinese glass industry is highly fragmented with a total of 268 manufacturers, with most classified as medium to small enterprises and only 4% of manufacturers classified as large enterprises. Efficiency gains in the Chinese industry is thus likely to result from both technical improvements in the production process as well as the consolidation of manufacturers and subsequently more efficient production lines with economies of scale savings. Under the Max Tech scenario, the entire glass industry is expected to reach on average, the Shandong Top 1000 Project's best practice energy intensity of 13.46 kgce per 50 kg of glass, which is comparable to the U.S. best practice intensity of 7.88 GJ/ton of flat glass. Under the reference scenario, efficiency improvements are less aggressive and will not reach the best practice energy intensity of 0.262 tce per ton of flat glass until at least 2050. A comparison of the final energy intensity of glass production under both scenarios is shown in Table 8 below, revealing that Max Tech scenario can achieve 12% reduction in energy intensity of glass production by 2030.

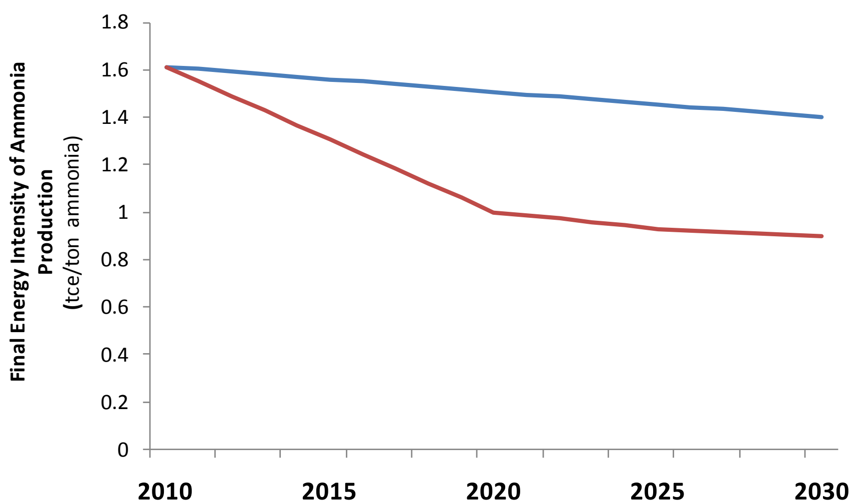
Table 8 Final Energy Intensity of Glass Production (tce/ton of flat glass)

	2010	2020	2030
Reference	0.335	0.316	0.298
Max Tech	0.335	0.298	0.262
% savings	*-*	*6%*	*12%*

Ammonia

Although China's current energy intensity for ammonia production lags behind the world best practice level, the national Five Year Plan goals for 2020 is on par with current world best-practice energy intensity. For example, the 11th FYP energy intensity goal of 29.3 GJ/ton NH_3 for 2020 is actually higher than current world best practice levels. This model assumes that ammonia production in China will reach the current world best practice energy intensity by 2030 under the reference scenario. Under the Max Tech scenario, China will reach the 11th FYP goals for 2010 and 2020 and then decline at the same rate as the reference scenario after 2020. This results in a 36% lower energy intensity of production in 2030 under Max Tech (Figure 35).

Figure 35. Average Final Energy Intensity of Ammonia Production



Ethylene

As with other petrochemical refining, ethylene is produced through a thermal or steam cracking process using a feedstock of either ethane or naphtha. In China's case, naphtha is becoming increasingly dominant because of a shortage of natural gas and refinery-based ethane production. However, naphtha requires more energy for the cracking process as a heavier feedstock. As a result of this heavy reliance on naphtha, China's 11th FYP target energy intensity values for ethylene production is much higher than the current world best practice intensity.

At the same time, a recent technology trend with important implications for efficiency gains is the increase in production unit size both in terms of newer units coming online and capacity expansion of existing units. The average production unit size has nearly doubled from 260,000 tons/year in 2001 to 460,000 tons/year in 2006 (Yu, 2007) with new Sinopec and CNPC units of greater than 500,000 tons/year capacity coming online in the last few years.

In this model, ethylene production is assumed to meet the 11th FYP intensity targets for 2010 and 2020 under the reference scenario. For the more aggressive Max Tech scenario, ethylene production is expected to reach the current world best practice energy intensity of 478 kgce per ton of ethylene output by 2025 in spite of a naphtha-dominated feedstock. (Table 9)

Table 9. Final Energy Intensity of Ethylene Production (tce/ton of ethylene)

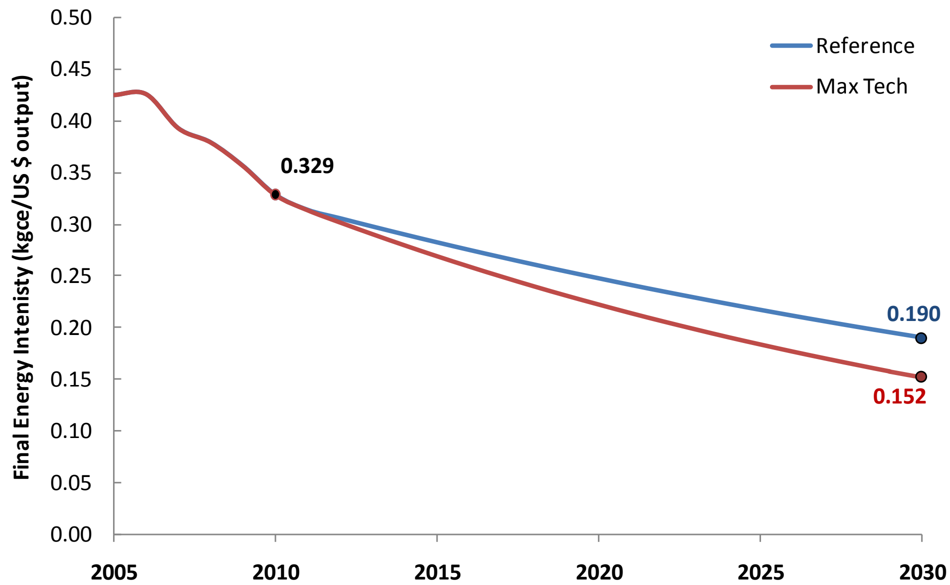
	2010	2020	2030
Reference	0.65	0.6	0.559
Max Tech	0.65	0.535	0.478
% savings	-	11%	14%

Other Industry

The Other Industry subsector encompasses a range of industries and thus cannot be analyzed on a technology-specific level. Nevertheless, past international experiences such as that of the United States and Japanese manufacturing and other industries can shed light on the likely development pathway and energy intensiveness of activity in China's other industries. Under the reference scenario, the economic energy intensity of Other Industry, measured in terms of kgce per US$ of value-added GDP, is expected to decline by 50% from current levels by 2030 (Figure 36). This decline follows the path of Japan's manufacturing industries' energy intensity which declined by 45% from 1970 to 1998 (IEEJ, 2010). Similarly, the U.S manufacturing industries also saw a 50% decline in its aggregate fuel intensity between 1977 and 1995 (Al-Ghandoor, et. al., 2008). This decline in Chinese Other Industry economic energy intensity reflects a confluence of factors that lead to declining energy consumption but growing value-added output over time, including: continued economic development that shifts manufacturing and other industries away from energy intensive, low value-added production to skill-intensive, higher value-added activity; higher wages with increasingly skilled labor force and peak in working-age population; and market-driven pace of efficiency gains in various production processes.

The Max Tech scenario diverges from the reference scenario in that it represents 20% additional efficiency improvements consistent with reaching a maximum technically feasible level beyond expected efficiency gains by 2030. The 20% efficiency improvement under Max Tech represents significantly improving the efficiency of all technologies used in manufacturing and processing industries, such as 10% gains from maximizing the efficiency of motors and an additional 10% from improvements in the industrial production balance of system (e.g., pumps, condensers, heat exchangers). As a result, the 2030 final energy intensity of 0.152 kgce per US$ of Other Industry output under Max Tech is 20% lower than the reference energy intensity of 0.190 kgce per US$.

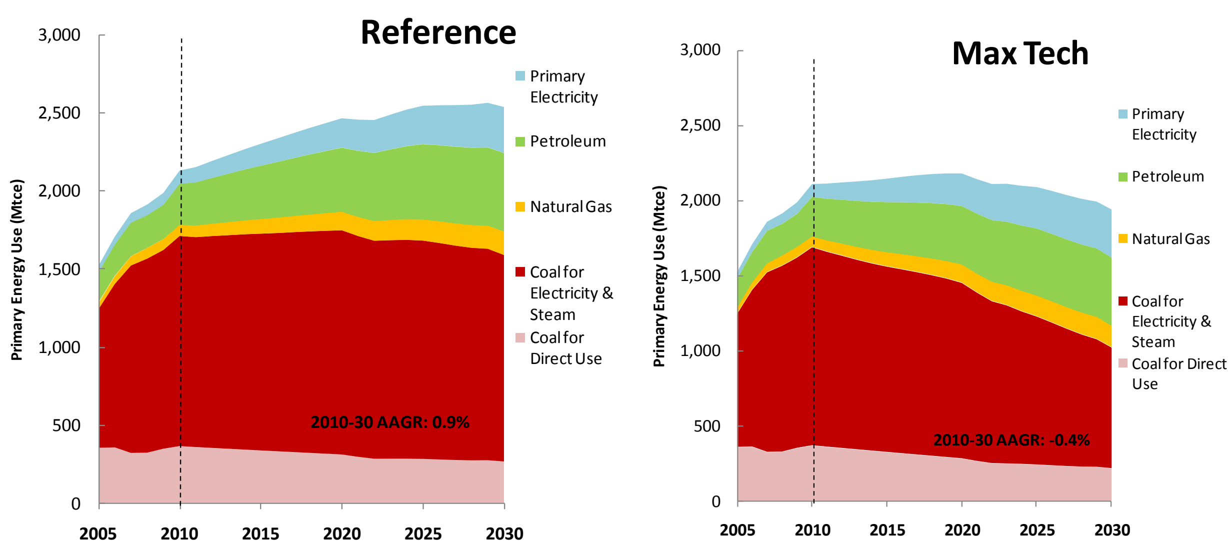
Figure 36. Final Energy Intensity of Other Industry Value-Added Output



6.2 Industrial Sector Energy and CO_2 Emissions Findings

Industrial sector primary energy use will peak very late at 2564 Mtce under the reference scenario, but earlier with 2182 Mtce under Max Tech if aggressive efficiency improvements and technology switching are adopted beyond the current pace (Figure 37). Most of the savings from Max Tech is in the form of coal, particularly coal used for generating electricity and steam, which declines by as much as 570 Mtce per year in 2030.

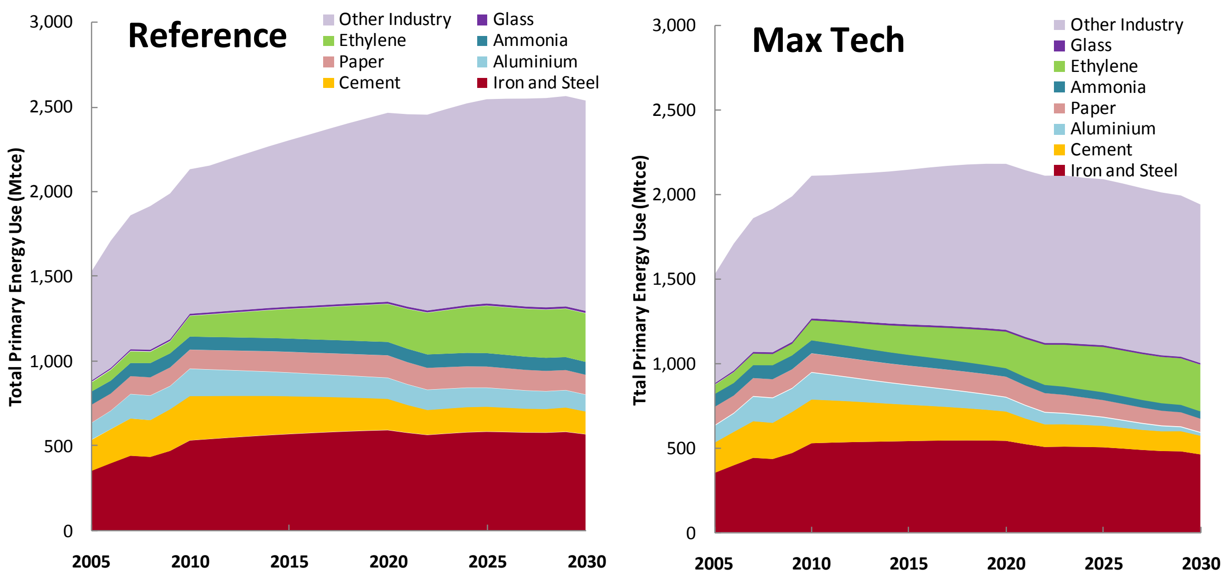
Figure 37. Industrial Primary Energy Use by Fuel, Reference and Max Tech



Within industry, the energy consumption of the seven sectors singled out in China's long-term development plan for substantial energy efficiency improvements will gradually decline relative to other sectors, though still accounting for 52% of total energy consumption in 2030, down from 70% in 2005 in the reference scenario. In the case of iron and steel and cement in particular, China's expected transition from rapid industrialization and infrastructure development to faster growth and expansion in the services sector after 2010 underlies the slowdown and eventual decline in total iron and steel output and in the decline of the cement industry (Figure 38).

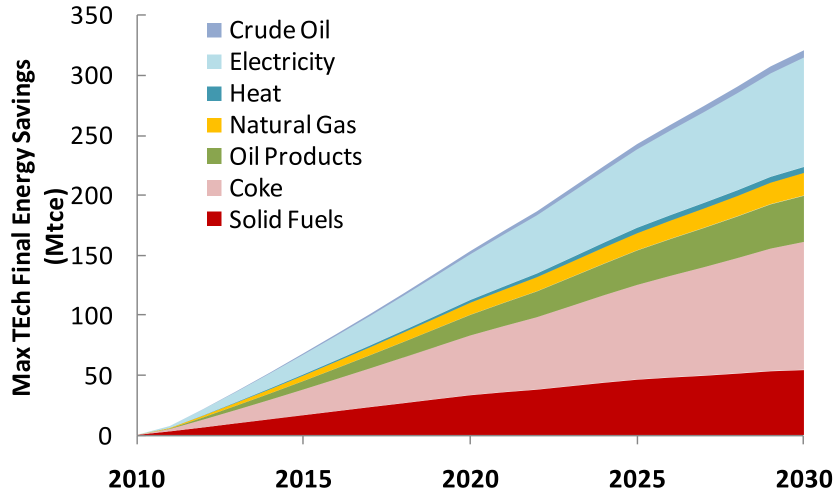
The energy use of each of these sub-sectors in absolute terms all decline modestly over time. The only exception is in energy use by the ethylene sub-sector, which grows notably from a 6% share of total industrial energy use in 2010 to 11% share in 2030 as energy consumption growth from increased production outpaces efficiency gains. The model results for projected Reference and Max Tech industrial energy use reflect key differences in efficiency improvements and technology switching, with a 600 Mtce reduction in annual energy use under the Max Tech scenario in 2030 (Figure 39).

Figure 38. Primary Energy Use by Industrial Subsector, Reference and Max Tech



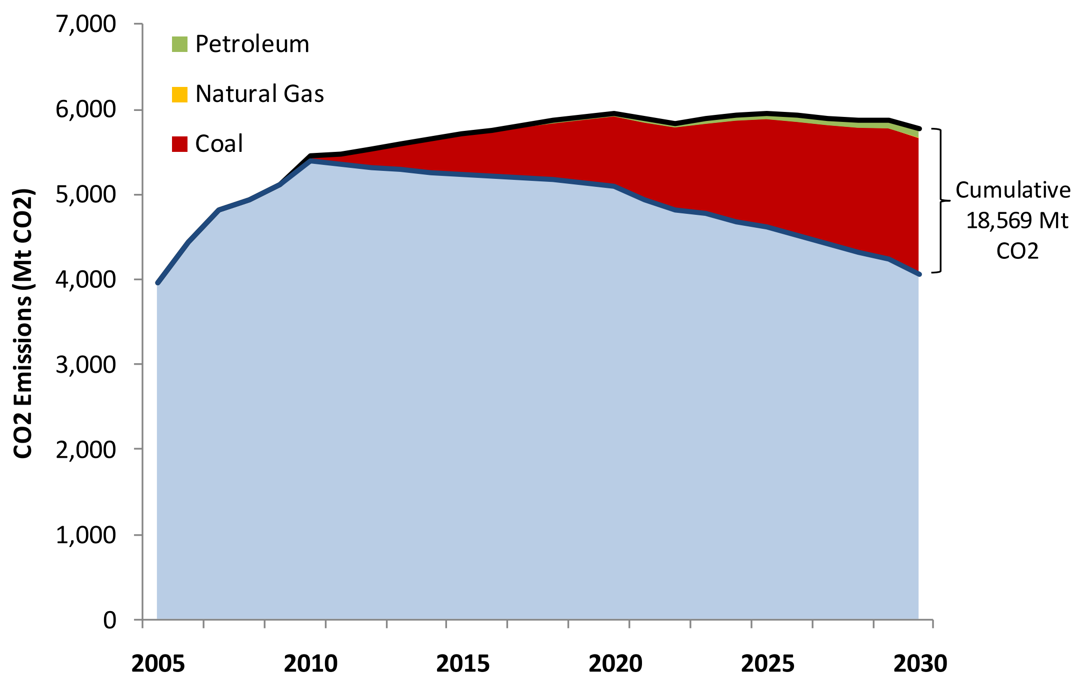
For final energy demand, the Max Tech scenario will achieve significant reductions in solid fuels (coal), coke and electricity as a result of technology switching (e.g., BOF to EAF in steel production) and efficiency improvements (aluminum primary versus secondary production).

Figure 39. Industrial Final Energy Savings by Fuel under Max Tech



Efficiency improvements as well as power sector decarbonization under the Max Tech scenario have a notable effect on steadily reducing CO_2 emissions by 1.4% annually to 2030 (Figure 40). In the reference scenario, CO_2 emissions dip after 2020 but rises again until it appears to peak at 5960 Mt CO_2. This results in annual CO_2 reductions on the order of 1702 Mt CO_2 by 2030, or cumulative reduction of 18.6 billion tonnes of CO_2.

Figure 40. Industrial CO_2 Emission Trajectories and Savings by Fuel



6.3 Analysis of Industrial Subsector Savings Potential

Energy demand in China is currently dominated by a few energy-intensive sectors, particular by the main construction inputs – cement, iron and steel and aluminum. The recent explosion of construction in

China has had a driving role in these industries, and therefore Chinese energy demand as a whole. The slowing of this construction boom will have a major impact as seen by the peaking of industrial primary energy use before 2030 for both scenarios. Under Max Tech, the largest subsector potential for energy savings is in Other (mainly non-heavy) Industry, which accounts for more than half of all annual energy savings (Figure 41). This is followed by iron and steel and aluminum subsectors, which together accounts for 32% of energy savings in 2030. By 2030, the aluminum industry also achieves significant energy savings as a result of the very aggressive shift to 80% secondary production under Max Tech (Figure 42). In contrast, ethylene and glass have the two lowest savings potential in 2030 because the gap between reference and Max Tech energy intensity is relatively small.

Figure 41. Industrial Subsector Primary Energy Savings Potential

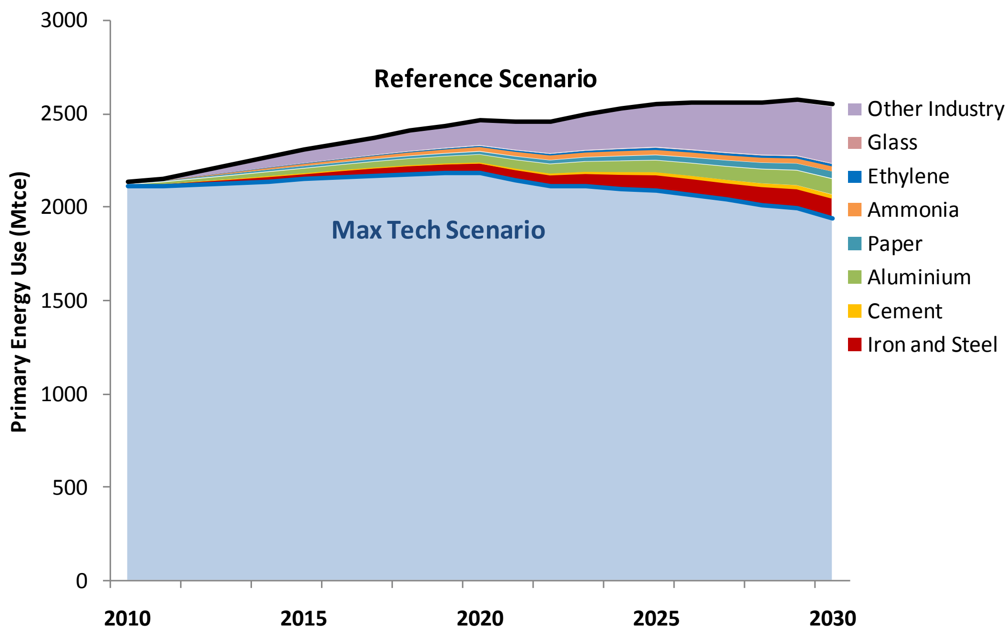
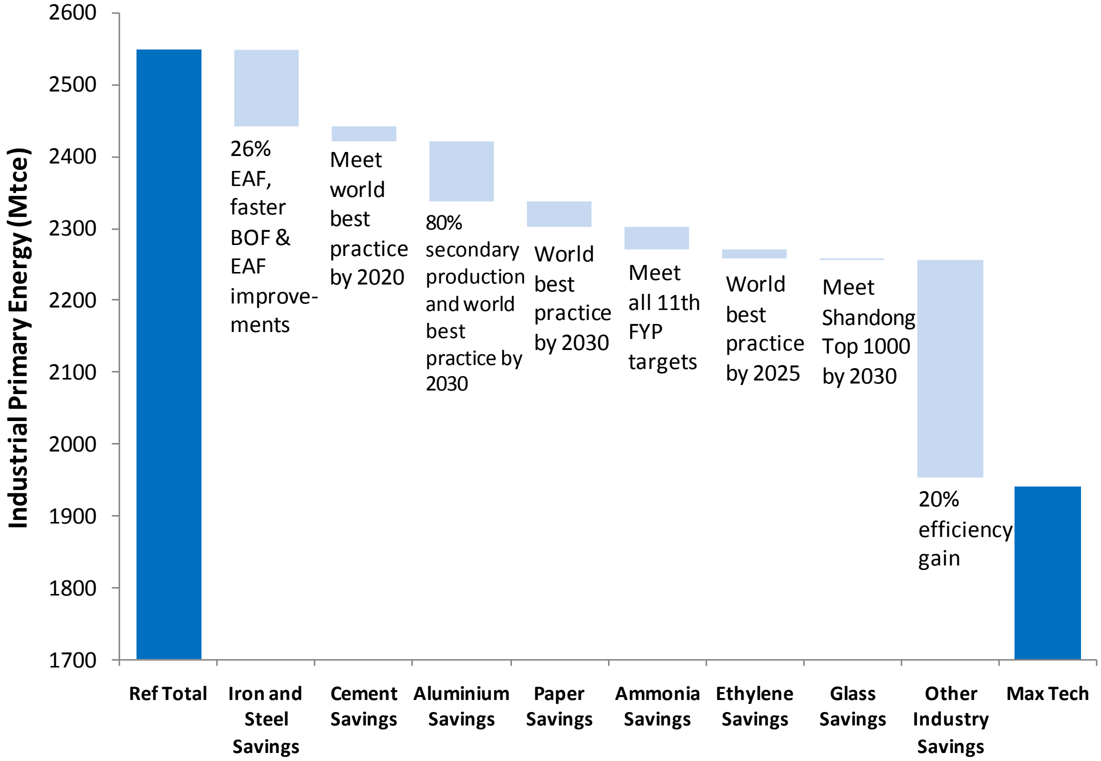


Figure 42. 2030 Industrial Primary Energy Savings by Subsector



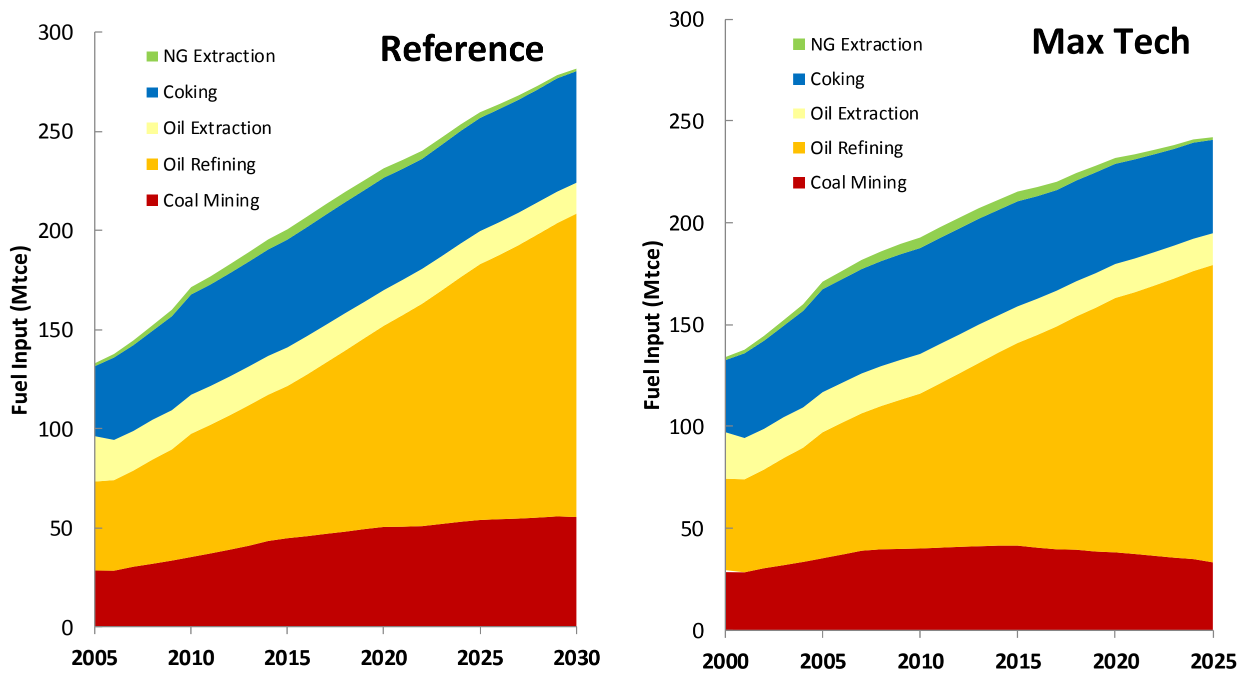
Note: Y-axis not scaled to zero.

6.4 Energy Extraction and Non-Power Transformation

Although the energy extraction and non-power sector energy transformation subsectors (oil and natural gas extraction, coal mining, oil refining, and coking) are typically considered part of the industrial sector, these subsectors are modeled separately in the transformation (or supply-side) module in our model and their energy consumption (inputs to oil, gas and coal extraction; refining losses and self-use and coking conversion losses and self-use) is captured as auxiliary inputs and calculated as part of final demand. Because these sectors are modeled as transformation processes, the final energy consumed in each sector is reported as part of primary energy consumption in the consuming sector (e.g. "petroleum" primary energy consumption in the transportation sector includes gasoline, diesel and LPG consumed as well as the final energy consumed in the refinery to produce these products).

Under both scenarios, total energy consumption in these sectors is expected to continue to rise through 2030, driven primarily by the expansion of refinery energy use (Figure 43). China's refining sector, already challenged by the requirements to produce cleaner fuels in the face of a rising proportion of high-sulfur and heavier crude oil in the processing mix, will need to add substantial numbers of energy-intensive secondary processing units such as hydrotreaters at existing refineries. Although the efficiency of individual process units is expected to improve over this period, process intensity will increase as well, while total throughput rises commensurate to the increase in product demand. Total energy use in the coking sector is primarily driven by the level of iron and steel production and the demand for metallurgical coke. The energy intensity of the coal, oil, and natural gas extraction sectors is expected to increase as reflected in rising unit energy costs of extraction as the resource base is drawn down. In the case of oil and natural gas, total energy consumption rises then falls through this period as domestic production peaks and begins to decline. The extraction energy of imported oil and gas is not included. It is expected that domestic coal production will continue to supply the majority of China's domestic demand, and the change in total energy use in the coal extraction sector varies between the two scenarios owing to the lower level of coal demand in the Max Tech case. In total, because of changes in the activity drivers of the energy extraction and transformation sector, total final energy demand in the Max Tech scenario is 40 Mtce lower than the reference case in 2030.

Figure 43. Energy Consumption in the Energy Extraction and Non-Power Transformation Sectors



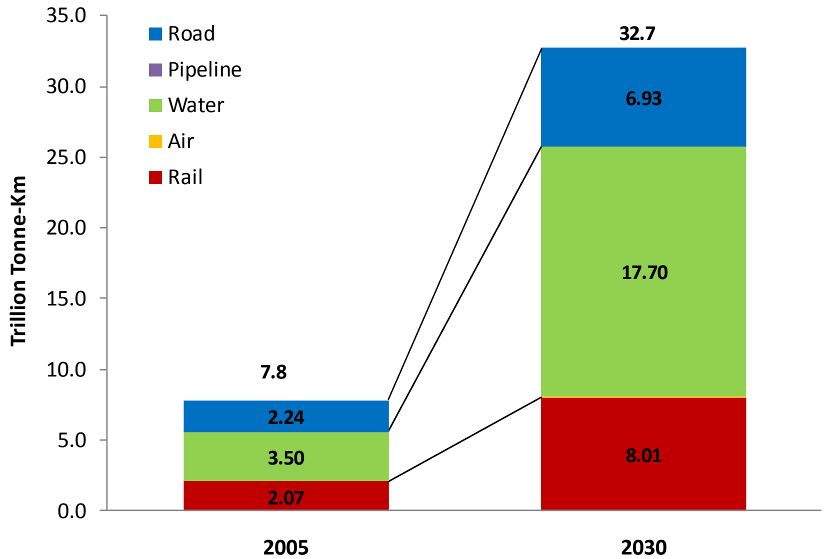
7. Transport Sector

7.1 Key Assumptions and Technology Outlook

7.1.1 Basis for Transport Energy and Emissions Outlook

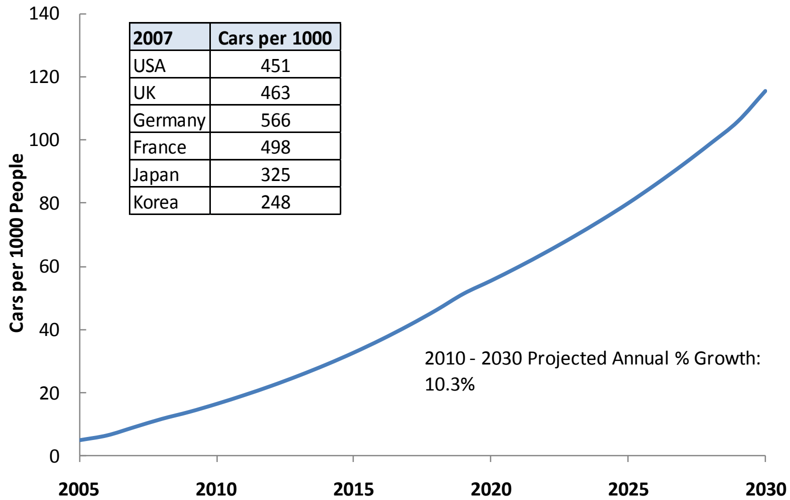
China's transportation demand is driven by demand for freight and passenger transport. Freight transport is calculated as a function of economic activity measured by value added GDP while passenger transport is based on average vehicle-kilometers traveled by mode (bus, train, car) moving people. As illustrated in Figure 44, freight transport demand is driven by faster economic growth in the years to 2030 as GDP is continues its rapid growth. The important roles of both domestic and international freight transport demand is reflected in two major modes of freight transport: water and rail transport. Water transport includes growing international ocean transport as well as domestic coastal and inland transport while demand for road freight transport reflects primarily high demand for domestic truck transport as well as doubling freight intensity for rail transport.

Figure 44. Freight Transport by Mode



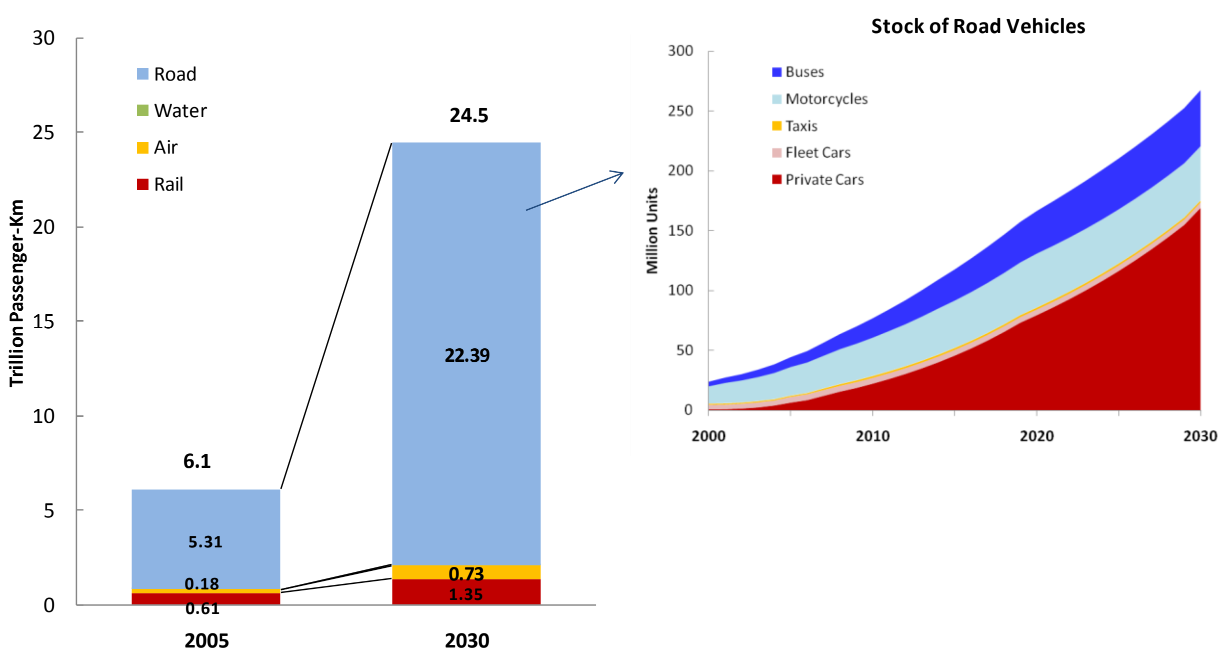
For passenger transport, growing vehicle-kilometers traveled in different modes is driven by population growth and growing demand for personal transport with rising income levels. Air transport activity is driven by demand for both domestic and international travel, which grows with GDP per capita (Figure 45). Passenger rail transport activity will rise with growth of high-speed rail and increased use of rail for short distance domestic travel, displacing some of what would otherwise have been short-distance air transport. Road transport is the largest mode of passenger travel, which is driven primarily by the burgeoning ownership of private cars that follows rising per capita income (Figure 46 inset). Despite the boom in car sales in recent years, China's car ownership rate is currently 20 times lower than that in developed countries, so annual growth rates of as high as 10% can be expected for the next two decades.

Figure 45. Projected Car Ownership per 1000, 2005-2030



In the model, personal car ownership is forecasted on a per-household basis by relating current car ownership rates around the world to household income, with a slight adjustment for the fact that current Chinese personal car ownership is low even compared to countries of similar income. By 2030, personal car ownership reaches 0.338 per household, which while extremely high compared to current values, is still below current levels in the United States and Europe. The high population density in China, like that of New York City, means that cars are generally driven less. Nonetheless, road transport activity grows rapidly at an annual rate of 5% after 2010. As personal income and private car ownership rises, motorcycle and taxi passenger transport plateaus and water passenger transport declines modestly after 2020.

Figure 46. Passenger Transport by Mode and Stock of Road Vehicles

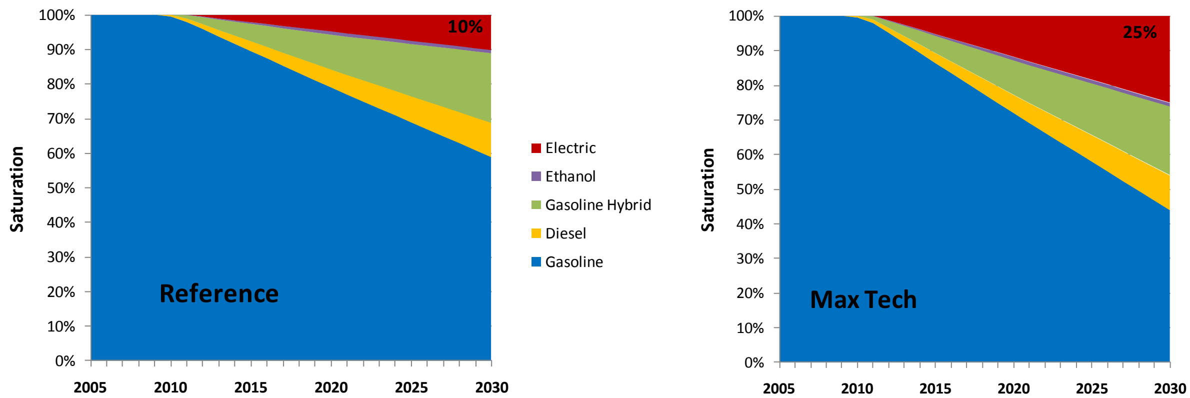


7.1.2 Efficiency Improvements and Technology Outlook

Cars and Taxis

A key element of transport energy use is the fuel share of the transport stock, which determines the fuel economy of the vehicle and fuel consumed. In terms of car fuel shares, 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 the reference scenario given that mass production has not yet started in China (Figure 47, left). Under accelerated mass deployment of EVs in Max Tech, the share is expected to be 25% in 2030 (Figure 47, right).

Figure 47. Car Fuel Shares, Reference and Max Tech



To model the final energy demand from the projected 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 (Table 10). 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 (Ou et. al., 2009).

Table 10. Car and Taxi Final Energy Intensity Assumptions, Reference and Max Tech

	Reference Scenario	**Max Tech Scenario**
Cars: 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	Reach best fuel economy equal to current day hybrids of 1.88 (40 mpg) by 2030
Diesel	2.20 (34 mpg) in 2020 to 1.97 (38 mpg) in 2030	1.51 (50 mpg) by 2030
Gasoline Hybrid	Constant at 1.5 (50 mpg) thru. 2030	1.3 by 2030
Ethanol	2.52 in 2020 to 2.31 in 2030	1.8 by 2030

Electric	Constant at 0.5 (~14.3 kWh/veh-km) based on Chinese literature	Same as Reference
Taxis: 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	Similar improvements as cars to 1.88 by 2030
LPG	2.4 (25 mpg) in 2020 to 2.3 (33 mpg) in 2030	Same as Reference
Motorcycle	Constant at 0.7 after 2020	Constant at 0.7 after 2020

Buses

The assumed final energy intensities for buses in the model reflect different paces of improvement in the fuel economy of heavy (HDB) and medium-duty (MDB) and light-duty and mini-buses under the two different scenarios. Under both scenarios, gasoline fueled HDB and MDB see small improvements in fuel economy from 10.5 MJ/veh-km in 2010 to 10.02 MJ/veh-km in 2030 (Table 11). Under Reference, there is a 15% efficiency gain with diesel buses under the assumption that diesel hybrid buses become available before 2030. Max Tech has faster efficiency improvements for diesel buses and can reach 6.55 MJ/veh-km by 2030. Natural gas buses are assumed to follow the same improvement trend as diesel buses under the two scenarios, but uses 5% more energy/veh-km following findings from a recent California study (Schuber and Fable, 2005). The efficiency of light-duty and mini gasoline buses is also expected to remain relatively constant after 2020, with 15% efficiency gain in diesel hybrids by 2030. Under Max Tech, there are additional efficiency gains from improvements in LDB and MB, with both following the trend of achieving best currently available ICE technology similar to best available cars by 2030.

Table 11. Buses Final Energy Intensity Assumptions, Reference and Max Tech

	Reference Scenario	**Max Tech Scenario**
Heavy and Medium Duty Buses: Final Energy Intensity (MJ/veh-km)		
Gasoline	Relatively flat intensity after 2020 at 10.03 MJ/veh-km (7.5 mpg)	Same as Reference
Diesel	15% efficiency gain with more diesel hybrids, from 8.65 (8.7 mpg) in 2020 to 7.95 in 2030	Greater efficiency improvements to 6.55 in 2030
Natural Gas	5% less efficient than diesel, assuming same trend of improvements	5% less efficient than diesel, assuming same trend of improvements
Light-duty and Mini Buses: Final Energy Intensity (MJ/veh-km)		
Gasoline	Relatively flat at 3.31 (22.7 mpg) after 2020	Trend of reaching best ICE technology after 2030, with 1.88 in 2030

Diesel	15% efficiency gain with more diesel hybrids to 2.66 (28 mpg) in 2030	30% efficiency gain with more diesel hybrids to 2.2 in 2030

Trucks

The assumed truck 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 (Ruzzenenti and Basosi, 2009). For the Max Tech scenario, fuel economy improvements are expected to be more aggressive, particularly after 2020, and often reach the EU rate of improvement ten years earlier (Table 12).

Table 12. Truck Final Energy Intensity Assumptions, Reference and Max Tech

	Reference Scenario	**Max Tech Scenario**
Heavy-Duty Trucks: Final Energy Intensity (MJ/veh-km)		
Diesel	8.5 (8.8 mpg) in 2020 to 8.34 (9 mpg) in 2030	8.5 (8.8 mpg) in 2020 to 8 (11 mpg) in 2030
Medium-duty Trucks: Final Energy Intensity (MJ/veh-km)		
Gasoline	8.33 MJ/veh-km (9 mpg) in 2020 to 8.14 MJ/veh-km (9.2 mpg) in 2030	8.33 MJ/veh-km (9 mpg) in 2020 to 7.76 MJ/veh-km (9.7 mpg) in 2030
Diesel	6.60 MJ/veh-km (11.4 mpg) in 2020 to 6.46 MJ/veh-km (14.1 mpg) in 2030	6.60 MJ/veh-km (11.4 mpg) in 2020 to 6.17 MJ/veh-km (14.7 mpg) in 2030
Light-duty Trucks: Final Energy Intensity (MJ/veh-km)		
Gasoline	4.21 MJ/veh-km (17.9 mpg) in 2020 to 4.06 MJ/veh-km (18.5 mpg) in 2030	4.06 (18.5 mpg) in 2020 to 3.77 MJ/veh-km (20 mpg) in 2030
Diesel	4.33 MJ/veh-km (17.4 mpg) in 2020 to 4.18 MJ/veh-km (18 mpg) in 2030	4.18 MJ/veh-km (18 mpg) in 2020 to 3.87 MJ/veh-km (23 mpg) in 2030
Mini Trucks: Final Energy Intensity (MJ/veh-km)		
Gasoline	2.16 MJ/veh-km (34.8 mpg) in 2020 to 2.06 MJ/veh-km (36.5 mpg) in 2030	2.06 MJ/veh-km (36.5 mpg) in 2020 to 1.86 MJ/veh-km (40 mpg) in 2030
Diesel	2.1 MJ/veh-km (35.9 mpg) in 2020 to 2 MJ/veh-km (37.7 mpg) in 2030	2.00 MJ/veh-km (45 mpg) in 2020 to 1.80 MJ/veh-km (50 mpg) in 2030

Air

China's air transport sector will continue undergoing efficiency improvements over the next twenty years, with fuel economy rising from current levels of 1.6 MJ/passenger-km to 1.45 in 2020 and 1.3 in

2030 under the reference scenario. This efficiency improvement follows the improvement path of the modern fleet in the last fifty years with the modern aircraft energy intensity of 1 MJ/passenger-km reached after 2030 (Peeters et. al., 2005). For Max Tech, China is expected to improve at a pace faster than the efficiency improvement path of the modern fleet (twenty instead of fifty years) by reaching 1 MJ/passenger-km in 2030. Similarly, the same improvement trends are experienced by freight air transport, with 8.45 and 6.5 MJ/ton-km in 2030 under Reference and Max Tech, respectively.

Rail

The fuel share assumptions in the model explicitly accounts for different paces of rail electrification under Reference and Max Tech. Although rail electrification is expected to quicken from its current level of ~36% to higher levels by 2020 following the government's recently announced electrification goals, the model accounts for even faster electrification after 2020 under Max Tech (Table 13). No significant changes are expected in the diesel or electric rail's final energy intensity as China's rail system already uses highly efficient equipment.

Table 13. Rail Fuel Share and Final Energy Intensity Assumptions, Reference and Max Tech

	Reference Scenario	Max Tech Scenario
Fuel Share		
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
Final Energy Intensity (MJ/pass or veh-km)		
Gasoline	Constant at 0.3 through 2030	Same as Reference
Diesel	Constant at 0.1 after 2020	Same as Reference

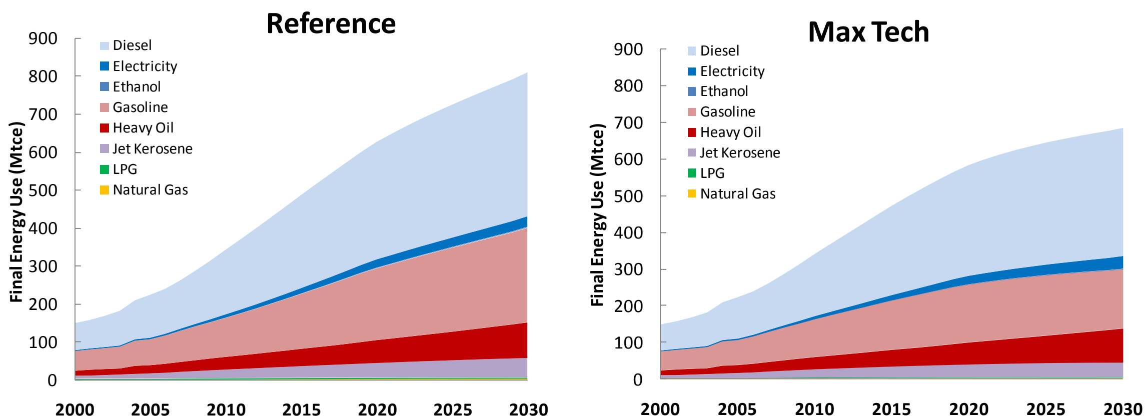
Water

With air and rail transport becoming more common for longer distance passenger and freight travel, no significant efficiency improvements in water transport are expected. Passenger water transport is assumed to remain constant at 0.21 MJ/passenger-km and freight water transport at 0.27 MJ/ton-km under both scenarios.

7.2 Transport Energy and CO_2 Emissions Findings

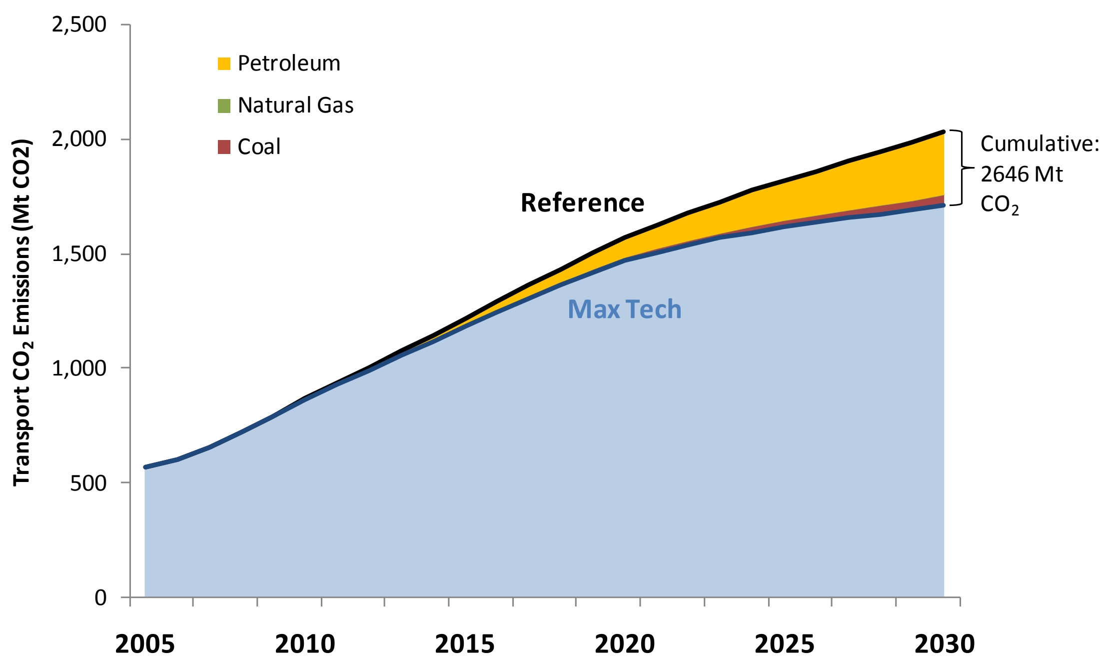
Unlike the other sectors, final energy use will not peak in the transport sector before 2030 under either scenario. Rather, the total final energy use for the transport sector will grow rapidly after 2010 to reach 810 Mtce under Reference and 686 Mtce under Max Tech. The final energy demand is 123 Mtce lower under Max Tech in 2030 with majority of the reduction in the form of gasoline with few other changes in fuel shares (Figure 48). In fact, diesel remains the largest share of fuel consumed, followed by gasoline, heavy oil and jet kerosene under both scenarios.

Figure 48. Transport Final Energy Use by Fuel, Reference and Max Tech



The vast majority of CO_2 emissions reduction from Max Tech is due to lower petroleum use, with a small reduction in coal as a primary energy use due to reduction in the power sector. As with final energy use, neither scenario achieves a CO_2 emissions peak before 2030, although the growth in emissions does slow after 2020 (Figure 49). In 2030, CO_2 emissions are reduced by 324 Mt CO_2 under Max Tech with cumulative reduction through 2030 totaling 2.6 billion tonnes of CO_2.

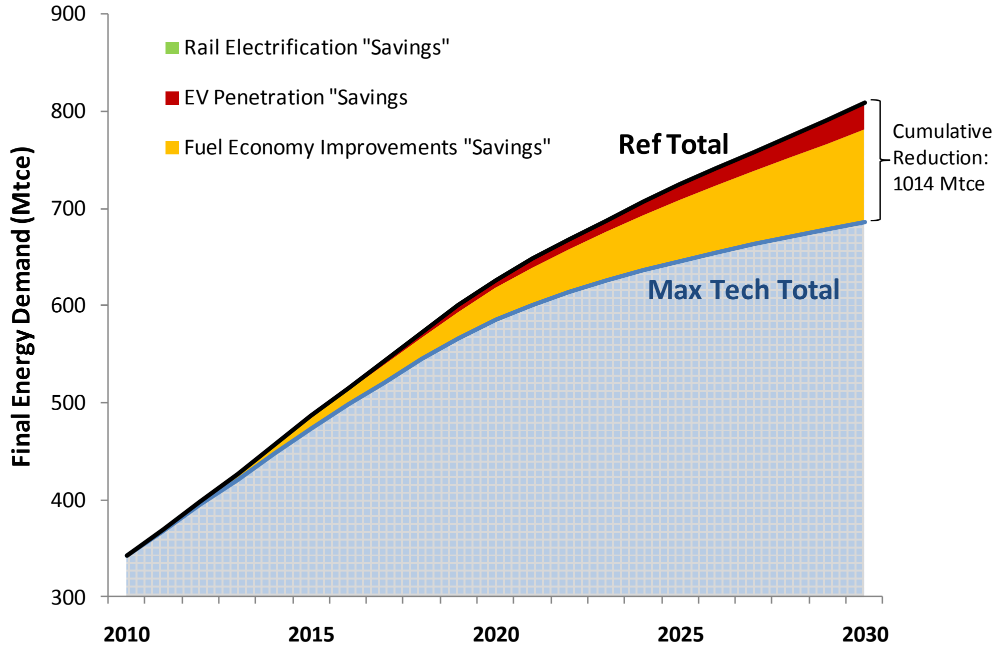
Figure 49. Transport CO_2 Emissions and Reduction Potential



7.3 Analysis of Transport Sector Savings Potential

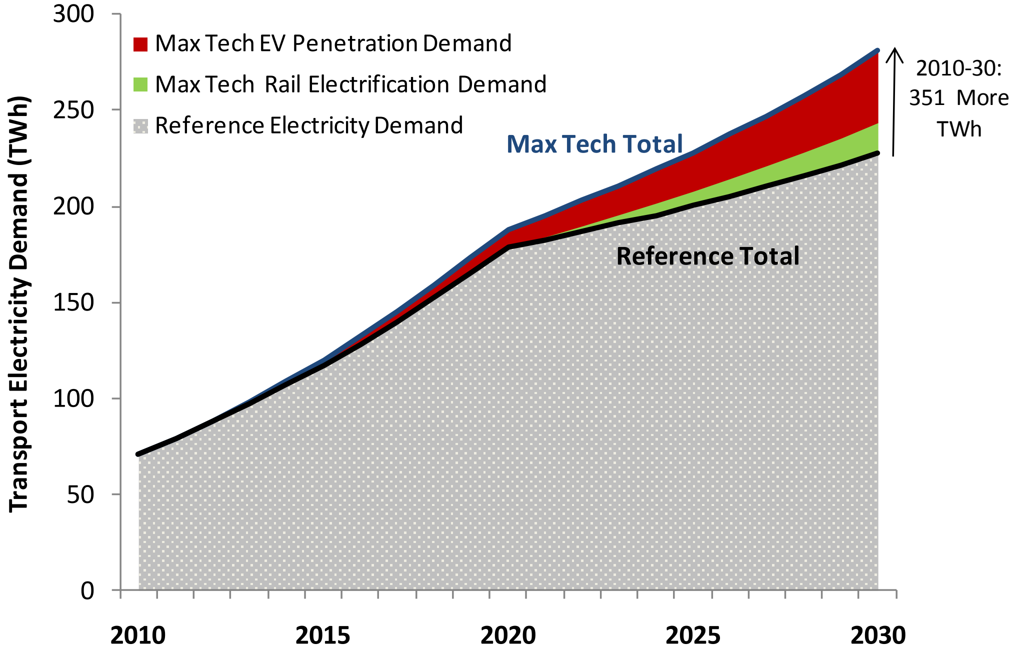
The lower transport final energy demand in Max Tech can mostly be attributed to savings from more aggressive fuel economy improvements in all internal combustion engine (ICE) vehicles and greater EV penetration, with rail electrification having a diminutive effect (Figure 50). In particular, additional fuel economy improvements under Max Tech had the greatest final energy savings with 95 Mtce in 2030, followed by accelerated vehicle electrification at 28 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) between the two scenarios is relatively small.

Figure 50. Transport Final Energy Savings Potential under Max Tech



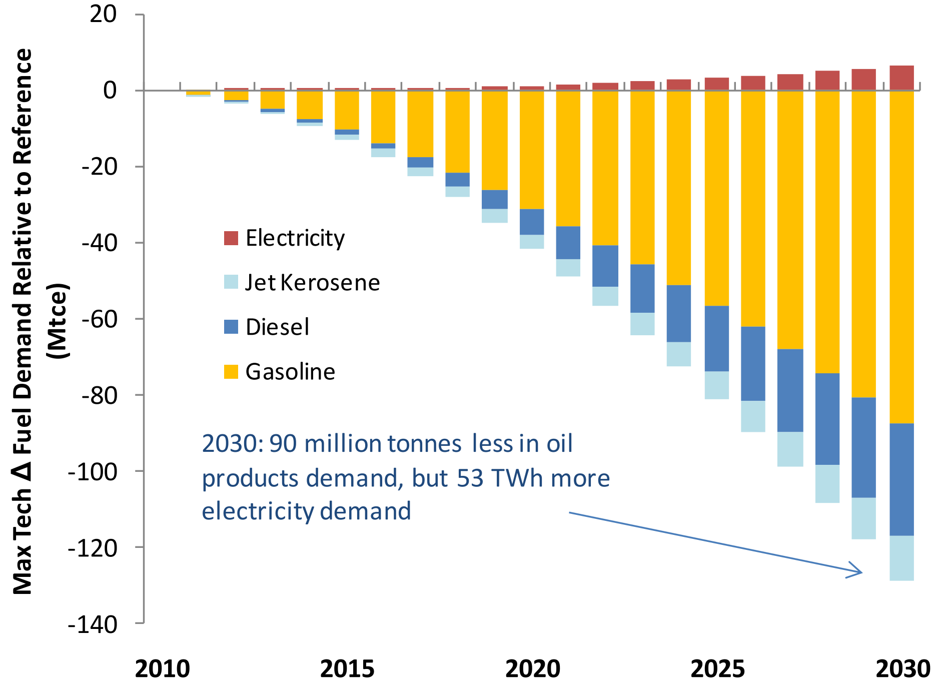
While gasoline and diesel demand will be lowered by greater rail and road electrification, electricity demand from the transport sector will increase under Max Tech. Most of the increased electricity demand will be to power the larger EV fleet under Max Tech, with an additional 38 TWh needed in 2030 relative to reference (Figure 51). 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 351 additional TWh will be needed under the Max Tech scenario.

Figure 51. Transport Electricity Demand Reduction under Max Tech



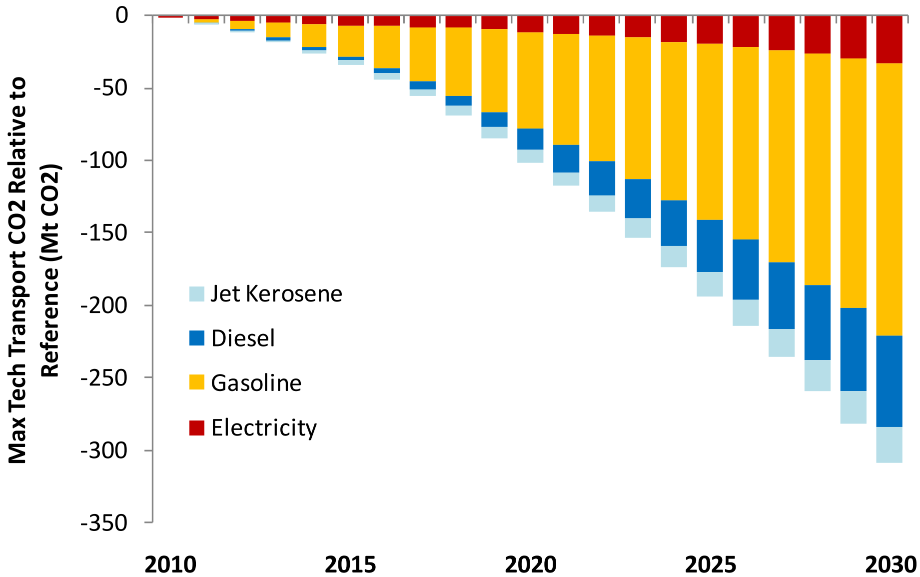
The fuel impact of Max Tech transport relative to reference is a substantial reduction in gasoline demand with smaller reduction in diesel demand (from decreased diesel fuel share of rail transport) and even smaller reduction in jet kerosene from airplane fuel economy improvements (Figure 52). There is also some offset of final demand reduction for oil products by an increase in electricity demand but overall, the reductions in oil products more than offset the increase in electricity demand, resulting in a net reduction in final transport fuel demand.

Figure 52. Change in Max Tech Final Energy by Fuel Type



As with the change in transport fuel consumption between the two scenarios, the majority of transport CO_2 reductions will also be from lower gasoline use resulting from fuel economy improvements and EV technology switch (Figure 53). Moreover, with electrification playing an important role in both scenarios, transport CO_2 emissions outlook will also be interlinked with decarbonization of the power supply. This is most evident in Max Tech scenario's net CO_2 emissions reduction compared to reference despite increased electricity demand. In fact, greater transport electricity use under Max Tech actually results in net CO_2 reduction on the order of 2 to 33 Mt CO_2 per year because the Max Tech power supply becomes increasingly less carbon intensive than the Reference power supply. Specifically, the Reference power sector has an emission factor of 0.44 Mt CO_2/TWh electricity generated while Max Tech has an emission factor of only 0.24 Mt CO_2/TWh by 2030.

Figure 53. Transport CO_2 Emission Reduction by Fuel in Max Tech



The important impact of decarbonization on transport electrification is illustrated by the case of CO_2 reduction from EV technology switch. Under Max Tech, the CO_2 reduction from the 15% larger EV fleet share by 2030 actually results from two compounded effects: a cleaner power supply and gasoline demand reduction with the technology switch. In the absence of decarbonization in the power sector, the EV impact on carbon mitigation will be smaller as part of the emission reduction from lower gasoline demand will be offset by higher CO_2 emissions from additional electricity demand.

8. Power Sector

Although the total power generation output is dictated by the demand module in the model, the actual generation mix and subsequent CO_2 emissions from the power sector is determined through a series of algorithms and variables such as installed capacity and capacity factor to dispatch generation according to an environmental dispatch priority order. Specifically, this model uses an environmental dispatch order where low-carbon and renewable fuels are dispatched first to meet demand, with coal capacity dispatched to meet the gap between electricity demand and non-fossil electricity supply. This "maximum non-fossil" merit order differs from economic or equally-distributed generation dispatch in that nuclear power is given first priority followed by wind, hydro, natural gas, solar, biomass, and finally coal.

8.1 Key Parameters of Power Sector

Capacity Factor

Within the power sector, fossil fuels have the highest capacity factors, followed by nuclear, hydro, and renewable fuels as seen in Table 14. However, not all fossil fuel generation technologies are fully utilized due to the environmental dispatch algorithm. 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. The power generation capacity factors are held constant with the exception of natural gas and wind power. Wind and natural gas capacity factors are expected to increase over time to a maximum of 30% and 45% by 2030.

Table 14. 2030 Capacity Factor by Generation

	Wind	Nuclear	Hydro	Biomass	Solar	Natural Gas	Coal
2030 Modeled Capacity Factor	30%	88%	39%	25%	19%	45%	90%

Installed Capacity

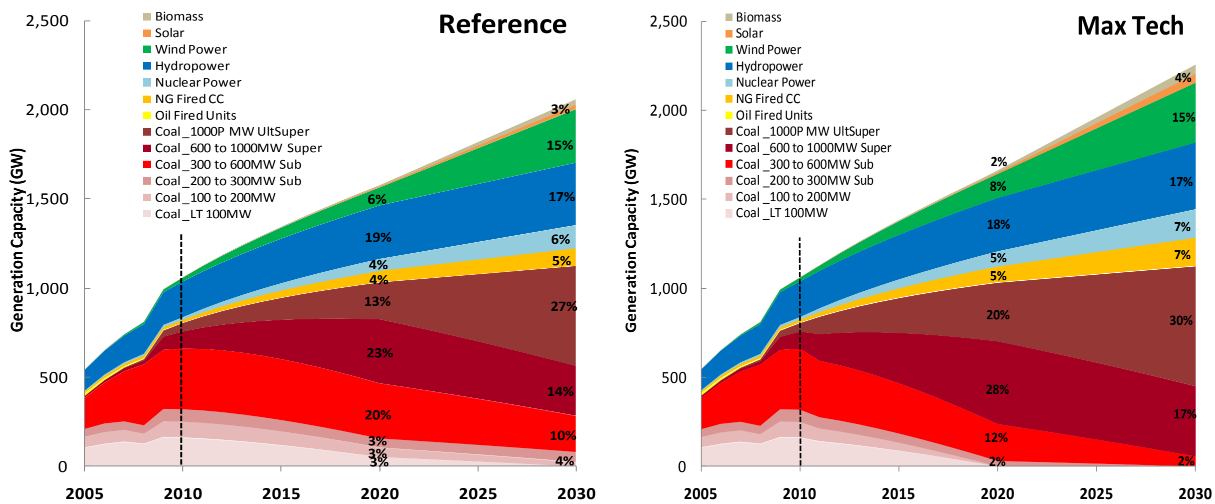
As a result of the environmental dispatch order, the key constraint on the generation of renewable and nuclear power is the construction of new generation capacity. Projections of installed capacity for each non-fossil generation type were collected from a variety of international and Chinese sources, including official government statements and targets, projections by research groups and in academic journals, and our own estimates. The reference scenario capacity projections incorporates published Chinese government targets for non-fossil capacity growth while the Max Tech scenario projections is based on more aggressive non-fossil capacity growth to the maximum technically feasible level given constraints such as construction and commissioning of new plants. The 2020 and 2030 installed capacity for each generation source in the reference and Max Tech scenarios are illustrated in Table 15 below.

Table 15. 2020 and 2030 Installed Capacity by Generation, Reference and Max Tech

	Reference		**Max Tech**	
GW Installed Capacity	**2020**	**2030**	**2020**	**2030**
Coal	1032	1126	1032	1068
Oil	0	0	0	0
Natural Gas	65	100	89	159
Nuclear	67	130	86	160
Hydro	300	350	300	375
Biomass & Others	7	31	12	53
Wind	100	300	135	337
Solar	6	24	10	51

Under the reference scenario, renewable fuels (wind, biomass and solar) increase their share of total installed capacity from less than 2% in 2010 to 7% in 2020 and 17% in 2030 (Figure 54, left). By 2030, the reference scenario includes 300 GW of wind, 24 GW of installed solar capacity and 31 GW of biomass and other renewable capacity. Combined with nuclear and hydropower, the total share of non-fossil fuels nearly doubles from 22% in 2010 to 41% in 2030.

Figure 54. Generation Capacity by Fuel, Reference and Max Tech



Under the Max Tech scenario, the share of renewable installed capacity grows even faster to 9% in 2020 and 20% in 2030 (Figure 54, right). By 2030, there is 37GW of additional wind capacity, 27 GW of additional solar capacity and 22 GW of additional biomass and other renewable capacity compared to the reference capacities. The total share of non-fossil fuel capacity (including hydropower and nuclear power) is also slightly higher at 23% in 2020 and 43% in 2030.

8.2 Efficiency Improvements and Technology Outlook

Besides the facilitation of greater fuel switching from coal to low carbon non-fossil and renewable generation, the power sector also features efficiency improvements in generation, plant self-use, transmission and end-use under both reference and Max Tech. The average generation efficiency of nuclear power rises from 32% in 2005 to 38% in 2020 and 41% in 2030. Transmission and distribution efficiency also continue to improve to a 6% loss rate by 2030 as a result of China's large grid-improvement investments, and power plant self-use averages about 0.01 kWh/kWh less in the Max Tech case because of the increased proportion of hydropower in the national generation mix.

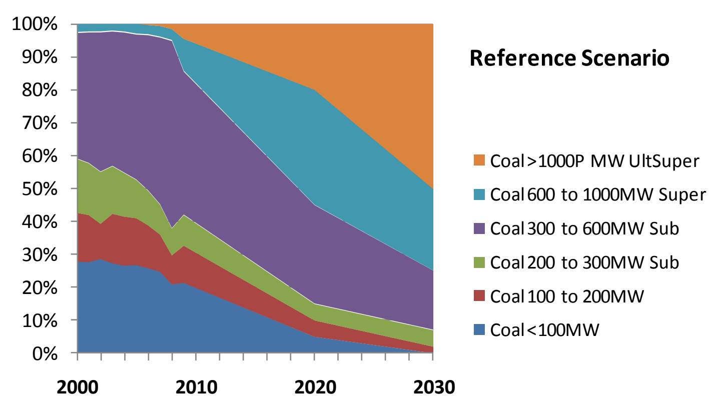
In the model, coal generation is divided into six types of generation technology by size and efficiency. The heat rates and process efficiency for each category of coal generation technology is listed in Table 16. There is a significant range in efficiency depending on the size of the generation unit as units larger than 1 GW have an average efficiency of 44% while those less than 100 MW are just 27% efficient. Of these six types of coal generation units, the model applies merit order dispatch to coal generation technologies with the largest, most efficient units coming online first.

Table 16. China Coal-Fired Electricity Generation Efficiency by Technology Type

	Heat Rate (gce/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 Ultra-Sup.-Cri	282	44%

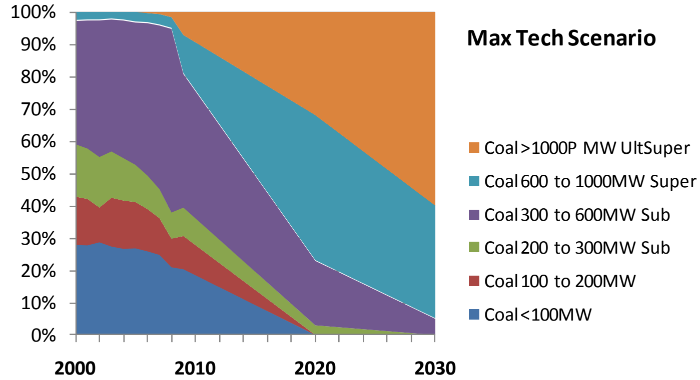
Under the reference scenario, Figure 55 shows the rapid increase of ultra-super critical units larger than 1 GW from less than 1% in 2005 to 50% of total installed coal capacity in 2030 while the least-efficient units with a scale of less than 100 MW are completely phased out by 2030. This result in the average coal-fired efficiency improving as the average heat rate declines from 358 gce per kWh in 2009 to 323 and 304 gce/kWh in 2020 and 2030, respectively, as coal power restructuring policies continue to be implemented.

Figure 55. Reference Coal Generation by Size



For Max Tech, average coal-generation efficiency improves even more rapidly with ultra-supercritical units greater than 1 GW rising to 60% of installed coal capacity in 2030 and the complete phase-out of units less than 100 MW by 2020 (Figure 56). Additionally, 100 to 200 MW units are also phased out by 2020 while 200 to 300 MW subcritical units are phased out by 2030. The resulting average heat rate declines to only 307 gce/kWh – a level comparable to the reference 2030 level – by 2020, and further to only 295 gce/kWh by 2030.

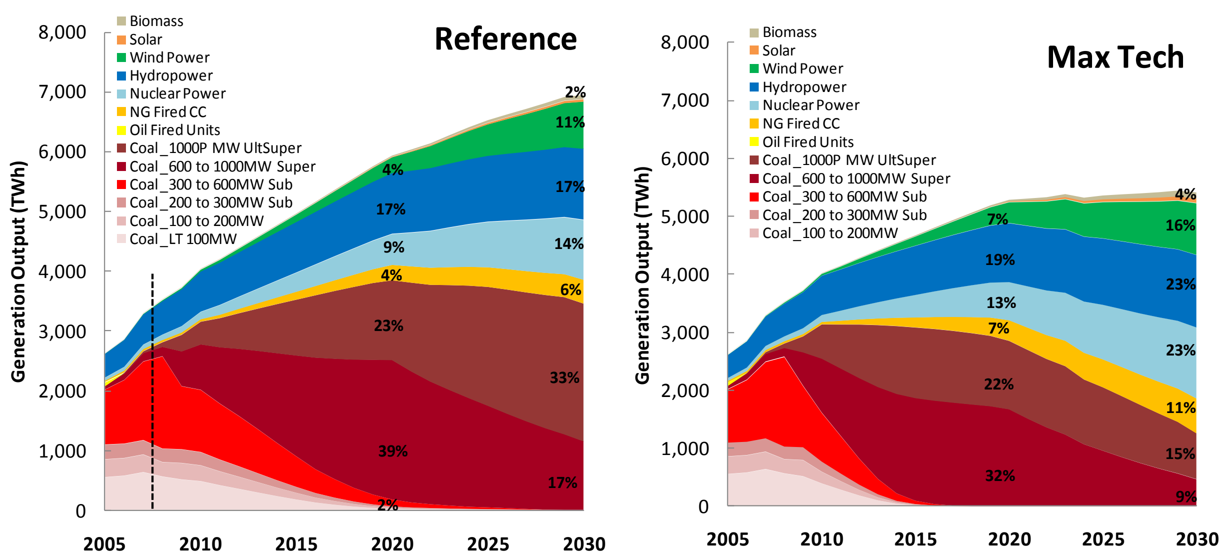
Figure 56. Max Tech Coal Generation by Size



8.3 Power Sector Analysis and Findings

The power sector accounts for a large growing share of China's energy use and related carbon emissions. On the demand side, the acceleration of efficiency gains from technical improvements, technology and fuel switching under Max Tech results in 22% lower total electricity generation in 2030 than the reference scenario (Figure 57, right). On the supply side, efficiency improvements and fuel substitutions bring the 2030 coal share of total electricity generation from 50% in the reference scenario to only 24% in Max Tech. In Max Tech, coal-fired generation is largely replaced by rising shares of solar and wind power generation, which account for 18% of all generation in 2030, followed by nuclear and hydropower at 23% each. Thus, by 2030, 64% of the power generation under Max Tech is from non-carbon-emitting sources versus 44% under the reference scenario.

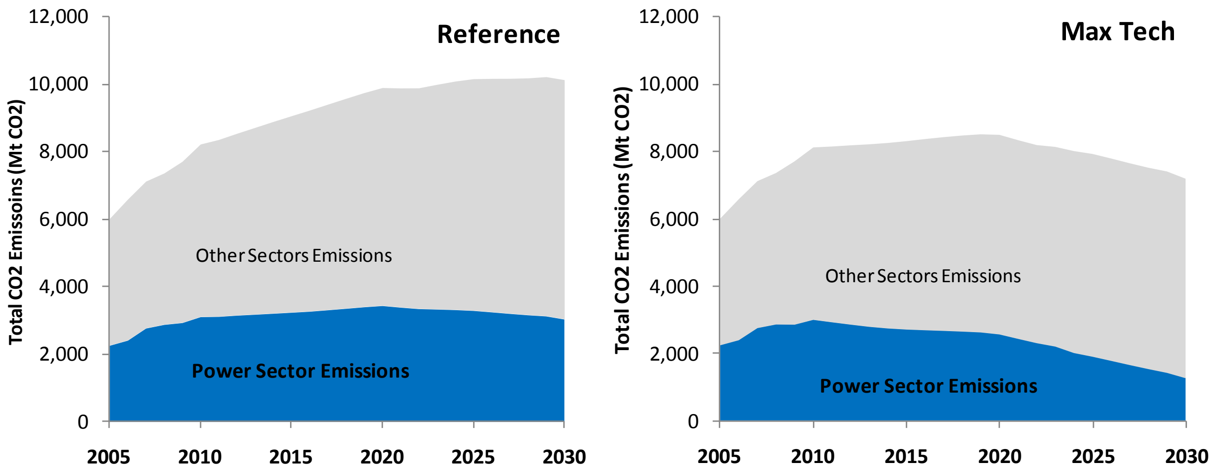
Figure 57. Electricity Generation Output by Fuel, Reference and Max Tech



Besides efficiency gains which reduce electricity demand, decarbonization also plays a significant role in shaping the trajectory of carbon emissions in the power sector. In fact, Max Tech power sector emissions peak at 3 billion tonnes of CO_2 and begin declining rapidly to only 1.3 billion tonnes in 2030

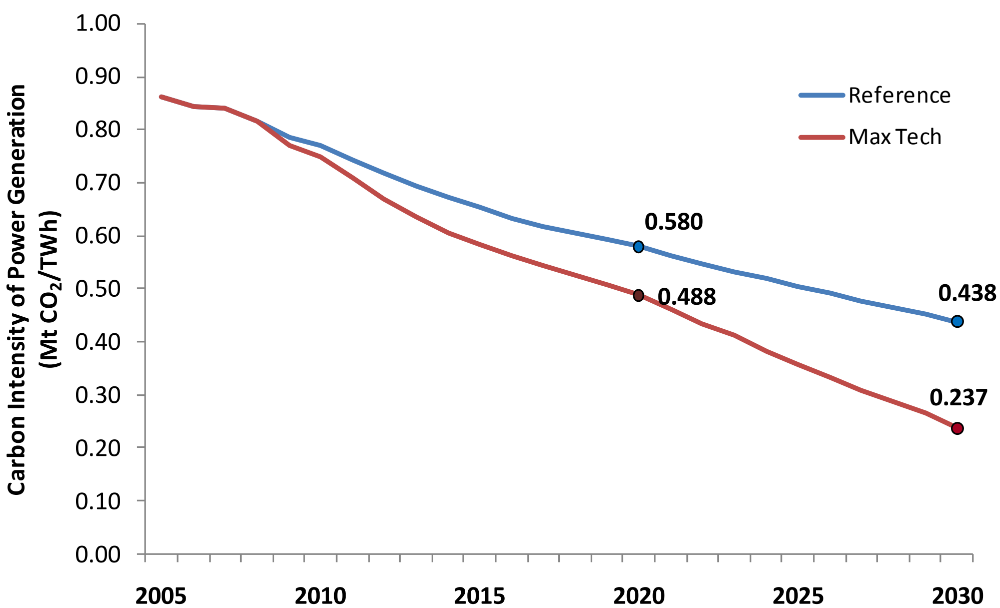
(Figure 58, right). In contrast, the reference power sector emissions peak at a higher level of 3.4 billion tonnes and declines slowly to current levels of 3 billion tonnes by 2030 (Figure 58, left). Besides decline in absolute emissions under both scenarios, the power sector's relative share of total emissions also declines from 38% in 2010 to 30% under reference and only 18% under Max Tech in 2030.

Figure 58. Power Sector CO_2 Emissions, Reference and Max Tech



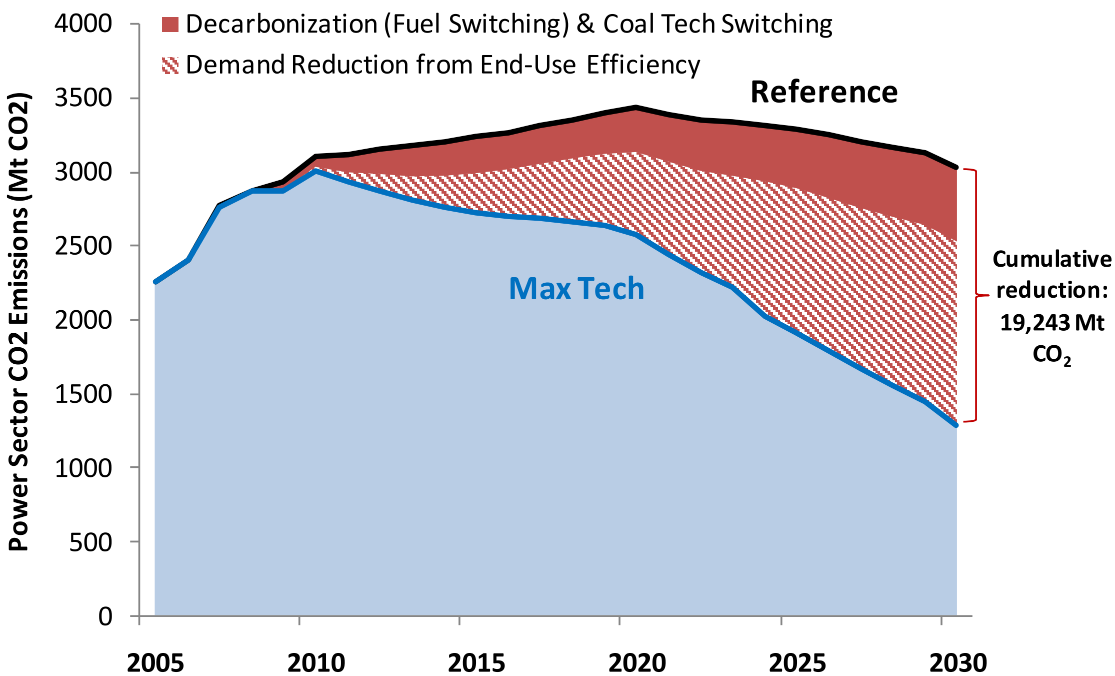
As a result of the supply-side improvements in generation efficiency and fuel switching away from coal, the carbon intensity of electricity generation will decline significantly from current levels under both scenarios (Figure 59). Under Max Tech, the carbon intensity of electricity generation in 2030 will be 50% less than the 2030 reference level, and 72% less than the 2005 carbon intensity.

Figure 59. Carbon Intensity of Power Generation, Reference and Max Tech



Within the power sector, the greatest carbon emission mitigation potential from a Max Tech trajectory is from direct electricity demand reduction as a result of more aggressive end-use efficiency improvements in industrial, residential, commercial, and transport sectors. Figure 60 illustrates the two key components that lead to power sector emissions reductions of 1.7 billion tonnes of CO_2 per year by 2030, where the solid wedge represents CO_2 reduction from fuel switching and efficiency improvements in the power sector and the striped wedge represents CO_2 reduction due to electricity demand reduction. Clearly, the larger and continuously growing power sector mitigation potential is from end-use efficiency improvements that lower final electricity demand and related CO_2 emissions. Specifically, efficiency-driven electricity demand reduction comprises of 65% and 71% of total power sector CO_2 reduction in 2020 and 2030, respectively. These results emphasize the significant role that energy efficiency improvements will continue to play in carbon mitigation in the power sector (vis-à-vis lowering electricity demand), as efficiency improvements greatly outweigh CO_2 savings from decarbonized power supply through greater renewable and non-fossil fuel generation prior to 2030.

Figure 60. Power Sector CO_2 Emission Reduction Potential by Source

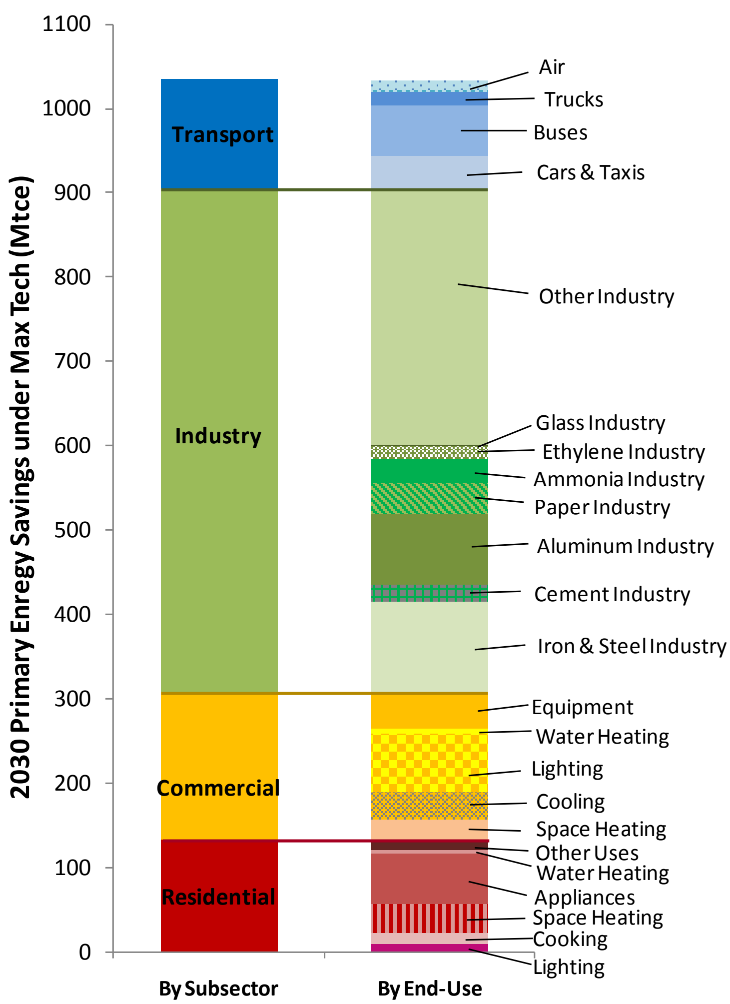


9. Summary and Comparison of Savings Potential

In spite of continuing the current pace of efficiency improvements across all demand sectors as well as decarbonization of the power sector consistent with announced targets under the reference scenario, there remain significant opportunities for further efficiency gains and carbon mitigation when the maximum technically feasible levels of efficiency are considered. In terms of primary energy, additional annual savings on the order of 1.03 billion tonnes of coal equivalent are possible if the maximum technically feasible levels of efficiency are achieved across all sectors in 2030 (Figure 61) . The vast majority of this savings potential is from the industrial sector, which in turn is dominated by savings in the "Other Industry" subsector. In fact, energy savings from Other Industry" alone surpass the combined savings from 11 different end-use savings in the residential and commercial sector in 2030. However, the high savings potential for Other Industry span across a wide-range of industries in the mining, manufacturing, processing and other sectors with greater uncertainties than for the seven selected industries.

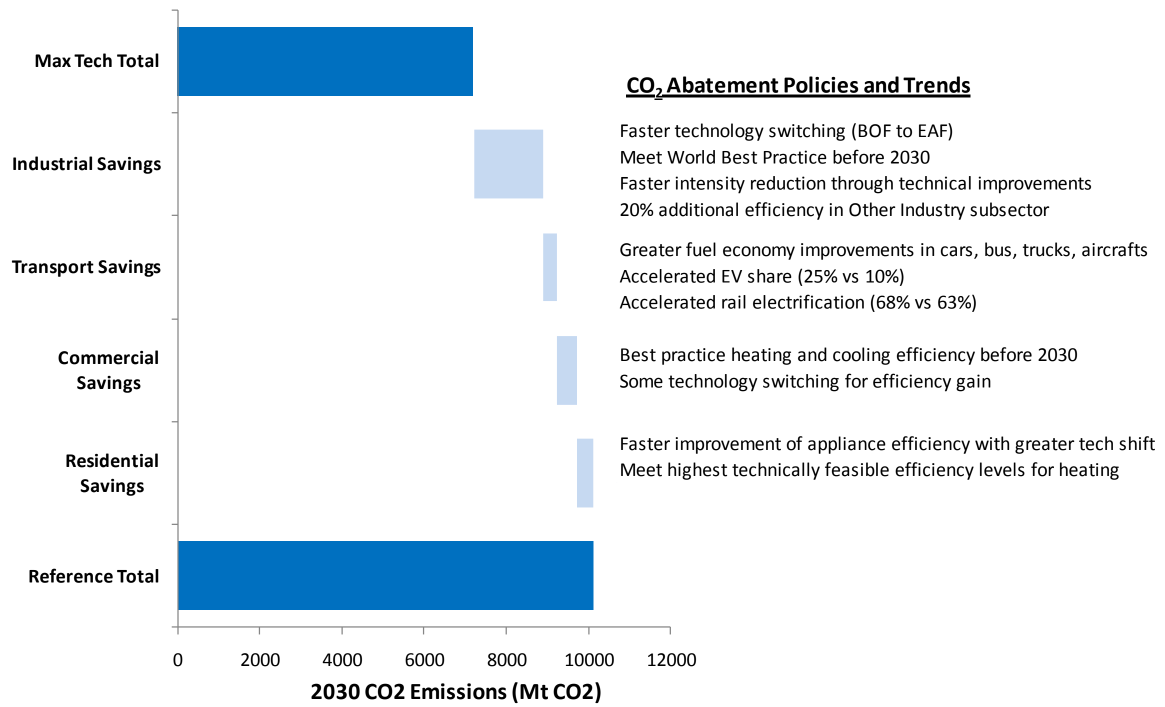
In terms of the well-defined end-uses characterized by specific technologies, it is interesting to note that lighting has much greater room for improvement in the commercial sector than residential sector, with its savings potential greater than the combined savings from major appliances. Improving residential and commercial buildings shell as well as the efficiency of space heating and cooling technologies can also result in important savings that rival or surpass savings from several of China's leading industries, including glass, ethylene, cement and paper. In the transport sector, most of the energy savings will be from buses, rather than the fast-growing car population, because cars are already relatively efficient under the reference scenario and there is only small incremental gain from fuel economy improvements and 15% greater electrification.

Figure 61. Comparison of 2030 Primary Energy Savings by Sector and Measure under Max Tech



As illustrated by Figure 62, of the 2.9 billion tonnes of CO_2 saving potential in 2030, the greatest sectoral CO_2 abatement opportunity in 2030 is from aggressive technology switching in industrial production and technical improvements that help achieve the world's best practice energy intensity in all major industrial production processes within the next 20 years. Despite rapid growth in the residential, commercial and transport sectors as a result of urbanization, there is smaller CO_2 abatement potential because much of the emission reduction associated with policies such as fuel economy and equipment efficiency standards, market-driven electrification of vehicles and technology switching are already captured by continued progress under the reference scenario. This suggests that the efficiency gap between the expected reference case and a maximum technically feasible case is actually relatively small for the buildings and transport sectors.

Figure 62. 2030 CO_2 Abatement Potential by Sector



From the supply side, Figure 60 shows that most of the carbon abatement opportunities will be from electricity demand reduction due to efficiency improvements across end-use sectors. Concurrently decarbonizing the power supply through greater renewable and non-fossil generation will maximize power sector emissions reduction, with much lower annual emissions and carbon intensity of electricity generation than current levels.

10. Energy Conservation Supply Curves for China's Cement and Iron and Steel Industry

Authors' Note: Analysis and findings in this section have been revised and updated since the release of the 1st Edition of this report on July 12, 2011.

10.1 Introduction

10.1.1 Cement Industry in China

China's cement industry, which produced 1,388 million metric tons (Mt) of cement in 2008, accounts for nearly half of the world's total cement production (Shandong ETC and CBMA, 2009; USGS, 2009). Nearly 40% of China's current cement production is from relatively obsolete vertical shaft kiln (VSK) cement plants, with the remainder from modern rotary kiln cement plants, including plants equipped with new suspension pre-heater and pre-calciner (NSP) kilns. To accelerate kiln technology switch, official Chinese government policy calls for the phase-out and replacement of all VSK cement plants with more modern kilns (NDRC, 2006). Figure 63 and Table 17 show that cement production from rotary kilns has grown rapidly in recent years, jumping from 116 Mt in 2000 to 833 Mt in 2008 (ITIBMIC 2004; Kong, 2009).

Figure 63. Cement Production in China by Major Kiln Type, 1990-2008

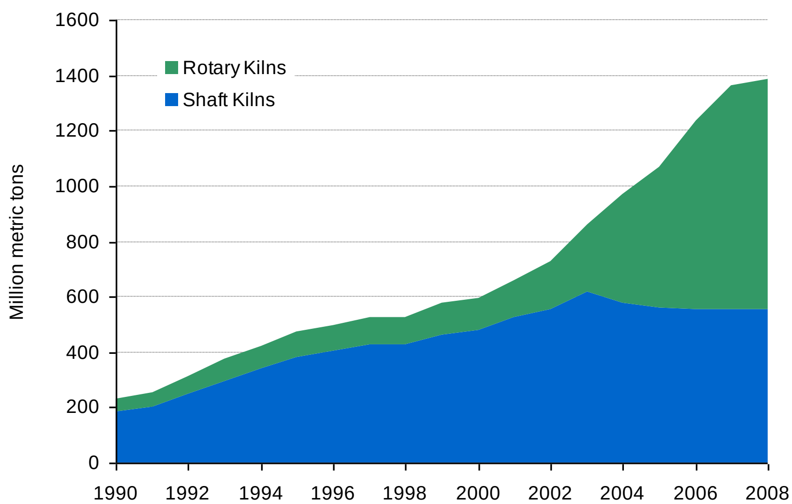


Table 17. Cement Production in China by Major Kiln Type (Mt), 1990-2008

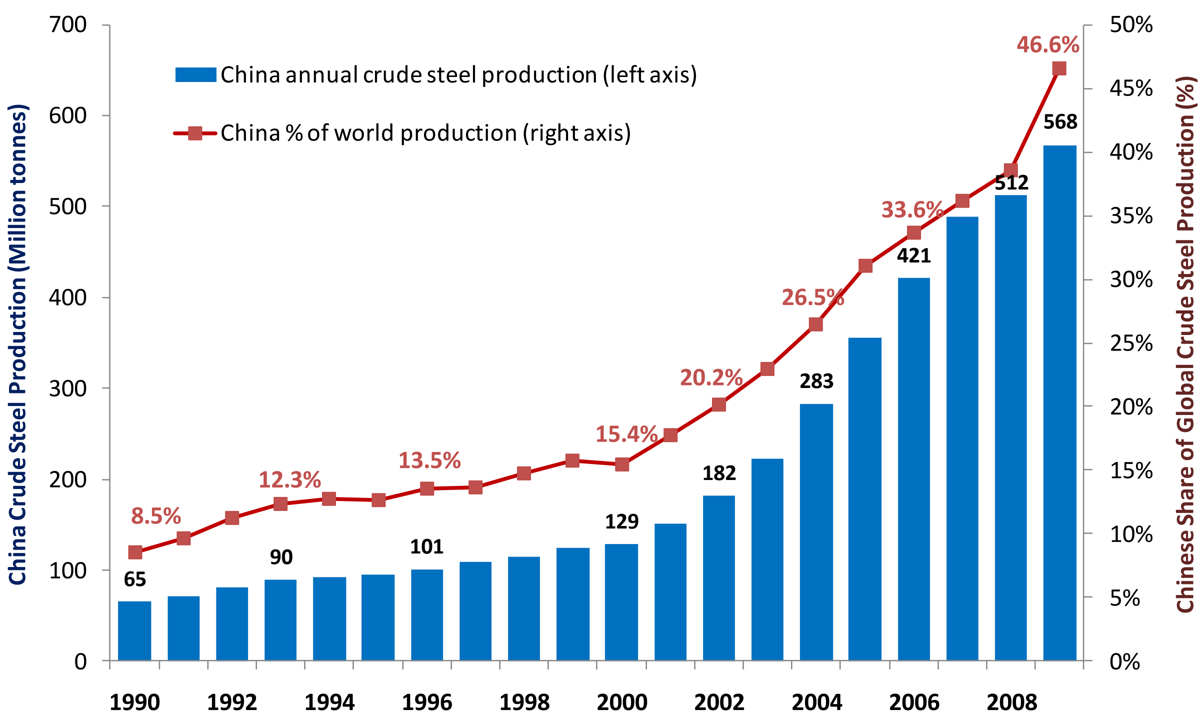
	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008
Shaft Kilns	183	383	481	528	555	616	578	561	552	554	555
Rotary Kilns	49	93	116	133	170	246	395	508	684	807	833
Total	232	476	597	661	725	862	973	1069	1236	1361	1388

Source: ITIBMIC 2004; Kong, 2009

10.1.2 Iron and Steel Industry in China

The iron and steel industry, a pillar industry of Chinese economic development, has grown rapidly along with the national economy since the 1990s, with crude steel production in 1996 exceeding more than 100 Mt. Since then, China has grown to become the world's largest crude steel producer for 14 continuous years. The average annual growth rate of crude steel production was 18.5% during the first nine years of the 21st Century, and steel production in 2009 was 568 Mt (WSA, 2010), or 46.6% of the world total production (see Table 64).

Figure 64. China's Crude Steel Production and Share of Global Production



Source: China Iron and Steel Industry Yearbook, various years; World Steel Association 2010

As two of the largest industrial energy consumers, efficiency improvements in the cement and iron and steel industries will be integral in lowering China's future energy and emissions. In order to understand the economic implications of the necessary efficiency improvements in the two industries, this section provides analysis and results of the development of energy conservation supply curves (CSC) as well as for the cement and iron and steel industry in China. The methodology for the study is presented including a description of the data collection efforts and the construction of energy-conservation supply curves model. The results of the energy-conservation supply curve analysis are presented in the next section, followed by key findings and conclusions of this portion of the study.

10.2 Methodology

10.2.1 Data Collection

The analysis presented in this chapter draws upon the work done by Lawrence Berkeley National Laboratory (LBNL) on the assessment of energy efficiency and CO_2 emission reduction potentials of the cement industry in the U.S. (Worrell et al. 2000; Worrell et al., 2008; LBNL & ERI, 2008) and in Shandong province of China (Hasanbeigi et al. 2010), the U.S. iron and steel industry (Worrell et al. 2006; Worrell et al. 2011) and the recent comparison of energy intensity of iron and steel industry in China and the U.S. (Price et al. 2011) as well as other references. The data on the energy saving, cost, lifetime, and other details on each technology were obtained from these LBNL reports.

Many of the energy-efficient technologies examined in LBNL publications and reports are used in this analysis because other studies on energy efficiency in these two industries do not provide consistent and comprehensive data on energy savings, CO_2 emission reductions, and the cost of different technologies. Information on some of the technologies examined, however, are presented in other studies. Furthermore, the methodology used for this analysis, i.e. construction of the energy conservation supply curve and abatement cost curve, is also used by LBNL for the cement and iron and steel industry (Worrell et al., 2000, Hasanbeigi et al. 2010d).

The national level data for the production of different products for the China's cement industry was obtained from China Cement Almanac (China Cement Association, 2009) and from China Steel Yearbook (EDRC, 2009) for the steel industry. For the penetration rate of the energy efficient measures, a questionnaire was developed and sent to individual experts in China for both cement and iron and steel industry. In addition, we obtained details from the "National Key Energy Conservation Technologies Promotion Catalogue" published by National Development and Reform Council (NDRC, 2008, 2009, 2010).

10.2.2 Conversion Factors and Assumptions

Because of data availability, the year 2009 was selected as the base year for analysis for the cement industry and the year 2010 as the base year for the steel industry. To convert electricity to primary energy, the conversion factor of 2.94 and 2.9 are used for the cement industry and steel industry analysis, respectively. These two conversion factors were determined using China's national average net heat rate of fossil fuel-fired power generation of 0.337 kgce/kWh and 0.333 kgce/kWh in 2009 and 2010, respectively, plus national average transmission and distribution losses of around 6.5%[1] (SERC, 2011). The Lower Heating Value (LHV) of the fuel is used in the analysis. The carbon conversion factors for fuels used for calculating CO_2 emissions from energy consumption are taken from the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The emission factor for grid electricity is assumed to be 0.82 and 0.77 kg CO_2/kWh in 2009 and 2010, respectively, and forecasted emission factors through 2030 were based on the LEAP model values used in previous chapters.

[1] It should be noted that this value was the average net heat rate for units larger than 6MW.

[3] The descriptions of the measures presented in this section are excerpted from Worrell et al. (2006 and 2011).

The average unit price of electricity paid by the cement industry in 2009 and 2010 is used as the electricity price in the base year for the cement and steel industry analysis, respectively. Since more than 99% of the fuel use in the Chinese cement industry is coal, the average unit price of coal consumed in the cement industry in 2009 is used as the fuel price in the base year. Using energy prices in the base year and estimated real electricity and fuel price escalation rates based on Ni (2009), we calculated the future energy prices in constant dollars for this study . Then, the same discount rate used to calculate the NPV of the future capital costs was used to calculate the present value of future energy prices in constant dollars in the base year. Finally, we calculated the discounted average unit price of electricity and coal used in electricity and fuel CSCs, respectively.

Future energy prices (i.e., prices in 2010-2030) govern the future benefits from energy cost savings and are treated the same as future capital and operation and maintenance (O&M) costs over the study period by discounting them to a present value using the same discount rate. This consistent treatment represents the cost-benefit from the cement industry perspective. If future energy prices are not treated the same as capital and O&M costs (i.e., not discounted to present value using the same discount rate), then the results could be misleading by overestimating benefits (energy cost savings) relative to the costs of measures and misrepresenting measures as cost-effective.

10.2.3 Energy Conservation Supply Curves

A bottom-up model based on the concept of a "Conservation Supply Curve" was developed in order to capture the cost effectiveness and technical potential for efficiency improvements and CO_2 emission reduction in China's cement and iron and steel industries. The Conservation Supply Curve (CSC), first introduced by Art Rosenfeld and his colleagues at LBNL, is an analytical tool that captures both the engineering and the economic perspectives of energy conservation. The curve shows the energy conservation potential as a function of the marginal Cost of Conserved Energy and has been used in various studies to assess energy efficiency potentials in different economic sectors and industries (Koomey et al. 1990, Levine and Meier 1999, Lutsey 2008, Hasanbeigi 2010a,b). Recently, McKinsey & Company (2008) also developed GHG abatement cost curves for different countries using the concept of the conservation supply curve. The CSC can be developed for a plant, a group of plants, an industry, or for the whole economic sector.

The work presented in this chapter is a unique study of China as it provides a detailed analysis of energy-efficiency improvement opportunities in the cement and iron and steel industry. In addition, the potential application of a larger number of energy efficiency technologies is assessed when compared with other studies.

The Cost of Conserved Energy required for constructing the CSC can be calculated as shown in Equation 1:

$$\text{CCE} = \frac{\sum_{n=1}^{N} \frac{(ACC+\Delta\ AO\&M)_n}{(1+d)^n}}{\sum_{n=1}^{N} (Annual\ Energy\ Saving)_n} = \frac{\text{NPV (Annual Costs)}}{\text{Sum (Annual Energy Saving)}} \quad \text{(Equation 1)}$$

Where:
CCE = Cost of Conserved Energy
ACC = Annualized Capital Costs
Δ AO&M = Change in Annual Operations and Maintenance Cost
n= year
N = time horizon of the analysis period
d = discount rate

The annualized capital cost can be calculated from Equation 2.

Annualized capital cost = Capital Cost*(d/ (1-(1+d)$^{-n}$)   (Equation 2)

Where:
d = discount rate
n = lifetime of the energy efficiency measure

After calculating the Cost of Conserved Energy for all energy-efficiency measures separately, the measures were ranked in ascending order of their Cost of Conserved Energy to construct the Energy CSC. In an Energy CSC, an energy price line is determined that reflects the current cost of energy (i.e. 2008). All measures that fall below the energy price line are considered "cost-effective". Furthermore, the CSC can show us the total technical potential for electricity or fuel savings accumulated from all the applicable measures. On the curve, the width of each measure (plotted on the x-axis) represents the annual energy saved by that measure. The height (plotted on the y-axis) shows the measure's CCE.

The methodology used for the analysis consists of five main steps as follows:

1. Establish 2009 and 2010 as the base year for energy, material use, and production in the cement and iron and steel industry, respectively. The base year is also used to calculate the costs in constant base year dollar. The study period for which the CSC was developed is 2010-2030.

2. Develop a list of commercially available energy-efficiency technologies and measures in the cement industry to include in the construction of the conservation supply curves. We assumed that the energy efficiency measures are mutually exclusive and there is no interaction between them.

3. Determine the potential application of energy-efficiency technologies and measures in the Chinese cement and iron and steel industry in the base year based on information collected from several sources. We assumed 70% of the potential for energy efficiency measures will be realized by the end of 2030 (3.5% per year) (except for a few measures that were treated differently), with a linear deployment rate assumed between the base year (2008) and end year (2030).

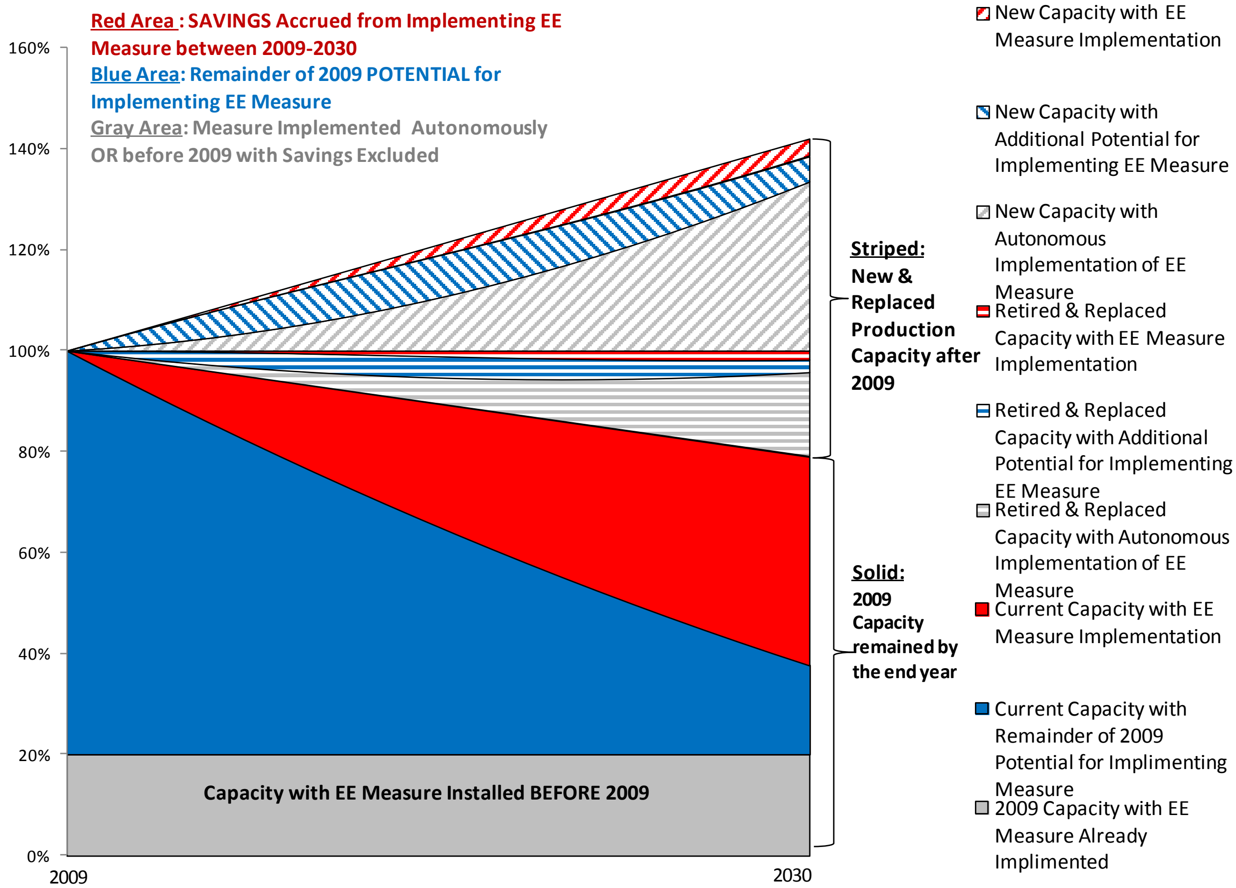
4. Obtain annual forecast data for clinker, cement, and crude steel demand up to 2030. The adoption rate explained in step 3 was based on the base year's production capacity. However, there will be new capacity installed between 2010 and 2030 to meet increased demand. Additionally, there will be plant retirements of the existing capacity that will be replaced with new capacity. To define the potential application of the measures to the new production capacity, we used the "new capacity with EE implementation" indicator. By defining this indicator, we take into consideration how much of the new capacity will have already implemented energy efficiency measures from the start and how much potential still remain in each subsequent year. We apply the same adoption assumptions to the retired and replaced capacity as we do to the new capacity.

5. Construct an Electricity Conservation Supply Curve (ECSC) and a Fuel Conservation Supply Curve (FCSC) separately in order to capture the accumulated cost-effectiveness and total technical potential for electricity and fuel efficiency improvements in the cement and iron and steel industry from 2008 to 2030. For this purpose, the Cost of Conserved Electricity (CCE) and Cost of Conserved Fuel (CCF) were calculated separately for respective technologies in order to construct the CSCs. After calculating the CCE or CCF for all energy-efficiency measures, rank the measures in ascending order of CCE or CCF to construct an Electricity Conservation Supply Curve (ECSC) and a Fuel Conservation Supply Curve (FCSC), respectively. Two separate curves for electricity and fuel are constructed because the cost-effectiveness of energy-efficiency measures is highly dependent on the price of energy. Since average electricity and fuel prices differ between industries and because many technologies save either solely electricity or fuel, it is appropriate to separate electricity and fuel saving measures. Hence, the Electricity Conservation Supply Curve (ECSC) with average 2008 electricity price only plots technologies that save electrical energy while the Fuel Conservation Supply Curve (FCSC) with average 2008 fuel prices only plots technologies that save fuel.

However, it should be noted that there are a few technologies that either save both electricity and fuels, or increase electricity consumption as a result of saving fuel. Technologies where the fuel savings account for a significant portion of their total primary energy savings are included in the Fuel Conservation Supply Curve (FCSC).

An important aspect of the conservation supply curves is the methodology that was used to determine how energy efficiency measures are implemented. An illustrative graph is used below to explain the underlying basis for the implementation of each energy efficiency measures in the model (Figure 65).

Figure 65. Illustration of Methodology for Determining Implementation of Energy Efficiency Measures from 2009 to 2030



Note: This graph is only for illustrative purposes; y-axis values are notional

Based on data received from Chinese experts and our previous studies on the actual penetration rate of energy efficiency measures in the base year, we can calculate the remaining potential for adoption of efficiency measures in the existing capacity in the base year. We first estimate how much of the existing capacity should be retired and replaced with new capacity based on historic capacity expansions and the assumption that cement and steel plants have a lifetime of 40 and 30 years, respectively(IEA 2011). This is shown in the figure as "Retired and Replaced Capacity". For the remaining existing potential, we assumed 70% adoption will be reached by 2030 (3.5% per year) for almost all measures. We developed a linear line which serves as the slope for the new implementation of the measure in each year between 2010 and 2030. We can then calculate the proportion of production capacity where savings are achieved through implementation of the efficiency measures beginning in 2010 (solid red area in Figure 2).

In addition, industrial production capacity may grow between 2010 and 2030. To determine the implementation potential of efficiency measures in the new additional capacity, we did the following. First, we used estimated production capacity growth for the cement industry from (Ke et al. 2012) and for the steel industry from the projections made in the previous chapter above. Then, we assumed that a certain proportion of the new capacity will adopt the efficiency measures autonomously each year (4% per year between 2010 and 2030) as a result of the installation of new efficient technology in the new stock (gray angular striped area in Figure 65**Error! Reference source not found.**). Since the autonomous implementation of the measure in some of the new capacity will occur regardless of new policies, the savings potential of the autonomous implementation is excluded from the supply curves calculation. Second, the new capacity with additional potential for implementing the efficiency measures (not captured in autonomous improvement) is determined for each year (blue angular striped area in Figure 65). We assumed that a certain portion of the new capacity with additional potential for implementing the efficiency measures adopts the measures each year (2% per year between 2010 and 2030) (the red angular striped area in Figure 65). We treat the *retired and replaced* capacity the same as new capacity expansions by assuming the same rates for autonomous adoption of energy efficiency measures and the same adoption rates for the additional potential for implementing the efficiency measures (the horizontal striped area in Figure 65). Because the *new capacity* and *retired and replaced* capacity are both calculated as the product of growth rates and adoption rates, the resulting wedges are not always straight lines (e.g., gray stripped areas – both horizontal and angular). To sum up, the red solid and red stripped areas in Figure 65 are the total source of energy savings potential captured on the supply curves.

In forecasted years when the demand for products declines either relative to the previous year or even relative to the base year (as seen in the Chinese cement demand forecast), we assumed that *new capacity* added after 2009 remains in production. Thus, we assumed that reduced demand results in reduced production at inefficient plants. However, we first estimated energy efficiency adoptions in the existing capacity regardless of reduced demand. Therefore, if the demand decline between 2010 and 2030 is large enough, the entire inefficient capacity can be decommissioned with zero production during this period. This results in saturated adoption in the remaining existing capacity and no additional adoptions are possible since the entire existing capacity has either adopted the measures or been decommissioned by the saturation year. This represents one approach of dealing with the sharp declining cement demand in the future. An extreme case in the opposite direction is that production never falls despite domestic demand reduction. Instead, excess production is exported resulting in the same energy consumption, emissions, and energy efficiency adoption potential as would be the case if demand kept rising. Because of high transportation costs, exporting cement is not a highly profitable trade and Chinese companies have not exported large volumes of cement. However, a large domestic demand reduction could put considerable downward price pressure on the cement industry and could result in significant exports in the future. Another case could be the export of old yet not retired equipment to another country when Chinese domestic demands fall considerably and exporting cement is economically attractive. We have no way of modeling exported equipment and therefore made a conservative assumption that inefficient capacity will no longer be available within China to adopt energy conservation measures.

Although the CSC model developed is a good screening tool for evaluating the potentials of energy-efficiency measures, the actual energy savings potential and cost of each energy-efficiency measure and technology may vary and depend on various conditions such as raw material quality (e.g. moisture content of raw materials, hardness of the limestone, etc.), technology provider, production capacity, size of the kiln, fineness of the final product and byproducts, time of the analysis, and other factors. Moreover, it should be noted that some energy efficiency measures also provide additional productivity and environmental benefits which are difficult and sometimes impossible to quantify. Including quantified estimates of other benefits could significantly reduce the CCE for the energy-efficiency measures (Worrell et al., 2003; Lung et al., 2005).

10.2.4 Discount Rate

In this study, a real discount rate of 15% was assumed for the analysis. However, it should be noted that the choice of the discount rate depends on the purpose and approach of the analysis (prescriptive versus descriptive) used. A prescriptive approach (also known as social perspective) uses lower discount rates (4% to 10%), especially for long-term issues like climate change or public sector projects (Worrell et al. 2004). Low discount rates have the advantage of treating future generations equally to current generations but may favor relatively certain, near-term effects over more uncertain, long-term effects (NEPO/DANCED, 1998).

A descriptive approach (or private-sector or industry perspective), however, uses relatively high discount rates between 10% and 30% in order to reflect the existence of barriers to energy efficiency investments (Worrell et al. 2004). These barriers include perceived risk, lack of information, management concerns about production and other issues, capital constraints, opportunity cost, and preference for short payback periods and high internal rates of return (Bernstein, et al. 2007 and Worrell, et al. 2000). Hence, the 15% discount rate used for these analyses is close to the higher end of discount rates from a social perspective and the lower end of the discount rates from private-sector or industry perspective.

Other industrial sector analyses use varying real discount rates. Carlos (2006) used a range of 10% to 16% discount rate in the financial analysis for cogeneration projects in Thailand. Garcia et al. (2007) used three discount rates of 12%, 15%, and 22% in three different investment scenarios for high efficiency motors in Brazil. McKinsey & Company used a 7% social discount rate for developing Conservation Supply Curves and GHG abatement cost curve for the US (McKinsey & Company, 2007 and 2009a) and a 4% social discount rate for developing a GHG abatement cost curve for China (McKinsey & Company, 2009b). ICF developed an abatement cost curve for the cement industry in Brazil and Mexico in 2015 using a 10% discount rate (ICF International, 2009a, b). In the Asia Least-cost Greenhouse Gas Abatement Strategy (ALGAS) project, a 10% real discount rate is assumed for the calculation of GHG emissions abatement scenarios for various economic sectors including industry in Thailand (ADB/GEF, 1998).

10.3 Technologies and Measures to Reduce Energy and CO_2 Emissions

10.3.1 Energy Efficiency Technologies for the Cement Industry

The initial list of energy efficiency measures considered for the cement industry in this analysis includes 23 measures/technologies, all of which were used in the development of the conservation supply curves. The descriptions of the measures presented below are taken from Worrell et al. (2008). Table 18 presents data related to the production capacity in each step of the cement production process in China.

It also presents the energy savings, capital costs, change in O&M cost, and potential application share for each energy-efficiency technology and measure when applied to China's cement industry.

Table 18. Energy Savings and Costs for Energy-Efficient Technologies and Measures Applied to the Cement Industry

No.	Technology/Measure	Clinker Production Capacity in base year to which the measure is applied (Mt/year)	Fuel Savings (GJ/t-cl)	Electricity Savings (kWh/t-cl)	Capital Cost (US$/t-cl)	Change in annual O&M cost (US$/t-cl)	Share of clinker production capacity in base year to which measure is applicable (%) *
	Fuel Preparation						
1	Replacing a ball mill with vertical roller mill for coal grinding	788.35		1.47	0.04	0.00	60%
2	High efficiency drive and fan system in coal grinding mill	788.35		0.16	0.03	0.00	20%
	Raw Materials Preparation						
3	High Efficiency classifiers/separators for raw material grinding	788.35		5.08	3.44	0.00	90%
4	Replacing a ball mill with vertical roller mill /High pressure roller presses in raw material grinding	788.35		10.17	8.60	0.00	50%
5	Efficient (mechanical) transport system for raw materials preparation	788.35		3.13	4.69	0.00	80%
6	Raw meal blending (homogenizing) systems	788.35		2.66	5.79	0.00	90%
7	High efficiency fan for raw mill vent fan with inverter	788.35		0.36	0.03	0.00	30%
	Clinker Making						
8	Kiln shell heat loss reduction (Improved refractories)	788.35	0.26		0.25	0.00	10%
9	Energy management and process control systems in clinker making	788.35	0.15	2.35	1.00	0.00	5%
10	Optimize heat recovery/upgrade clinker cooler	788.35	0.11	-2.00 **	0.20	0.00	50%
11	Low temperature Waste Heat Recovery power generation	788.35		30.80	0.17	0.82	60%
12	Upgrading of a Preheater kiln to a Preheater/Precalciner Kiln	788.35	0.43		18.00	-1.10	100%
13	Low pressure drop cyclones for suspension preheater	788.35		2.60	3.00	0.00	60%
	Finish Grinding						
14	Energy management & process control in grinding	788.35		4.00	0.47	0.00	10%
15	Replacing a ball mill with vertical roller mill in finish grinding	788.35		25.93	7.82	0.00	3%
16	High pressure roller press as pre-grinding to ball mill in finish grinding	788.35		24.41	7.82	0.00	60%
17	Improved grinding media for ball mills	788.35		6.10	1.10	0.00	80%
18	High-Efficiency classifiers for finish grinding	788.35		6.10	3.13	0.00	70%

No.	Technology/Measure	Clinker Production Capacity in base year to which the measure is applied (Mt/year)	Fuel Savings (GJ/t-cl)	Electricity Savings (kWh/t-cl)	Capital Cost (US$/t-cl)	Change in annual O&M cost (US$/t-cl)	Share of clinker production capacity in base year to which measure is applicable (%) *
19	Replacement of cement mill vent fan with high efficiency fan	788.35		0.13	0.01	0.00	50%
	General Measures						
20	High efficiency motors	788.35		4.58	0.34	0.00	10%
21	Adjustable Speed Drives	788.35		9.15	1.41	0.00	30%
22	Use of Alternative Fuels	788.35	0.6		1.10	0.00	0%
	Product Change [2]	**Cement Production Capacity to which the measure is applied (Mt/year)**	**Fuel Savings (GJ/t-cem)**	**Electricity Savings (kWh/t-cem)**	**Capital Cost (US$/t-Cem)**	**Change in annual O&M cost (RMB/t-cem)**	**Share of cement production capacity in base year to which measure is applicable ***
23	Blended cement (Additives: fly ash, pozzolans, limestone or/and blast furnace slag)	1187.28	1.77	-7.21 **	0.72	-0.04	90%

* The share of production capacity in base year to which the measure is **applicable** is different than the share of cement production capacity in the base year to which the measure is **applied**. The method for determining the application rates of the measures are described in detail in the methodology section with Figure 65 as an illustration.
** The negative value for electricity saving indicates that although the application of this measure saves fuel, it will increase electricity consumption. However, it should be noted that the total primary energy savings of these measures is positive.
Note: cem = cement, cl=clinker

Fuel Preparation

Replacing a ball mill with vertical roller mill for coal grinding:

Efficient vertical roller mills have been developed for on-site fuel preparation at cement plants. Fuel preparation may include crushing, grinding and drying of coal. Passing hot gases through the mill combines the grinding and drying.

Installation of variable frequency drive & replacement of coal mill bag dust collector's fan:

Variable frequency drives can be installed on coal mill bag dust collector fans to improve energy efficiency.

Raw Materials Preparation

High Efficiency classifiers/separators for raw material grinding:
High efficiency classifiers can be used in both the raw materials mill and in the finish grinding mill. Standard classifiers may have low separation efficiency, leading to the recycling of fine particles that causes additional power demands in the grinding mill. In high-efficiency classifiers, the material stays in the separator for a longer period of time, leading to sharper separation and thus reducing over-grinding.

Replacing a ball mill with vertical roller mill /High pressure roller presses:
Traditional ball mills used for grinding certain raw materials (mainly hard limestone) can be replaced by vertical roller mill or high-efficiency roller mills, by ball mills combined with high-pressure roller presses, or by horizontal roller mills. Adoption of these advanced mills saves energy without compromising product quality. An additional advantage of the inline vertical roller mills is that they can integrate raw material drying with the grinding process by using large quantities of low grade waste heat from the kilns or clinker coolers.

Efficient (mechanical) transport system for raw materials preparation:
Transport systems are required to move powdered materials such as kiln feed, kiln dust, and finished cement throughout the plant, with transport usually in the form of either pneumatic or mechanical conveyors. Mechanical conveyors use less power than pneumatic systems. Conversion to mechanical conveyors is cost-effective when conveyor systems are replaced to increase reliability and reduce downtime.

Raw meal blending (homogenizing) systems:
Most plants use compressed air to agitate the powdered meal in so-called air-fluidized homogenizing silos. Older dry process plants use mechanical systems, which simultaneously withdraw material from six to eight different silos at variable rates. Modern plants use gravity-type homogenizing silos (or continuous blending and storage silos) that reduce power consumption. In these silos, material funnels down one of many discharge points, where it is mixed in an inverted cone. Silo retrofit options are cost-effective when the silo can be partitioned with air slides and divided into compartments which are sequentially agitated, as opposed to the construction of a whole new silo system.

High efficiency fan for raw mill vent fan with inverter: In the Birla Vikas Cement Works, Birla Corporation Limited, India, the raw mill vent fans were older generation, less-efficient, high energy-consuming fans. These fans were replaced with high efficiency fans, resulting in power consumption savings. Further, the air volume of these fans was controlled by controlling the damper, which consumes more energy; hence it was decided to provide suitable speed control system for AC drives for controlling the speed.

Clinker Making

Kiln shell heat loss reduction (Improved refractories):
There can be considerable heat losses through the shell of a cement kiln, especially in the burning zone. The use of better insulating refractories (for example Lytherm) can reduce heat losses. Extended lifetime of the higher quality refractories can offset their higher costs by extending operating periods and thereby lowering the lost production time between relining of the kiln. The use of improved kiln-refractories may

also improve kiln reliability and reduce the downtime, which will lower production costs considerably and reduce energy needs during start-ups. Structural considerations may limit the use of new insulation materials.

Energy management and process control systems in clinker making:
Automated computer controls systems help optimize the combustion process and conditions. Improved process control will also improve product quality and grindability such as the reactivity and hardness of the produced clinker, which may lead to more efficient clinker grinding. A uniform feed allows for steadier kiln operation, reducing fuel requirements. Expert control systems simulate the best human operator, using information from various stages of the process. An alternative to expert systems or fuzzy logic is model-predictive control using dynamic models of the processes in the kiln. Additional process control systems include the use of on-line analyzers that permit operators to instantaneously determine the chemical composition of raw materials being processed, thereby allowing for immediate changes in the blend of raw materials. Process control of the clinker cooler can help improve heat recovery, material throughput, control of free lime content in the clinker and reduce NO_x emissions. Control technologies also exist for controlling the air intake. Raw materials and fuel mix can be improved by a careful analysis of the chemical and physical characteristics of them, and by automating the weighing process, the pellet production (water content and raw feed mixtures), the blending process and kiln operation (optimizing air flow, temperature distribution, and the speed of feeding and discharging).

Optimize heat recovery/upgrade clinker cooler:
The clinker cooler lowers the clinker temperature from 1200°C to 100°C. The most common cooler designs are the planetary (or satellite), traveling and reciprocating grate type. All coolers heat the secondary air for the kiln combustion process and sometimes also tertiary air for the precalciner. Reciprocating grate coolers are the modern variant and are suitable for large-scale kilns (up to 10,000 tpd). Grate coolers use electric fans and excess air. The portion of the remaining air with the highest temperature can be used as tertiary air for the precalciner. Rotary coolers (used for plants up to 2200 to 5000 tpd) and planetary coolers (used for plants up to 3300 to 4400 tpd) do not need combustion air fans and use little excess air, resulting in relatively lower heat losses. Heat recovery can be improved through reduction of excess air volume, control of clinker bed depth and new grates such as ring grate. Improving heat recovery efficiency in the cooler results in fuel savings, but may also influence product quality and emission levels. Controlling the cooling air distribution over the grate may result in lower clinker temperatures and high air temperatures. Additional heat recovery results in lowered energy use in the kiln and precalciner due to higher combustion air temperatures.

Low temperature Waste Heat Recovery power generation:
A large amount of energy consumption for cement production occurs in the calcination process. This involves passing raw materials through a preheater stack containing cyclone heaters to a long rotating kiln to create clinker and then cooling clinker in the clinker cooler. In the clinker production process, a significant amount of heat is typically vented to the atmosphere without being used, resulting in wasted heat that can lead to heat pollution. If the waste heat is captured and used for power generation, it can significantly improve energy efficiency and reduce the amount of power imported from the electric grid. A

Waste Heat Recovery (WHR) system can effectively utilize the low temperature waste heat of the exit gases from Suspension Preheater (SP) and Air Quenching Chamber (AQC) in cement production. The WHR captive power plant consists of WHR boilers (SP boiler and AQC boiler), steam turbine generators, controlling system, water-circulation system and dust-removal system etc. The steam from SP boiler and AQC boiler is fed to the steam turbine generator to produce power.

Upgrading of a Preheater kiln to a Preheater/Precalciner Kiln:
An existing preheater kiln may be converted to a multi-stage preheater/precalciner kiln by adding a precalciner and an extra preheater when possible. The addition of a precalciner will generally increase the capacity of the plant, while lowering the specific fuel consumption and reducing thermal NO_x emissions (due to lower combustion temperatures in the precalciner). Using as many features of the existing plant and infrastructure as possible, special precalciners have been developed by various manufacturers to convert existing plants, for example Pyroclon®-RP by KHD in Germany. Generally, the kiln, foundation and towers are used in the new plant, while cooler and preheaters are replaced. Cooler replacement may be necessary in order to increase the cooling capacity for larger production volumes. Older precalciners can be retrofitted for energy efficiency improvement and NO_x emission reduction.

Low pressure drop cyclones for suspension preheater:
Cyclones are a basic component of plants with pre-heating systems. The installation of newer cyclones in a plant with lower pressure losses will reduce the power consumption of the kiln exhaust gas fan system. Installation of the cyclones can be expensive, since it may often entail the rebuilding or the modification of the preheater tower, and the costs are very site specific. New cyclone systems may increase overall dust loading and increase dust carryover from the preheater tower. However, the dust carryover problem is less severe if an inline raw mill follows it.

Finish Grinding

Energy management and process control in grinding:
Control systems for grinding operations are developed using the same approaches as for kilns. The systems control the flow in the mill and classifiers, attaining a stable and high quality product. Several systems are marketed by a number of manufacturers. Expert systems have been commercially available since the early 1990's. The systems result in electricity savings as well as other benefits such as reduced process and quality variability as well as improved throughput/production increases.

Replacing a ball mill with vertical roller mill:
Roller mills employ a mix of compression and shearing, using 2-4 grinding rollers carried on hinged arms riding on a horizontal grinding table. The raw material is grounded on a surface by rollers that are pressed down using spring or hydraulic pressure, with hot gas used for drying during the grinding process. A vertical roller mill can accept raw materials with up to 20% moisture content and there is less variability in product consistency.

High pressure roller press as pre-grinding to ball mill:

A high pressure roller press, in which two rollers pressurize the material up to 3,500 bar, can replace ball mills for finish grinding, improving the grinding efficiency dramatically.

Improved grinding media for ball mills:
Improved wear-resistant materials can be installed for grinding media, especially in ball mills. Grinding media are usually selected according to the wear characteristics of the material. Increasing the ball charge distribution and surface hardness of grinding media and wear-resistant mill linings have shown potential for reducing wear as well as energy consumption. Improved balls and liners made of high chromium steel is one such material but other materials are also possible. Other improvements include the use of improved liner designs, such as grooved classifying liners.

High-Efficiency classifiers for finish grinding:
A recent development in efficient grinding technologies is the use of high-efficiency classifiers or separators. Classifiers separate the finely ground particles from the coarse particles. The large particles are then recycled back to the mill. Standard classifiers may have a low separation efficiency, which leads to the recycling of fine particles, resulting in extra power use in the grinding mill. In high-efficiency classifiers, the material is more cleanly separated, thus reducing over-grinding. High efficiency classifiers or separators have had the greatest impact on improving product quality and reducing electricity consumption. Newer designs of high-efficiency separators aim to improve the separation efficiency further and reduce the required volume of air (hence reducing power use).

Replacement of cement mill vent fan with high efficiency fan: In the Birla Cement Works in Chittorgarh Company, India, the cement mill # 2 vent fan was an older generation, less-efficient, high energy-consumption fan. Therefore, it was replaced with a high-efficiency fan resulting in the power savings.

General measures

Use of Alternative Fuels:
Alternative fuels can be substituted for traditional commercial fuels in a cement kiln. A cement kiln is an efficient way to recover energy from waste. The CO_2 emission reduction depends on the carbon content of the waste-derived fuel, as well as the alternative use of the waste and efficiency of use (for example incineration with or without heat recovery). For biomass fuels that are considered carbon neutral, the CO_2 emission reduction is 100% compared to the commercial fossil fuels used in the cement industry. The high temperatures and long residence times in the kiln destroy virtually all organic compounds, while efficient dust filters may reduce some other potential emissions to safe levels. Alternative fuels include tires, carpet and plastic wastes, filter cake, paint residue and (dewatered) sewage sludge, and hazardous wastes.

High efficiency motors:
Motors and drives are used throughout the cement plant to move fans (preheater, cooler, alkali bypass), to rotate the kiln, to transport materials and, most importantly, for grinding. In a typical cement plant, 500-700 electric motors may be used, varying in size from a few kW to MW. Power use in the kiln (excluding grinding) is roughly estimated to be 40-50 kWh/tonne clinker. Variable speed drives, improved control strategies and high-efficiency motors can help reduce power use in cement kilns. If the replacement does

not influence the process operation, motors may be replaced at any time. However, motors are often rewired rather than being replaced by new motors.

Adjustable Speed Drives:

Drives are the largest power consumers in cement making. The energy efficiency of a drive system can be improved by reducing energy losses or by increasing motor efficiency. Most motors are fixed speed AC models. However, motor systems are often operated at partial or variable load. Also, large variations in load can occur in cement plants. Within a plant, adjustable speed drives (ASDs) can mainly be applied for fans in the kiln, cooler, preheater, separator and mills, and for various drives. Decreasing throttling can reduce energy losses in the system and coupling losses through the installation of ASD. ASD equipment is used more and more in cement plants, but the application may vary widely depending on electricity costs. ASDs for clinker cooler fans have a low payback, even when energy savings are the only benefit to installing ASDs.

Product Change

Blended cement (Additives: fly ash, pozzolans, limestone or/and blast furnace slag):

The production of blended cement involves the intergrinding of clinker with one or more additives (fly ash, pozzolans, blast furnace slag, volcanic ash) in various proportions. Blended cement demonstrates a higher long-term strength, as well as improved resistance to acids and sulfates, while using waste materials for high-value applications. Short-term strength (measured after less than 7 days) of blended cement may be lower, although cement containing less than 30% additives will generally have setting times comparable to concrete based on Portland cement. Blended cement has been used for many decades around the world. Blended cement are very common in Europe; blast furnace and pozzolanic cements account for about 12% of total cement production with Portland composite cement accounting for an additional 44%.

10.3.2 Energy Efficiency Technologies for the Iron and Steel Industry[3]

The initial list of energy efficiency measures considered for the iron and steel industry in this analysis includes on 64 measures/technologies. However, we could only obtain information, especially about the penetration rate of the measures, for 23 measures/technologies. Therefore, these 23 measures were used in the development of the conservation supply curves. The descriptions of the measures presented below are excerpted from Worrell et al. (2006 and 2011). Table 19 presents the data related to production capacity in each step of iron and steel production process in China. It also presents the energy savings, capital costs, change in O&M cost, and potential application share for each energy-efficiency technology and measure when applied to China's iron and steel industry.

[3] The descriptions of the measures presented in this section are excerpted from Worrell et al. (2006 and 2011).

Table 19. Energy Savings and Costs for Energy-Efficient Technologies and Measures Applied to the Iron and Steel Industry

No.	Technology/Measure	Production capacity in base year to which the measure is applied (Mt/year)	Fuel Savings (GJ/t-product)	Electricity Savings (kWh/t-product)	Capital Cost (US$/t-product)	Change in annual O&M cost (US$/t-product)	Share of production capacity to which measure is applicable in base year (%) *
	Iron Ore Preparation (Sintering)	**Sinter Production capacity in base year to which the measure is applied (Mt/year)**					**Share of Sinter production capacity in base year (2010) to which measure is applicable (%) ***
1	Heat recovery from sinter cooler	688.22	0.52		3.0		90%
2	Increasing bed depth	688.22	0.01	0.06	0.0		0%
	Coke Making	**Coke production capacity in base year to which the measure is applied (Mt/year)**					**Share of Coke production capacity in base year (2010) to which measure is applicable (%) ***
3	Coal moisture control	123.36	0.17		49.0		95%
4	Coke dry quenching (CDQ)	123.36	1.41		50.0		45%
	Iron Making – Blast Furnace (BF)	**Pig Iron production capacity in base year to which the measure is applied (Mt/year)**					**Share of Pig Iron production capacity in base year (2010) to which measure is applicable (%) ***
5	Injection of pulverized coal in BF to 130 kg/t hot metal	559.72	0.77		7.0	-2.0	5%
6	Injection of natural gas in BF	559.72	0.37		4.5	-2.0	100%
7	Injection of coke oven gas in BF	559.72	0.36	18.5	4.5		100%
8	Top-pressure recovery turbines (TRT)	559.72		46.0	20.0		17%
9	Recovery of blast furnace gas	559.72	0.04		0.3		94%
	Steelmaking – basic oxygen furnace (BOF)	**BOF crude steel production capacity in base year to which the measure is applied (Mt/year)**					**Share of BOF crude steel production capacity in base year (2010) to which measure is applicable (%) ***
10	Recovery of BOF gas and sensible heat	572.38	0.73		22.0		70%
	Steelmaking – Electric Arc Furnace (EAF)	**EAF crude steel production capacity in base year to which the measure is applied (Mt/year)**					**Share of EAF crude steel production capacity in base year (2010) to which measure is applicable (%) ***
11	Scrap preheating	66.31		61.0	5.5	-3.0	0%
	Casting and Refining	**Total crude steel production capacity**					**Share of Total crude steel production**

No.	Technology/Measure	Production capacity in base year to which the measure is applied (Mt/year)	Fuel Savings (GJ/t-product)	Electricity Savings (kWh/t-product)	Capital Cost (US$/t-product)	Change in annual O&M cost (US$/t-product)	Share of production capacity to which measure is applicable in base year (%) *
		in base year to which the measure is applied (Mt/year)					capacity in base year (2010) to which measure is applicable (%) *
12	Integrated casting and rolling (Strip casting)	638.70	0.05	42.0	180.0	-20.9	80%
	Hot Rolling	**Hot rolled finished (HRF) steel production capacity in base year to which the measure is applied (Mt/year)**					**Share of HRF steel production capacity in base year (2010) to which measure is applicable (%) ***
13	Efficient recuperative burner or the use of regenerative burner	649.63	0.70		2.5		70%
14	Process control in hot strip mill	649.63	0.30		0.7		0%
15	Waste heat recovery from cooling water	649.63	0.04	-0.17	0.8	0.07	80%
	Cold Rolling	**Cold rolled finished (CRF) steel production capacity in base year to which the measure is applied (Mt/year)**					**Share of CRF steel production capacity in base year (2010) to which measure is applicable (%) ***
16	Heat recovery on the annealing line	112.28	0.30	3.0	2.7		45%
17	Automated monitoring and targeting systems	112.28		60.0	1.1		45%
	General measures	**Total crude steel production capacity in base year to which the measure is applied (Mt/year)**					**Share of Total crude steel production capacity in base year (2010) to which measure is applicable (%) ***
18	Preventative maintenance in integrated steel mills	638.70	0.43	5.56	0.01	0.02	60%
19	Preventative maintenance in EAF plants	638.70	0.09	13.89	0.01	0.02	60%
20	Energy monitoring and management systems in integrated steel mills	638.70	0.11	2.78	0.15		85%
21	Energy monitoring and management systems in EAF plants	638.70	0.02	2.78	0.15		85%
22	Variable speed drives for flue gas control, pumps, fans in integrated steel mills	638.70		11.11	1.3		85%
23	Cogeneration for the use of untapped coke oven gas, blast furnace gas, and basic oxygen furnace-gas in integrated steel mills	638.70	0.03	97.22	14.5		50%

HRF steel: Hot rolled finished steel; CRF steel: Cold rolled finished steel

* The share of production capacity in base year (2010) to which the measure is **applicable** is different than the share of production capacity in the base year to which the measure is **applied**. The method for determining the application rates of the measures are described in detail in the methodology section with Figure 2 as an illustration.

** The negative value for electricity saving indicates that although the application of this measure saves fuel, it will increase electricity consumption. However, it should be noted that the total primary energy savings of these measures is positive.

*** The descriptions of these 23 measures can be found at Worrell et al. (2010).

Iron Ore Preparation (Sintering)

Heat recovery from sinter cooler:
Two kinds of potentially reusable waste heat are discharged from sinter plants: sensible heat from the main exhaust gas from sintering machines and sensible heat of the cooling air from the sinter cooler. Under normal operating conditions, the use of a heat exchanger to recover heat from the waste process gases would result in unacceptable condensation and corrosion problems. The only practical method of recovering heat from waste gases is by transferring the sensible heat directly back to the sinter bed by the hot gases, or what is known as waste gas recirculation. In contrast, there are five practical ways to recover the sensible heat from the hot air from a sinter cooler: steam generation in a waste gas boiler, hot water generation for district heating, preheating combustion air in the ignition hood of the sinter plant, preheating the sinter raw mix, or using the waste gas in a recirculation system.

Increasing bed depth:
Increasing bed depth in the sinter plant results in lower fuel consumption, improved product quality and a slight productivity improvement. The savings amount to 0.3 ton coke per kton sinter per 0.4 inch (10 mm) bed thickness increase and an electricity savings of 0.06 kWh/tonne sinter.

Coke Making

Coal moisture control:
Coal moisture control reduces the carbonization heat amount and improves the productivity and coke quality by reducing the moisture of the feed coal for coke making from a normal 8 - 10% to approximately 6% without hindering the feeding operation. Generally, low-pressure steam is used as the humidity control heat source, but in some cases the sensible heat of the coke oven gas (COG) is collected by using a heat medium and used as part of the heat source.

Coke dry quenching (CDQ):
CDQ is an alternative to the traditional wet quenching of the coke. The process reduces dust emissions, improves the working environment, and recovers the sensible heat of the high temperature coke (in a red-hot condition) which accounts for approximately 45% of energy consumption in coke ovens. Furthermore, the treatment of coke by CDQ enhances its quality, which is beneficial because using higher quality coke reduces the use of coke in the subsequent blast furnace. The enhancement of coke quality by CDQ also makes it possible to reduce the use of expensive heavy coking coal and increase the use of inexpensive semi-coking coal. The ability to substitute for less expensive coals depends on the required coke quality.

CDQ equipment broadly consists of a coke cooling tower (pre-chamber and cooling chamber) and a waste heat recovery boiler. Red-hot coke (approximately 2,200°F or 1,200°C) is charged into the coke cooling tower, and inert gas is blown into the tower from the bottom. Heat exchange is performed with the circulating inert gas. After the gas is heated to high temperature (approximately 1450°F or 800°C), it circulates through the heating tubes of the waste heat boiler, converting the water in the boiler into steam. The temperature of the coke at the cooling tower outlet is reduced to approximately 400°F (200°C).

Iron Making – Blast Furnace (BF)

Injection of pulverized coal in BF to 130 kg/t hot metal:
PCI is a process in which fine granules of coal are blown in large volumes into the blast furnace as a supplemental carbon source to speed up the conversion of iron ore into metallic iron. Pulverized coal injection eliminates part of the coke production, thereby saving energy and reducing emissions and maintenance costs. The energy savings in the blast furnace from coal injection have been estimated at 3.76 GJ/tonne coal injected. Fuel injection does, however, require energy for oxygen injection, coal, electricity and equipment to grind the coal. For every ton of coal injected, approximately 0.85-0.95 ton of coke production is avoided. The theoretical maximum for coal injection at the tuyère level is thought to be 0.27 ton/ton hot metal. This limit is set by the carrying capacity of the coke and the thermochemical conditions in the furnace.

Injection of natural gas in BF:
Like PCI, natural gas injection allows a reduction in coke production with associated benefits. Natural gas injection was developed in the former Soviet Union and the United States. This technology requires little extra capital investments and special equipment except for the gas pressure equalizer and gas distributor, and considerably reduces coke consumption. Due to these advantages, natural gas injection in North America has increased substantially since the 1990s. However, natural gas prices may limit its economic appeal as an injection fuel. Typical injection rates are within the range of 0.04–0.11 ton/ton hot metal, with the highest being 0.155 ton/ton hot metal. Replacement rates for natural gas vary between 0.9 and 1.15 ton natural gas/ton coke.

Injection of coke oven gas in BF:
Coke oven gas and basic oxygen furnace gas can also be injected in blast furnace (also see previous chapter: avoid flaring of excess coke oven gas). The maximum level for COG injection at the tuyère level is estimated at 0.1 ton/ton hot metal. The replacement rate of COG is about 1.0 ton of gas for 0.98 ton of coke. This limit is set by the thermochemical conditions in the furnace. A compressor unit is required for COG injection, resulting in an additional energy consumption of about 185 kWh/ton COG (204 kWh/tonne).

Top-pressure recovery turbines (TRT):
Top gas pressure in modern blast furnaces is approximately 3.6-36 psig (0.25-2.5 bar gauge). Electric power can be generated by employing blast furnace top gases to drive a turbine-generator. Although the pressure difference over the generator is low, the large gas volumes can make the recovery economically feasible. This is typically the case when the top pressure is in excess of 22 psig (1.5 bar

gauge). After the blast furnace gas is used in top-pressure recovery turbines it can be used as a fuel in iron and steel manufacturing processes.

Generating methods are classified as wet or dry depending on the blast furnace gas purification method. In the wet method dust is removed by Venturi scrubbers and in the dry method by a dry-type dust collector. When dust is treated by the dry method, the gas temperature drop is small in comparison to the wet method, and as a result generated output is at maximum 1.6 times greater than with the wet method.

Recovery of blast furnace gas:
A typical blast furnace produces about 1320 to 2210 Nm^3 of blast furnace gas per ton of pig iron (1200 to 2000 Nm^3 per tonne). The gas consists of 20-28% of carbon monoxide (CO) and 1-5% hydrogen (H_2), both of which are potential energy sources that can be recovered using certain measures. Blast furnace gas can be cleaned and stored in a gasholder for subsequent use as a fuel or alternatively to generate electricity in a gas turbine. The energy content of blast furnace gas typically varies between 2.3 and 3.4 kBtu/Nm^3 (2.7-4.0 MJ/Nm^3) depending on its CO concentration. This is only 10% of the energy content of natural gas, and therefore it is often enriched with coke oven gas or natural gas prior to use as fuel. Total export from the blast furnace is approximately 4.3 MBtu/ton (5 GJ/tonne) pig iron, which equals 30% of the gross energy consumption of the blast furnace.

Where a blast furnace is fitted with a two bell charging system, the volume of gas is lost to the atmosphere every time the furnace is charged. It is possible to recover most of this by allowing the high pressure gas between the two bells to discharge into the low pressure side of the gas collection system just prior to opening the top bell for charging, thus saving about 30 kBtu/ton (35 MJ/tonne) hot metal.

Steelmaking – basic oxygen furnace (BOF)

Recovery of BOF gas and sensible heat:
Recovery of BOF gas is the single most energy-saving improvement in the BOF process, making it a net energy producer. BOF gas produced during oxygen blowing leaves the BOF through the converter mouth and is subsequently caught by the primary ventilation. This gas has a temperature of approximately 2200°F (1200°C) and a flow rate of approximately 55-110 Nm^3/ton (50-100 Nm^3/tonne) steel. The gas contains approximately 70-80% CO when leaving the BOF and has a heating value of 7.6 kBtu/Nm^3 (8.8 MJ/Nm^3).

Heat recovery methods are classified as a combustion method or as a non-combustion method (method of recovering gas in an unburned condition). Non-combustion method facilities are designed to recover about 70% of the latent heat and sensible heat. By reducing the amount of air entering over the convertor, CO is not converted to CO_2. The sensible heat of the off-gas is first recovered in a waste heat boiler, generating high pressure steam. The gas is subsequently cleaned and stored. The recovered converter gas can be mixed with other by-product gases (coke oven gas, blast furnace gas).

Steelmaking – Electric Arc Furnace (EAF)

Scrap preheating:
This technology can reduce the power consumption of EAFs by utilizing the furnace waste heat to preheat the scrap charge. Old bucket preheating systems had various problems, e.g. emissions, high handling costs, and a relatively low heat recovery rate. Modern systems have reduced these problems, and are highly efficient. In the first half of the 1990s, an electric furnace with a direct-coupled scrap preheating function was developed to improve the scrap preheating device. Today, such preheating is performed either in the scrap charging baskets or in a charging shaft (shaft furnace) added to the EAF or in a specially designed scrap conveying system that allows continuous charging during the melting process.

The shaft technology has been developed in steps. With a single shaft furnace, at least 50% of the scrap can be preheated whereas a finger shaft furnace (which means a shaft having a scrap retaining system) allows preheating of the total scrap amount. A further modification is the double shaft furnace which consists of two identical shaft furnaces (twin shell arrangement) positioned next to one another and which are serviced by a single set of electrode arms. The most efficient shaft-furnace design is the finger shaft furnace.

Casting and Refining

Integrated casting and rolling (Strip casting):
When applying direct rolling, the casted slab is rolled directly in the hot strip mill, reducing handling and energy costs. Direct production of hot-rolled strip by connecting the thin slab caster with the hot-rolling process was introduced around 1990. In existing integrated plants, this option may be difficult to implement and costly as the rolling stands need to be located directly next to the continuous caster. Energy savings of direct rolling, with a charging temperature of 1110°F (600°C), may be up to 35-43%.

Near net shape casting is a process of casting metal to a form close to that required for the finished product. Near net shape casting integrates the casting and hot rolling of steel into one process step, thereby reducing the need to reheat the steel before rolling it. Several production processes have been developed for near net shape casting, most notably Thin Slab Casting (TSC) and Strip Casting (SC). In case of TSC, the steel is cast directly to slabs with a thickness between 1.2 and 2.4 in (30 and 60 mm), instead of slabs with a thickness of 4.72-11.8 in (120-300 mm). TSC has been a success in flat product mini-mills in the U.S.

Hot Rolling

Efficient recuperative burner or the use of regenerative burner:

Application of recuperative or regenerative burners can reduce energy consumption substantially. A recuperator is a gas-to-gas heat exchanger placed on the stack of the furnace. There are numerous designs, but all rely on tubes or plates to transfer heat from the outgoing exhaust gas to the incoming combustion air, while keeping the two streams from mixing. Recuperative burners use the heat from the exhaust gas to preheat the combustion air. Recuperative burners can reduce fuel consumption by 10-20% compared to furnaces without heat recovery.

Regenerators are basically rechargeable storage batteries for heat. During an operating cycle, process exhaust gases flow through the regenerator, heating a storage medium. After a while, the medium becomes fully heated (charged). The exhaust flow is shut off and cold combustion air extracts the heat from the storage medium, increasing in temperature before it enters the burners. For continuous operation, at least two regenerators and their associated burners are required. Regenerative burners can theoretically achieve savings of up to 35% compared to furnaces without heat recovery.

Since modern recuperative or regenerative burner systems can have significantly higher efficiencies than older systems, savings can also be attained by replacement of recuperative or regenerative burners. While, newer designs can also have lower NO_x emissions, the evaluation of recuperative or regenerative burner systems should include an assessment of the impact on NO_x emissions.

Process control in hot strip mill:
Process controls save energy and increase productivity and the quality of rolled steel products. Although direct energy savings may be limited, indirect energy savings can be substantial due to reduced rejection of product, improved productivity, and reduced down-time. This measure includes controlling oxygen levels and variable speed drives on combustion air fans, which both help to control the oxygen level, and hence optimize the combustion in the furnace, especially as the load of the furnace may vary over time. The savings depend on the load factor of the furnace and control strategies applied.

Waste heat recovery from cooling water:
Waste heat can be recovered from the cooling water of the hot strip mill. When ejected, the rolled steel is cooled by spraying water at a temperature of 175°F (80°C).

Cold Rolling

Heat recovery on the annealing line:
Losses on the annealing line can be reduced by implementation of heat recovery (using regenerative or recuperative burners in the annealing furnace), adoption of improved insulation, process management equipment, as well as installing variable speed drives, to reduce energy use by up to 40-60% compared to furnaces without heat recovery (i.e. from 1.8 MBtu/ton to 0.7 MBtu/ton for a continuous annealing line. Compared to current state-of-the-art furnaces, a modern furnace with regenerative burners would still reduce fuel consumption by 25%, while NO_x emissions would be reduced by 90%.

Automated monitoring and targeting systems:
Installing an automated monitoring and targeting system at a cold strip mill can reduce the power demand of the mill, as well as reduce effluents.

General measures

Preventative maintenance:
Preventative maintenance involves training personnel to be attentive towards energy consumption and efficiency. Successful programs have been launched in many industries. Examples of effective personnel practices in steel making include timely closing of furnace doors to reduce heat leakage and reduction of material wastes in the shaping steps.

Energy monitoring and management systems:
This measure includes site energy management systems for optimal energy recovery and distribution between various processes and plants. A wide variety of such energy management systems exist.

Variable speed drives for flue gas control, pumps, fans:
Based on experience in the UK, Worrell et al. (2006) assumed that electricity savings of 42% are possible through the use of variable speed drives (VSDs) on pumps and fans. They assumed that this technology can be applied to 5% of electricity use in integrated steel making.

Cogeneration for the use of untapped coke oven gas, blast furnace gas, and basic oxygen furnace-gas in integrated steel mills:
All plants and sites that need electricity and heat (i.e. steam) in the steel industry are excellent candidates for cogeneration. Conventional cogeneration uses a steam boiler and steam turbine (back pressure turbine) to generate electricity. Steam systems generally have low efficiency and high investment costs. Current steam turbine systems use low-cost waste fuels, which may have been vented before, e.g. Inland Steel and U.S. Steel Gary Works in the U.S. Modern cogeneration units are gas turbine based, using either a simple cycle system (gas turbine with waste heat recovery boiler), a Cheng cycle or STIG (with steam injection in the gas turbine), or a combined cycle integrating a gas turbine with a steam cycle for larger systems. The latter system can also be used to "re-power" existing steam turbine systems. Gas turbine systems mainly use natural gas. Integrated steel plants produce significant levels of off-gases (coke oven gas, blast furnace gas, and basic oxygen furnace-gas). Specially adapted turbines can burn these low calorific value gases at electrical generation efficiencies of 45% (low heating value, LHV) but internal compressor loads reduce these efficiencies to 33%.

10.4 Results and Discussions

10.4.1 Energy Conservation Supply Curves for China's Cement Industry

Based on the methodology explained above and the information from Table 18, Electricity Conservation Supply Curve (FCSC) and Electricity Conservation Supply Curve (ECSC) were constructed separately to capture the cost-effective and total technical potential for electricity and fuel efficiency improvement in the Chinese cement industry from 2010 to 2030. In addition, the CO_2 emission reduction potential from implementing efficiency measures was also calculated. Out of 23 energy-efficiency measures, 22 measures were applicable to the cement industry in China, 17 of which are electricity-saving measures that are included in ECSC and 5 of which are fuel-saving measures used to derive the FCSC.

It should be noted that some measures saved both fuel and electricity or in a few cases the fuel saving resulted in an increase in electricity use. For these measures, primary energy savings was used to calculate Cost of Conserved Fuel (CCF) based on both the electricity and fuel savings. Since the share of fuel saving is greater than that of electricity saving, this measure is included as one of the fuel saving measures.

Fuel Conservation Supply Curve for the Cement Industry

Five energy-efficiency measures were used to construct the cement FCSC. Figure 66 shows that all five energy-efficiency measures fall below the discounted average unit price of fuel (coal) in the cement industry from 2010 to 2030 (1.4US$/GJ), indicating that the CCF is less than the discounted average unit price of fuel for these measures. In other words, the cost of investing in these five energy-efficiency measures to save one GJ of energy in the period of 2010 - 2030 is less than purchasing one GJ of fuel at the given price.

Table 20 presents the fuel efficiency measures applicable to the cement industry ranked by their CCF. The fuel savings and CO_2 emission reduction achieved by each measure are also shown. Increased production of blended cement (additives: fly ash, pozzolans, limestone or/and blast furnace slag) and kiln shell heat loss reduction (improved refractories) are the two most cost-effective measures. The highest fuel savings is achieved by increased production of blended cement during 2010-2030. Table 21 shows the cumulative cost-effective and the total technical potential for fuel savings and CO_2 emission reduction from 2010 to 2030 as calculated by the model.

Figure 66. 2010-2030 FCSC for the Cement industry in China

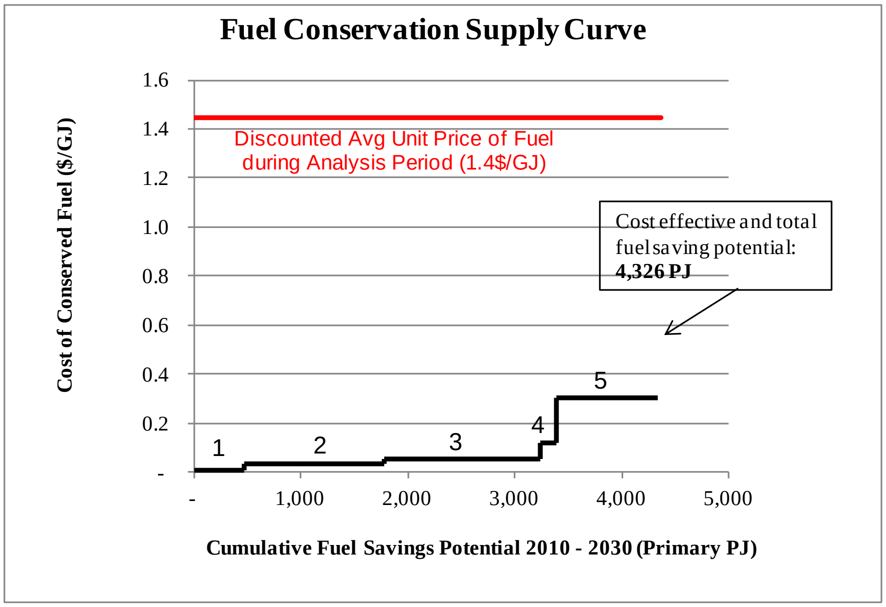


Table 20. Fuel Efficiency Measures for the Cement industry in China Ranked by Cost of Conserved Fuel (CCF)

CCE Rank	Efficiency Measure**	Fuel Savings (PJ)	Cost of Conserved Fuel (US$/GJ-saved)	CO_2 Emission Reduction (Mton CO_2)
1	Blended cement (additives: fly ash, pozzolans, limestone and/or blast furnace slag)**	458	0.01	44.1*
2	Kiln shell heat loss reduction (improved refractories)	1,311	0.04	124.0
3	Use of Alternative Fuels	1,467	0.05	138.8
4	Optimize heat recovery/upgrade clinker cooler**	141	0.12	14.6
5	Energy management and process control systems in clinker making**	949	0.30	84.1

*CO_2 emission reduction from reduced energy use only. The CO2 emission reduction as a result of reduced calcinations in clinker making process is not counted here.

**For this measure, primary energy saving was used to calculate CCF based on both the electricity and fuel savings. Since the share of fuel saving is more than that of electricity saving, this measure is included between fuel saving measures.

Table 21. Cost-Effective and Total Technical Potential for Fuel Savings and CO2 Emission Reduction in the Cement Industry in China during 2010-2030

	Cumulative Fuel Saving Potential (PJ)		Cumulative Carbon Dioxide Emission Reduction (Mt CO_2)	
	Cost-Effective	Technical	Cost-Effective	Technical
Cumulative saving potentials during 2010-2030	4,326	4,326	406	406

Electricity Conservation Supply Curve for the Cement Industry

For the cement industry, 17 energy-efficiency measures are included in the ECSC. Figure 67 and Table 22 show that out of 17 energy-efficiency measures, 10 measures fall below the discounted average unit price of electricity in studied plants (29US$/ megawatt-hour, MWh) during the period of 2010-2030. Therefore, the CCE is less than the discounted average electricity price during the study period for these measures. In other words, these measures can be considered cost-effective as the cost of investing in these 10 energy-efficiency measures to save one MWh of electricity is less than purchasing one MWh of electricity at the discounted average 2010-2030 unit price of electricity. The other 7 efficiency measures (grey area in Table 22) are technically applicable but not cost-effective; thus, their implementation may require financial incentives beyond energy savings alone.

The two most cost-effective measures are installation of high efficiency motors and high efficiency fan to replace raw mill vent fan with inverter. The largest electricity savings potential is from replacing a ball mill with vertical roller mill in finish grinding (ranked 7 on the curve) and low temperature waste heat recovery power generation, which saves purchased electricity by generating electricity from the waste heat onsite (ranked 9 on the curve). Table 23 shows the cumulative cost-effective and the total technical potential for electricity savings and CO_2 emission reduction from 2010 to 2030.

Figure 67. 2010-2030 ECSC for the Cement Industry in China

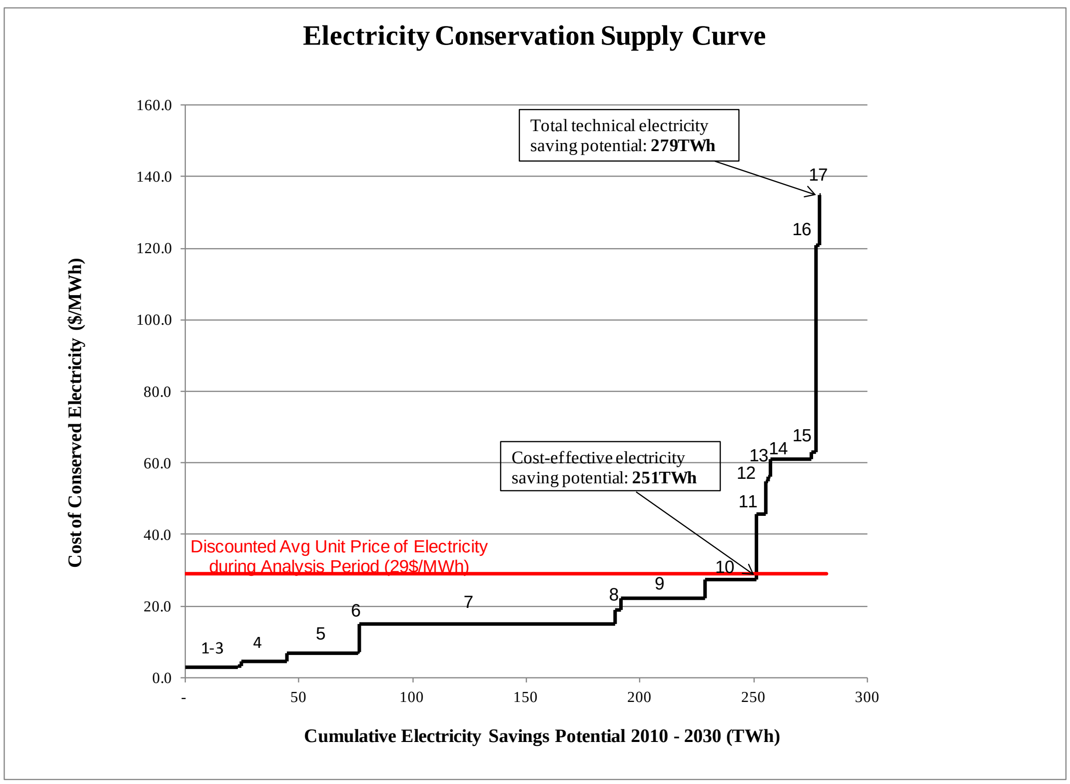


Table 22. Electricity Efficiency Measures for the Cement industry in China Ranked by Cost of Conserved Electricity (CCE)

CCE Rank	Efficiency Measure*	Electricity Savings (TWh)	Cost of Conserved Electricity (US$/MWh-saved)	CO_2 Emission Reduction (Mton CO_2)
1	Replacement of cement mill vent fan with high efficiency fan	23.1	3.03	12.5
2	High efficiency motors	1.2	3.38	0.7
3	High efficiency fan for raw mill vent fan with inverter	0.2	3.60	0.1
4	Energy management & process control in grinding	20.2	4.63	10.9
5	Adjustable Speed Drives	31.1	7.00	17.2
6	Installation of variable frequency drive & replacement of coal mill bag dust collector’s fan with high efficiency fan	0.7	7.22	0.4
7	Improved grinding media for ball mills	112.5	15.00	60.2
8	Low temperature Waste Heat Recovery power generation	2.4	18.98	1.4
9	Replacing a ball mill with vertical roller mill in finish grinding	36.8	22.14	22.4
10	High pressure roller press as pre-grinding to ball mill in finish grinding	22.9	27.65	13.9
11	High-Efficiency classifiers for finish grinding	3.9	45.69	2.4
12	Replacing a ball mill with vertical roller mill for coal grinding	0.9	54.99	0.5
13	High Efficiency classifiers/separators for raw material grinding	1.4	56.27	0.8
14	Low pressure drop cyclones for suspension preheater	17.5	61.27	10.2
15	Replacing a ball mill with vertical roller mill /High pressure roller presses in raw material grinding	2.4	63.16	1.5
16	Efficient (mechanical) transport system for raw materials preparation	1.2	121.09	0.7
17	Raw meal blending (homogenizing) systems	0.5	135.13	0.3

Table 23. Cost-Effective and Total Technical Potential for Electricity Saving and CO_2 Emission Reduction in the Cement Industry in China during 2010-2030

	Cumulative Electricity Saving Potential (TWh)		Cumulative Carbon Dioxide Emission Reduction (Mt CO_2)	
	Cost-effective	Technical	Cost-effective	Technical
Cumulative saving potentials during 2010-2030	251	279	140	156

10.4.2 Energy Conservation Supply Curves for China’s Iron and Steel Industry

Based on the information from Table 19 and the stated modeling methodology, Fuel Conservation Supply Curve (FCSC) and Electricity Conservation Supply Curve (ECSC) were constructed separately to capture the cost-effective and total technical potential for electricity and fuel efficiency improvement in the Chinese iron and steel industry from 2010 to 2030. Furthermore, the CO_2 emission reduction potential from implementing efficiency measures was also calculated. Out of 23 energy-efficiency measures, 20 measures were applicable to the iron and steel industry in China, 3 of which are electricity-saving measures that are included in ECSC and 17 of which are fuel-saving measures included in the FCSC.

It should be noted that some measures saved both fuel and electricity or in a few cases the fuel saving resulted in an increase in electricity use. For these measures, primary energy saving was used to calculate Cost of Conserved Fuel (CCF) based on both the electricity and fuel savings. Since the share of fuel saving is more than that of electricity saving, these measures are included as fuel saving measures.

Fuel Conservation Supply Curve for the Iron and Steel industry

Fifteen energy-efficiency measures were used to construct the steel FCSC. Figure 68 shows that fourteen energy-efficiency measures fall below the discounted average unit price of fuel in the iron and steel industry from 2010 to 2030 (3.4US$/GJ), indicating that the CCF is less than the discounted average unit price of fuel for these measures. In other words, the cost of investing in these fourteen energy-efficiency measures to save one GJ of energy in the period of 2010 - 2030 is less than purchasing one GJ of fuel at the given price. The other one efficiency measure (grey area in Table 24) is technically applicable but not cost-effective and may require financial incentives beyond energy savings alone.

Figure 68. 2010-2030 FCSC for the Iron and Steel industry in China

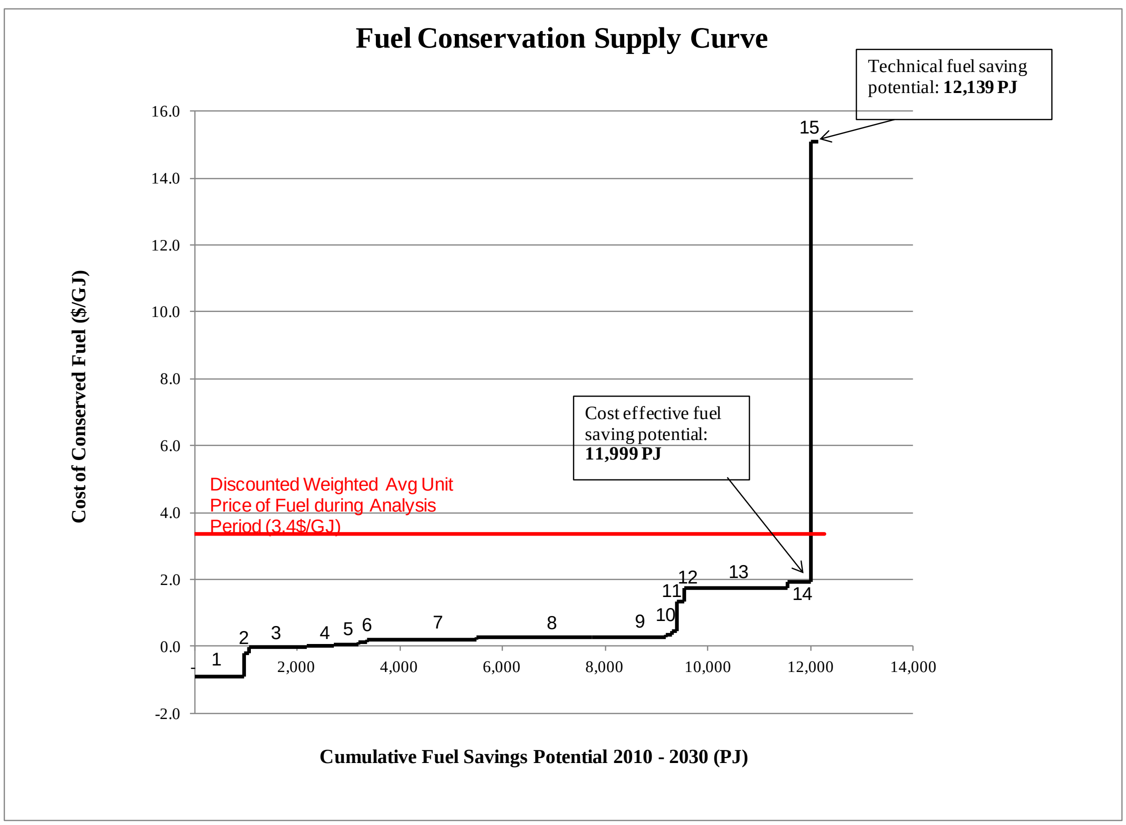


Table 24 presents the fuel efficiency measures applicable to the iron and steel industry ranked by their CCF. The fuel savings and CO_2 emission reduction achieved by each measure are also shown. Injection of natural gas in BF and injection of pulverized coal in BF to 130 kg/t hot metal are the two most cost-effective measures. The highest fuel savings during 2010-2030 is achieved by recuperative or regenerative burner in hot rolling followed by heat recovery from sinter cooler. Table 25 shows the cumulative cost-effective and the total technical potential for fuel savings and CO_2 emission reduction from 2010 to 2030 as calculated by the model.

Table 24. Fuel Efficiency Measures for the Iron and Steel industry in China Ranked by Cost of Conserved Fuel (CCF)

CCF Rank	Efficiency Measure***	Fuel Savings (PJ)	Cost of Conserved Fuel (US$/GJ-saved)	CO_2 Emission Reduction (Mton CO_2)
1	Injection of natural gas in BF	953	-0.87*	100
2	Injection of pulverized coal in BF to 130 kg/t hot metal	82	-0.20*	9
3	Preventative maintenance in integrated steel mills*	1,124	0.01	110
4	Preventative maintenance in EAF plants*	541	0.02	39
5	Energy monitoring and management systems in integrated steel mills*	479	0.05	45
6	Energy monitoring and management systems in EAF plants*	169	0.15	12
7	Recuperative or regenerative burner	2,139	0.22	223
8	Heat recovery from sinter cooler	2,244	0.29	234
9	Injection of coke oven gas in BF*	1,425	0.30	122
10	Recovery of blast furnace gas	129	0.36	13
11	Heat recovery on the annealing line*	97	0.46	10
12	Waste heat recovery from cooling water*	137	1.35	15
13	Recovery of BOF gas and sensible heat	2,016	1.74	210
14	Coke dry quenching (CDQ)	463	1.95	48
15	Coal moisture control	140	15.12	15

* For this measure, primary energy saving was used to calculate CCF based on both the electricity and fuel savings. Since the share of fuel saving is more than that of electricity saving for this measure, this measure is included between fuel saving measures.

** O&M costs of this measure show a net decrease due to reduced coke purchase costs and reduced maintenance costs of existing coke batteries. This negative O&M cost results in a negative CCF when calculated over the study period (2010-2030).

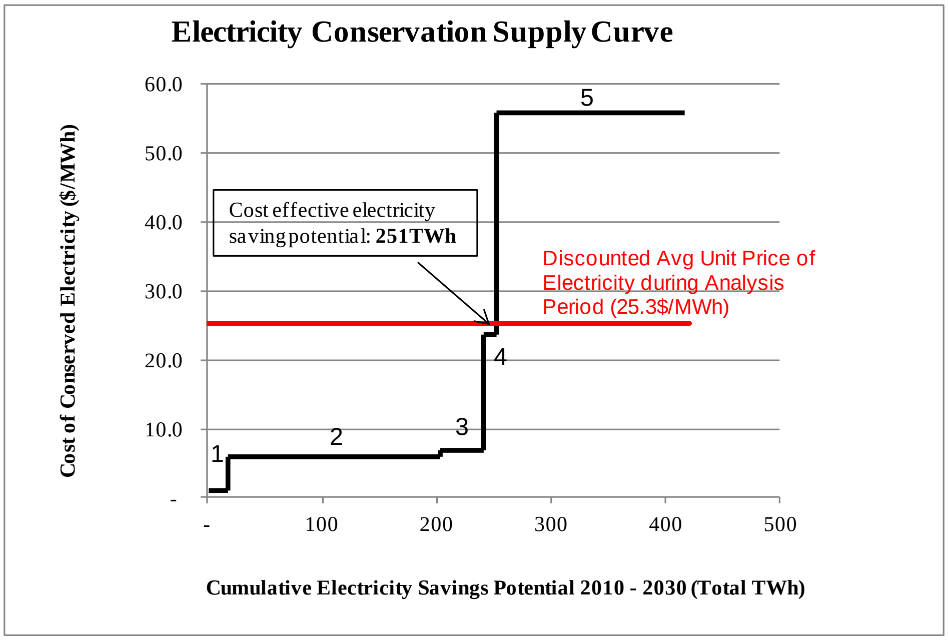
Table 25. Cost-Effective and Technical Potential for Fuel Savings and CO_2 Emission Reduction in the Iron and Steel Industry in China during 2010-2030

	Cumulative Fuel Saving Potential (PJ)		Cumulative Carbon Dioxide Emission Reduction ($MtCO_2$)	
	Cost-Effective	Technical	Cost-Effective	Technical
Cumulative saving potentials during 2010-2030	11,999	12,139	1,191	1,205

Electricity Conservation Supply Curve for the Iron and Steel industry

For the iron and steel industry, five energy-efficiency measures are included in the ECSC. Figure 69 and Table 26 show that four out of five energy-efficiency measures on ECSC fall below the discounted average unit price of electricity in studied plants during the period of 2010-2030 (25.3US$/ megawatt-hour, MWh). Therefore, the CCE for these four measures is less than the discounted average electricity price during the study period. In other words, these measures can be considered cost-effective as the cost of investing in these four energy-efficiency measures to save one MWh of electricity is less than purchasing one MWh of electricity at the discounted average 2010-2030 unit price of electricity.

Figure 69. 2010-2030 ECSC for the Iron and Steel Industry in China



The two most cost-effective measures are automated monitoring and targeting systems and cogeneration. The largest electricity savings potential is from cogeneration (ranked 2 on the curve) followed by integrated casting and rolling (strip casting) (ranked 5 on the curve). Table 27 shows the cumulative cost-effective and the total technical potential for electricity savings and CO_2 emission reduction from 2010 to 2030.

Table 26. Electricity Efficiency Measures for the Iron and Steel industry in China Ranked by Cost of Conserved Electricity (CCE)

CCE Rank	Efficiency Measure**	Electricity Savings (TWh)	Cost of Conserved Electricity (US$/MWh-saved)	Cumulative CO_2 Emission Reduction (Mton CO_2)
1	Automated monitoring and targeting systems	18	1.14	10

2	Cogeneration for the use of untapped coke oven gas, blast furnace gas, and basic oxygen furnace-gas in integrated steel mills*	185	6.11	103
3	Variable speed drives for flue gas control, pumps, fans in integrated steel mills	38	7.04	21
4	Top-pressure recovery turbines (TRT)	11	23.71	6
5	Integrated casting and rolling (Strip casting)*	165	56.04	98

* For this measure, the share of electricity saving is more than that of fuel saving; thus, this measure is included between electricity saving measures on ECSC. To convert fuel saving by this measure to electricity saving, the national average power generation efficiency is used.

Table 27. Cost-Effective and Technical Potential for Electricity Savings and CO_2 Emission Reduction in the Iron and Steel Industry in China during 2010-2030

	Cumulative Electricity Saving Potential (TWh)		Cumulative Carbon Dioxide Emission Reduction (Mt CO_2)	
	Cost-effective	Technical	Cost-effective	Technical
Cumulative saving potentials during 2010-2030	251	416	139	237

10.5 Barriers to the Adoption of Energy-Efficiency Technologies and Measures in the Cement and Iron and Steel Industry in China

There are various underlying factors behind why cement and iron and steel plants have not adopted the highly cost-effective measures identified in this study. Possible reasons include: the age of the plant (e.g., the plant was constructed earlier or the application of the measure was limited by the technical conditions at that time), overall technical knowledge of the staff, lack of knowledge about the energy-efficiency measure, uncertainty about the new technology, plant-specific operating conditions, and investor preferences. Furthermore, although some energy-efficient technologies have short payback periods, the high initial capital cost of the project often deters adoption and installation. For example, an efficient vertical mill system has a purchase price of approximately 30 million RMB, compared to the lower purchase price of only 8 million RMB for a less efficient ball mill system. Hence, if plant owners lack sufficient capital in the initial stage of building the plant, they cannot purchase the more efficient vertical mills.

In regards to the production of blended cement, the amount of cement available for blending is limited since preserving the basic properties of cement is a top priority. Currently, Chinese cement standards mandates the maximum amount of each type of supplementary cementitious materials in six categories of cement. For example, the national standard states that less than 20% of each type of supplementary cementitious materials can be blended into common Portland cement. If more than 20% of slag is blended, it will be classified as “slag cement” and if more than 20% of fly ash is blended, it will be classified as “fly ash cement”. If a large amount of supplementary cementitious materials is blended, cement characteristics may change. As a result, slag cement and fly ash cement are not popular in the Chinese market. In addition, concrete batching stations can blend certain amounts of supplementary cementitious materials into purchased common Portland cement in batching concrete to meet certain construction requirements.

The Chinese cement industry's utilization of alternative fuels has progressed in recent years, but still faces key barriers. For instance, because the recycling and reprocessing of scrap tires in China already result in resource utilization with higher economic benefits, scrap tires are less likely to be utilized by Chinese cement kilns. Additionally, more research, capacity building, and demonstration is still required for biomass applications in the cement industry.

A similar study that investigated barriers to the implementation of cost-effective, energy-efficiency technologies and measures in Thailand (Hasanbeigi, 2009) found the following key barriers:

- **Management concerns about the high investment costs of energy efficiency measures**: Even though the payback period of efficiency measures might be short, some cement plants still have difficulty acquiring the high initial investment needed to purchase energy efficiency measures.
- **Management considers production more important:** In many industrial production plants, upper management is focused solely on production output, final product quality and sales, with little or no attention to energy efficiency. This is also the case for some cement plants, although energy cost's high share of cement production cost makes it less of a barrier when compared to less energy-intensive industries .
- **Management concerns about time required to improve energy efficiency**: The high cost of disrupting industrial production may raise concerns about the time requirements for implementing energy efficiency measures.
- **Lack of coordination between external organizations**: The implementation of energy and environmental regulations lacks proper execution and enforcement as a result of the lack of coordination between different ministries and government institutions responsible for energy and environmental issues.
- **Current installations are already considered efficient**: This is especially true for newly-installed cement production lines, although they may not be as efficient as the best commercially available technologies.

10.6 Key Findings

Given the importance of the cement and iron and steel industry in China as two of the highest energy-consuming and CO_2-emitting industries, this study aims to understand the potential for energy-efficiency improvement and CO_2 emission reductions using a bottom-up model. Specifically, bottom-up Energy Conservation Supply Curves (i.e. ECSC and FCSC) were constructed for the Chinese cement and iron and steel industries to determine the savings potential and costs of energy-efficiency improvements by taking into account the costs and energy savings of different technologies.

We analyzed 23 energy efficiency technologies and measures for the cement industry and 23 measures for the iron and steel industry. Using a bottom-up electricity CSC model, the cumulative cost-effective electricity savings potential for the Chinese cement industry for 2010-2030 is estimated to be 251 TWh, and the total technical electricity saving potential is 279 TWh. The CO_2 emissions reduction associated with cost-effective electricity savings is 140 Mt CO_2 and the CO_2 emission reduction associated with technical electricity savings potential is 156 Mt CO_2. The fuel CSC model for the cement industry suggests the cumulative cost-effective fuel savings potential is 4,326 PJ which is equivalent to the total technical potential. The CO_2 emission reductions associated to total fuel saving potential is 406 Mt CO_2. . The cumulative cost-effective electricity savings potential for the Chinese iron and steel industry for 2010-2030 is estimated to be 251 TWh, and the total technical electricity saving potential is 416 TWh. The CO_2 emissions reduction associated with cost-effective electricity savings is 139 Mt CO_2 and the CO_2 emission reduction associated with technical electricity saving potential is 237 Mt CO_2. The FCSC model for the iron and steel industry shows cumulative cost-effective fuel savings potential of 11,999 PJ, and total technical fuel savings potential of 12,139 PJ. The CO_2 emissions reduction associated with cost-effective and technical fuel savings is 1,191 Mt CO_2 and 1,205 Mt CO_2, respectively. The approach used in this study and the model developed can be viewed as a screening tool for helping policymakers understand the savings potential of energy-efficiency measures and design appropriate policies to capture the identified savings. However, energy-saving potentials and the cost of energy-efficiency measures and technologies will vary according to country- and plant-specific conditions. This study shows that in China's case, an efficiency gap remains in the cement and iron and steel industries as many of the identified cost-effective opportunities for energy efficiency improvement still have not been adopted. The persistence of this efficiency gap result from various obstacles to adoption, especially non-monetary barriers in the cement industry, and suggests that effective energy efficiency policies and programs are needed to realize cost-effective energy savings and emission reduction potential.

11. Conclusions

Although recent announcements suggest that China achieved its 20% energy intensity reduction target for 2006 to 2010, continued rapid economic growth and urbanization creates additional opportunities for efficiency improvements. In evaluating China's energy savings and CO_2 mitigation potential over the next twenty years, it is important to contextualize and quantify the gap between current and expected technologies in use in China and the highest possible efficiency levels of the most advanced technologies. This study thus uses a bottom-up, end-use model with two scenarios (Reference and Max Tech) to evaluate China's possible energy and emission pathways through 2030. A separate cost analysis of selected measures in key industries is also conducted to provide insight into the economic cost-effectiveness of efficiency measures.

Under the Max Tech scenario in which the highest technically feasible efficiencies and advanced technologies are adopted across demand and power sectors, total annual savings potential of over one billion tonnes coal equivalent energy exists beyond the expected reference pathway of continuing the current pace of improvements by 2030. In terms of CO_2 emissions, the 2020s appear to be a likely turning point for both pathways with annual emissions peaking much earlier under the Max Tech pathway. From 2010 to 2030, Max Tech achieves cumulative savings of 10.5 billion tonnes coal equivalent energy and cumulative emission reductions of 30.9 billion tonnes of CO_2 beyond the reference pathway. At the same time, both emission pathways require that all announced and planned policies, targets and non-fossil generation targets be met before 2030, as failure to do so would result in an even wider gap.

The results of this study also show that energy savings and CO_2 mitigation potential vary by sector, though most of the energy savings potential remains in energy-intensive industry. The primary source of savings is from electricity rather than fuel, as the vast majority of reductions in coal demand is from the power sector. At the same time, electricity savings and the associated emission reduction are magnified by increasing renewable generation and improving coal generation efficiency, underscoring the dual importance of end-use efficiency improvements and power sector decarbonization.

The cost of conserved energy analysis indicates that nearly all of the 23 measures analyzed for the iron and steel and cement industry are cost-effective. For the cement industry, the cumulative cost-effective electricity savings potential for 2010-2030 is estimated to be 251 TWh, and the total technical electricity saving potential is 279 TWh. The cumulative cost-effective fuel savings potential is 4,326 PJ which is equivalent to the total technical potential. For the steel industry, the cumulative cost-effective electricity savings potential for 2010-2030 is estimated to be 251 TWh, and the total technical electricity saving potential is 416 TWh. The cumulative cost-effective fuel savings potential is 11,999 PJ, and the total technical fuel savings potential is 12,139. The total potential savings from these measures confirm the magnitude of savings in the scenario models, and illustrate that an efficiency gap remains in the cement and iron and steel industries with untapped cost-effective opportunities for efficiency improvement.

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