China’s green revolution

Prioritizing technologies to achieve energy and environmental sustainability

McKinsey&Company

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Preface

China's rapid pace of urbanization and economic development over the past three decades has lifted hundreds of millions of people out of poverty, and catapulted the nation into the ranks of the world's largest economies. Yet, rising demand for energy, increasing emissions of greenhouse gases, and the deterioration of critical natural resources such as arable land and water, pose enormous challenges for China. Like many countries, China faces the challenge of finding solutions that adequately address these issues without compromising its economic development goals and the living standards of its people.

To provide a quantitative, fact-based analysis to help policy makers and business leaders identify and prioritize potential solutions, McKinsey & Company, in cooperation with leading researchers in China and across the world, undertook a study of the range of technologies that China could deploy to address its energy and environmental sustainability challenges. Over the past year, the team studied over 200 efficiency and abatement technologies, with a special focus on five sectors: residential and commercial buildings and appliances; transportation; emissions intensive industries (including steel, cement, chemicals, coal mining and waste management); power generation; and agriculture and forestry. In the course of their research, the team interviewed more than 100 experts from government, business, and academia.

The methodology we employed in this report is consistent with the climate change abatement cost curve research that McKinsey has conducted globally over the past three years. In this report we use greenhouse gas (GHG) emissions as a consistent metric for evaluating the full range of different technologies that we studied, from wind turbines to LED light bulbs. This metric also serves as a proxy for assessing the impact of these technologies on other aspects of sustainability, such as energy savings, pollution control, and ecosystem preservation.

Our estimates are of the *maximum* technical abatement potential of each option. Several factors could limit the realization of the full abatement potential, such as labor market disruptions, budget constraints, and environmental concerns.

Our cost analysis only considers capital, operating and maintenance costs, and excludes taxes, tariffs and subsidies. We did not include positive or negative social costs (e.g., unemployment or public health), administrative costs, transaction costs associated with switching to new technologies, and communication costs. We also have not assumed any "price for carbon" (e.g., a carbon cap or tax) that might emerge due to legislation, or the impact on the economy of such a carbon price. Hence, the abatement cost does not necessarily reflect the exact cost of implementing that option.

We do not intend our findings to serve in any way as a forecast or target for GHG emissions abatement. Our analysis does not attempt to address broad policy questions with regard to the regulatory regimes or incentive structures the Chinese government might consider. This report does not endorse any specific legislative proposals or mechanisms to foster sustainable growth. The purpose of our study of energy security and environmental sustainability in China is not to present opinions or advice on behalf of any party.

In addition, this report does not endorse any specific proposals or frameworks for a global agreement regarding climate change. The purpose of this report is to facilitate the definition and prioritization of economically sensible approaches to address the challenges that China faces with regard to energy security and environmental sustainability. We hope this report will help policy makers, business leaders, academics and others to make more fully-informed, fact-based decisions.

Our research has been greatly strengthened by contributions from many outside experts and organizations (they might not necessarily endorse all aspects of the report). We would like to thank our sponsor organizations for supporting us with their expertise as well as financially: ClimateWorks, Vanke Group, and Shanghai Electric Corporation. We would also like to thank Dr. Jiang Kejun and his team from the Energy Research Institute of the NDRC for their close collaboration throughout the process to assist in the validation of our methodology and data. We also acknowledge the invaluable advice provided by Professor He Jiankun (Tsinghua University), Professor Zou Ji (Renmin University of China), Professor Lin Erda (China Academy of Agricultural Science), Professor Jiang Yi (Tsinghua University), and Professor Qi Ye (Tsinghua University; The Energy Foundation). Finally we would like to thank our many colleagues within McKinsey who have helped us with advice and support.

Jonathan Woetzel
Director

Martin Joerss
Principal

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Summary of findings

China has made enormous strides in the three decades since launching its program of economic reform. Rapid economic growth and massive urbanization, however, have placed enormous strains on energy resources as well as on the environment.

Over the next several decades, as urbanization and economic development continue, China will need to ensure that it has the energy resources it needs to fuel this growth, while mitigating the impact on the environment and contributing positively to the global effort to combat climate change.

Like many other countries, China faces the challenge of finding solutions that adequately address these issues without compromising its economic development goals and the living standards of its people. The sheer enormity of the population and the scale of its economy, however, place China in a uniquely challenging position. Indeed, China's policymakers have declared these challenges as a top priority. In recent years, China has installed an extensive body of regulations and policies aimed at improving energy efficiency. These, coupled with continuous advances in technology and actions by industry leaders, are expected to yield substantial improvements to China's energy efficiency and a significant reduction in greenhouse gases (GHG).[1] The estimates of energy efficiency improvement and GHG abatement potential from these policies and initiatives comprise the "baseline scenario" in this report.

Our baseline scenario estimates show that, for every five-year period over the next 20 years, China could achieve a 17 to 18 percent reduction in energy intensity per unit of GDP. While this represents a substantial improvement in energy efficiency over today, even if China manages to achieve these improvements, it is still expected to consume 4.4 billion tons of coal and 900 million tons of crude oil by 2030. Satisfying demand for these critical commodities could push China to rely on imports for as much as 10 to 20 percent and almost 80 percent of its coal and oil requirements, respectively.

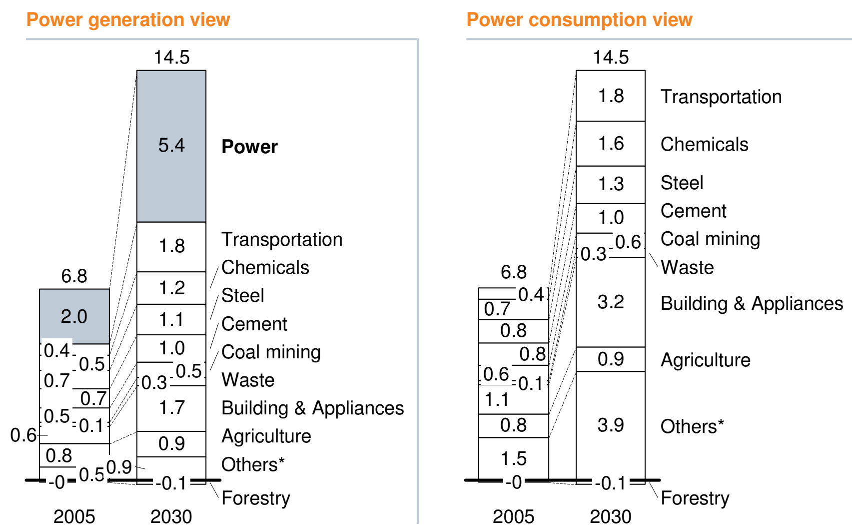
In addition, estimates in the baseline scenario show that China could emit up to 15 gigatons of CO_2e by 2030. (Exhibit 1)

1 We measure GHG abatement in tons of CO_2e, and measure the cost of reducing GHG emissions in euros per ton of CO_2e. We use CO_2e as a common metric to measure the intensity of the greenhouse effect of a variety of greenhouse gases other than carbon dioxide, such as methane and nitrous oxide.

Exhibit 1

BASELINE EMISSIONS SPLIT BY SECTOR IN 2005 AND 2030

Gigatons CO_2e per year



Note: Generation view shows direct emissions from each sector; consumption view shows both direct and indirect

* Including emissions from other manufacturing industries, construction industry, other mining industries, non-road transportation, and agriculture energy consumptions; including auxiliary power consumption from the power sec

Source: China Energy Statistical Year Book; expert interview; McKinsey analysis

The purpose of our analysis was to identify technologies that could enable China to make step-change improvements in energy efficiency and GHG abatement above and beyond the baseline scenario. All of the technologies that we studied are technically feasible and likely to be commercially available by no later than 2030. We explicitly excluded those technologies, such as hydrogen fuel cells, that have not yet been fully developed technically or commercially.

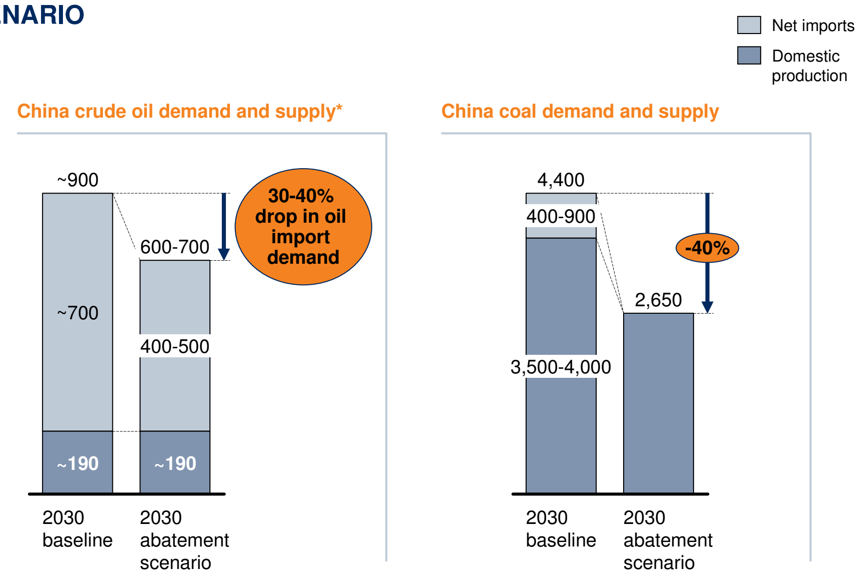
Many of the technologies we studied have not been deployed widely because of the high level of upfront investment, a lack of understanding regarding their potential efficacy, a lack of experience in deploying them, and shortages of technical and managerial talent necessary to implement them, among other barriers.

This report highlights the additional potential for China to substantially improve energy efficiency and reduce GHG emissions beyond the levels that we forecasted in the baseline scenario. The methodology we employed is consistent with similar research that McKinsey has conducted in several other countries over the past 1–2 years. In this report, we refer to this substantial improvement potential as the “abatement scenario.”

By fully deploying the technologies we studied in the abatement scenario, China could reduce its need for imported oil by up to 30 to 40 percent by 2030 over the baseline scenario. China could also stabilize coal demand at current levels, substantially reducing the proportion of coal in its overall power supply mix to as low as 34 percent by 2030, down from over 80 percent today. (Exhibit 2)

Exhibit 2

CHINA OIL AND COAL DEMAND AND SUPPLY IN THE ABATEMENT SCENARIO



* 2030 production is based on demand forecast of gasoline, diesel and other oil products

Source: EIA; IEA; expert interviews; McKinsey analysis

In addition to achieving substantially greater energy security, realizing the maximum potential of all the technologies we studied could help China hold its greenhouse gas (GHG) emissions to roughly 8 gigatons of CO_2e by 2030, a level that is roughly 10 percent higher than it was in 2005. This would represent a nearly 50 percent decrease in emissions in 2030 compared to our baseline scenario. (Exhibit 3)

Achieving the substantial improvements outlined in our abatement scenario will require considerable investment. We estimate that China will need up to 150-200 billion euros on average each year in incremental capital investment over the next 20 years. According to our analysis, approximately one-third of these investments will have positive economic returns; one-third will have a slight to moderate economic cost, and an additional one-third of the technologies will have a substantial economic cost associated with them. (Exhibit 4)

In addition to economic costs, several barriers stand in the way of the adoption of most of these technologies, including social costs such as employment dislocation associated with the implementation of new technologies, government administration costs, and information and transaction costs. All of these will limit the ability of China to realize the full potential of these technologies.

Exhibit 3
KEY FINDINGS BY SECTOR – 2030

Indirect (power generation) emissions
Abatement due to power demand reduction or cleaner electricity

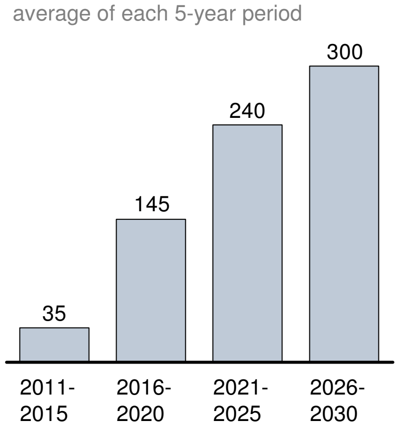
	Baseline emissions $GtCO_2e$	Abatement potential $GtCO_2e$	Abatement scenario emissions $GtCO_2e$	Incremental investment Annual average, billion EUR, 2010-2030	Key abatement options
Power	5.4	2.8 / 3.8	1.6	~50	• Nuclear and renewables • IGCC and CCS
Emissions intensive industries	4.1 / 4.8	1.6 / 2.1	2.5 / 2.7	~15	• Energy efficiency improvement • Waste recovery
Buildings & appliances	1.7 / 3.2	1.1 / 1.6	1.2 / 1.6	~50	• Enhanced building insulation • Efficient HVAC system and lighting
Road transportation	1.8	0.6	1.2	~70	• Advanced ICE efficiency improvement • Electric vehicle
Agriculture & forestry	0.8	0.6	0.1	~0	• Forestation and reforestation • Grassland management
Others	0.9 / 3.9	0 / 1.7	0.9 / 2.2	N/A	• N/A
Total	14.5	6.7	7.8	150-200	

Note: Numbers do not add up exactly due to rounding
Sources: McKinsey analysis

Exhibit 4
INCREMENTAL CAPITAL INVESTMENT NEEDED FOR IMPLEMENTING ABATEMENT OPTIONS IN 2010-2030 PERIOD

Incremental capital needed to capture the technical potential

Real 2005 EUR billions, annual average of each 5-year period



Key findings

- **Capital requirements increase over time mainly driven by**
  - Higher implementation shares of abatement levers over time
  - Implementation of high cost technologies such as CCS
- **Incremental capital investment needed is up to EUR 150-200 billion on average each year over the 2010-2030 period**
- **Capital investment needed in the year of 2030 represents 1.5-2.5% of forecast China GDP in that year**
- **Capital investment cash needs will be to a great extent offset by energy savings**

Source: McKinsey analysis

The window of opportunity for capturing the full potential of these technologies is limited. This problem is particularly acute in the building, industry and power generation sectors. Over the next 5 to 10 years, China will continue to rapidly add to its stock of commercial and residential buildings, expand industrial capacity, and construct new power plants. Given the expense and difficulty of retrofitting existing buildings and plants, most of the energy efficiency and GHG abatement gains depend on building it right the first time. We estimate that just a 5-year delay in starting to implement the abatement technologies we describe in our study would result in a loss of as much as one-third of the total abatement potential by 2030. If China waited 10 years before beginning to implement these technologies, it could lose up to 60 percent of the total abatement potential by 2030.

Making the leap from the baseline scenario to the abatement scenario will require no less than a “green revolution.” From our analysis, we identified 6 major categories of energy efficiency and greenhouse gas abatement opportunities between now and 2030, opportunities that would put China on a path toward achieving this “revolution”: the replacement of coal with clean energy sources; comprehensively adopting electric vehicles; improving waste management in high-emission industries; designing energy efficient buildings; restoring China’s carbon sink (forestry and agriculture), and rethinking urban design and adjusting consumer behavior.

1. “GREEN POWER” – REPLACING COAL WITH CLEAN ENERGY SOURCES

With concerted action by the government and industry in the investment and deployment of clean energy technologies, China can substantially reduce its reliance on highly-polluting coal for power generation.

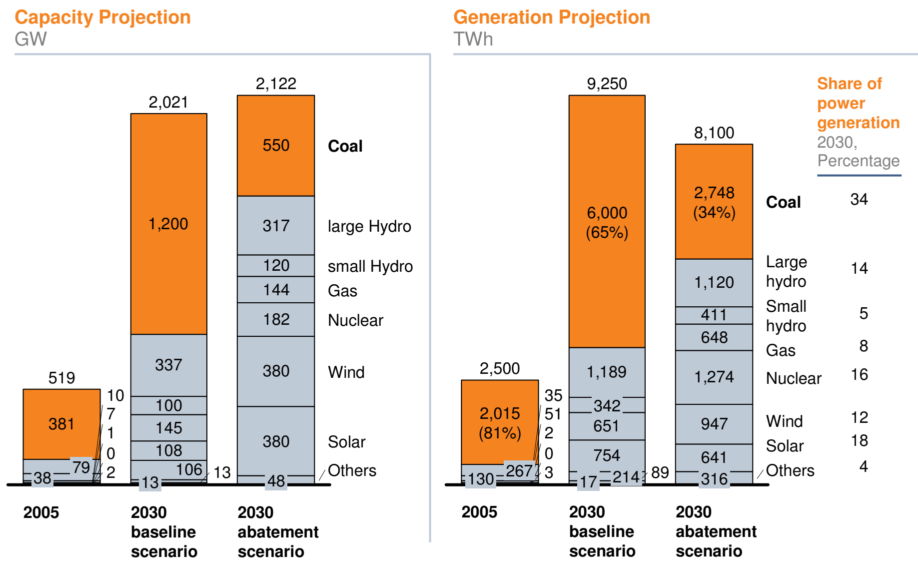
As manufacturers ramp up production and lower manufacturing costs through process and technological innovations, the cost of clean energy technologies such as wind, solar and nuclear will come down to a level that will make them attractive alternatives to coal.

Our analysis shows that if China were to comprehensively deploy these technologies, the share of coal as a percentage of China’s total power generation could drop substantially, from 81 percent today to 34 percent by 2030. By 2030, China’s coal demand could stabilize at about 2.6 billion tons, the amount it consumed in 2007. The reduction in coal supply would be met by a range of clean energy sources: solar could rise from just over 0 percent today to 8 percent in 2030; wind power could increase from just over 0 percent to 12 percent; nuclear will rise from 2 to 16 percent; hydropower will increase slightly, from 16 to 19 percent; and natural gas will rise from 1 to 8 percent. (Exhibit 5)

We estimate that in addition to a 1 Gt reduction coming from falling demand for power in end-user sectors such as buildings and industry, the GHG abatement potential in this sector is 2.8 Gt of CO_2e by 2030. These combined can lead to a reduction of coal consumption by 1.2 billion tons, or 27 percent of baseline coal demand.

Exhibit 5

CHINA POWER MIX



* Including geothermal, CBM, MSW, LFG and biomass

Source: Expert interviews; literature research; McKinsey analysis

Due to the capital intensive nature of this sector, the incremental investment needed to achieve the full potential in efficiency improvements and GHG abatement would reach roughly 50 billion euros on average each year. Due to the reliance on expensive technologies such as renewable energy technologies and CCS, this sector has one of the highest average costs, in the range of 30 to 40 euros per ton of CO_2e.

Achieving this vision would have significant, positive "knock-on effects" for other aspects of China's energy strategy. For instance, as China gradually shifts to cleaner sources of energy to power its electricity grid, the rationale for accelerating the movement toward a broad-based roll-out of electric vehicles gets stronger. On top of the positive environmental impact of a shift to electric vehicles, China will substantially reduce its reliance on imported oil to power its rapidly-expanding transportation fleet.

In addition to replacing coal with sources of renewable energy, deploying clean coal technologies can be another source of GHG abatement. Although their technical and economic feasibility is not yet completely proven, emerging technologies such as integrated gasification combined cycle (IGCC) and carbon capture and storage (CCS) have made noticeable progress in recent years.

2. "GREEN FLEET" – COMPREHENSIVELY ADOPTING ELECTRIC VEHICLES

Although transportation is not a big source of China's GHG emissions yet, this is about to change. By 2025, China is expected to replace the US as host to the world's largest auto fleet. By 2030, over 330 million vehicles will ply China's roads. China will therefore need a strategy to avoid the path to oil dependence that developed markets have followed.

Internal combustion engine (ICE) vehicles that have undergone significant technological improvement are still more affordable than electric vehicles. However, even with all possible cost-effective efficiency gains to ICE technology by 2030, which will cut today's average passenger car fuel requirement by 40 percent, we estimate that China would still have to rely on imports for 75 percent of its oil demand, assuming a continued reliance on ICE vehicles.

If, however, China were to begin to widely adopt electric vehicles starting in 2015, ramping up adoption to 100 percent of China's new vehicle fleet by 2020, our analysis shows that it could reduce its demand for imported oil by an additional 20 to 30 percent from what would be needed to support high-efficiency ICE vehicles. By leveraging its large supply of low-cost labor, fast-growing domestic market, proven success in rechargeable battery technology, and with substantial investments in R&D, China has the potential to emerge as a global leader in electric vehicle technology.

In addition, bio-ethanol will play a substantially smaller role as a future source of energy for China's transportation fleet. The bio-mass raw materials that would otherwise be used to make bio-ethanol could be allocated primarily to more economically feasible industrial uses.

Vehicle exhaust is the major source of urban air pollution in China today. By widely adopting electric vehicles, China could substantially improve the quality of air in its cities, resolving one of the most vexing environmental and public health issues facing China today.

However, electric vehicles still face a number of barriers. Until further technological breakthroughs are realized, the performance of electric vehicles will continue to lag behind ICE vehicles. Putting a battery recharging infrastructure in place will pose an additional challenge. Ultimately, cost will remain one of the biggest obstacles. By 2030, we expect an electric vehicle will cost 1000-3000 euros more than an advanced ICE car. If China were to extensively roll-out electric vehicles starting from 2016 through to 2030, this would require incremental capital investment of over 70 billion euros on average each year.

3. "GREEN INDUSTRY" – MANAGING WASTE IN HIGH-EMISSION INDUSTRIES

China's emissions-intensive industry (EII) sector – which in this report includes steel, chemicals, cement, coal mining and waste management – plays a crucial role in China's sustainable development. It represented about one-third of China's total energy consumption and 44 percent of China's total annual emissions in 2005. It is also one of the major sources of air and water pollution in China.

Our analysis identifies abatement opportunities in the sector to reduce emissions below our baseline scenario. The total maximum abatement potential is 1.6 Gt of CO_2e by 2030. Our research shows, that after actively improving energy efficiency in the baseline, recovery and reuse of by-products and waste will become the crucial driver of additional abatement potential beyond the baseline scenario.

China produces a lot of industrial and municipal waste that it currently does not recycle or does not manage properly. New technologies allow China to adopt innovative approaches to destroying waste or increasing the amount of waste that is converted into useful material. For example, blast furnace slag left over from steel production, and fly ash from the burning of coal during power production, are both currently being used as a substitute for clinker (the primary material in cement) in China. However, technological advancements may allow for a much higher rate of substitution.

Another example is the recovery of coal-bed methane, which could be used as a substitute for natural gas or as a source of energy in power generation. Coal-bed methane recovery could also substantially reduce both GHG emissions as well as reduce the casualties from gas explosions in mines.

China also has the opportunity to substantially reduce municipal solid waste landfill. Our analysis shows that with the adoption of technologies that burn waste to generate power, China could reduce its waste on a per unit volume basis to just 5 percent of the space that it currently requires. In addition, by employing these technologies, China could substantially reduce the pollutants such as methane that are generated from landfill.

The abatement potential of waste recovery is 835 million tons of CO_2e, accounting for more than 50 percent of the potential in the EII sector.

At the same time, improving energy efficiency still remains important for industries such as steel and chemicals. The total GHG abatement potential of energy efficiency improvements across the EII sector, beyond the baseline reductions, is 390 million tons of CO_2e, These improvements would also reduce energy consumption by up to 200 million tons of standard coal equivalent. Lastly, industrial CCS and other measures will cut another 340 million tons of CO_2e.

Incremental capital investment required to achieve these improvements would reach approximately 15 billion euros each year on average. While this is considerably less than the total capital investment required in other sectors, many of the technologies, such as waste recovery, will have higher ongoing operating costs.

4. "GREEN BUILDINGS" – DESIGNING ENERGY EFFICIENT BUILDINGS

As a result of rapid urbanization, China has undergone one of the biggest building booms in the history of mankind in the past decade. Going forward, as hundreds of millions more migrants move into China's cities, new apartments, office buildings, and commercial centers will be needed to accommodate them. As living standards rise, consumers will demand larger living and working spaces. As a result, per capita floor space is expected to double from 2005 to 2030, stoking consumer demand for energy.

By introducing energy-efficient designs in newly-constructed buildings, retrofitting existing buildings with customized technologies, installing energy-efficient lighting and appliances, and upgrading heating, ventilation and air-conditioning (HVAC) systems, Chinese consumers could enjoy higher living standards while consuming the same levels of energy per square meter as they do today.

One of the biggest areas of improvement will come from better insulation in walls, windows and roofs. This can be accomplished by complying with building codes, implementing passive design concepts, or retrofitting existing buildings. China mandates certain levels of energy efficiency in new buildings. However, by managing passive design elements in new buildings, China could achieve even greater energy savings than simply complying with building codes, and at approximately the same cost. For example, by orienting the position of buildings in a way that manages the absorption and deflection of sunshine, employing natural shading and ventilation devices, and sizing windows and doors appropriately, buildings can be naturally warmed or cooled while using less energy.

Retrofitting existing buildings with customized, economic insulation solutions that rely less on energy-consuming technologies is another important source of energy efficiency gains.

Because they consume much more energy, residential buildings in northern regions, and commercial buildings throughout the country, should be the focus of China's efforts for all of these insulation technologies.

In addition to building design, our analysis shows that lighting and appliances can provide additional savings in energy consumption. By switching from incandescent light bulbs to compact fluorescent lighting (CFL), and then eventually to LED lighting, China could save 190 billion kilowatt hours of electricity, or 2 percent of total expected power demand in 2030. The cost of an LED light bulb is expected to drop to 3-4 euros by 2015 as the technology is more widely commercialized.

HVAC system optimization can prove to be another source of higher energy efficiency. Examples of technologies include expanding the deployment of district heating, using better heating controls in district heating systems and household thermostats, and upgrading the building automation systems installed in today's commercial buildings.

This sector represents the best economics among all sectors. According to our analysis, the technologies responsible for generating about 70 percent of total abatement potential would have positive economic returns. While up to 50 billion euros each year on average will be required to make buildings "green", for most of the technologies that we studied, the savings they would generate from reduced energy consumption would more than offset the upfront investment.

5."GREEN ECOSYSTEM" – RESTORING AND PRESERVING CHINA'S CARBON SINK

China faces a delicate balancing act when it comes to managing its land resources. It needs to allocate enough arable land to agricultural production to ensure food security. At the same time, it is seeking to substantially increase forest coverage and preserve grasslands to maintain ecosystem sustainability. China has expanded its forest area from 14 percent of total land in 1993 to over 18 percent in 2005, and intends to increase forest coverage to 26 percent of total land area by 2050. These competing forces will be working against the backdrop of urbanization, which will only put further pressure on the supply of China's land resources.

By proactively preventing deforestation, reforesting marginal areas of land, recovering grasslands, and changing agricultural practices, China can substantially increase the level of natural carbon sequestration. This is a major abatement opportunity.

At about 10–20 euros per ton of CO_2e abated, the average cost of this sector falls into the medium range of all sectors. Because of the complexity involved in managing agriculture and forestry, much uncertainty surrounds the cost estimates in this sector. However, much of the benefits of ecosystem preservation, such as cleaner air, land and water, cannot be measured in monetary terms alone.

6. "GREEN MINDSET" – RETHINKING URBAN DESIGN AND CONSUMER BEHAVIOR

While most of the opportunities mentioned above will require the deployment of technologies, by rethinking approaches to urban planning and through encouraging a handful of small behavioral changes among consumers, China could reap additional savings in energy consumption and an additional almost 10 percent abatement in GHG.

Planning for denser urban areas calls for more high-rise buildings, which are generally 10 to 15 percent more energy efficient than their low-rise counterparts. In addition, denser cities could also cut private car use in favor of public transportation systems (as has been the case in Tokyo and Hong Kong). We estimate the abatement potential of increased urban density is about 300 million tons of CO_2e.

Through a combination of government policies, incentives, and public education, China could influence consumer behavior to encourage more efficient uses of energy. For instance, through such simple measures as adjusting room thermostats, buying more fuel-efficient cars, using mass transportation, and by adopting car pooling, consumers can individually and collectively reduce the energy they consume. They could also deliver a potential 400 million tons of GHG abatement.

While some investment will be required to initiate a number of these efforts, in general, the on-going investment and operating cost to deliver these reductions will be minimal, and will not require that consumers sacrifice their living standards.

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We discuss the principal findings of our analysis of energy and environmental sustainability in China in the following five chapters:

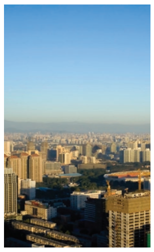
1. Scope and methodology

2. The rising challenge of sustainability

3. Overview of China's sustainability improvement opportunities

4. Five clusters of sustainability improvement potential

5. Areas of further research



Scope and methodology

Over the past year, McKinsey & Company has led a study to understand the costs of various (mostly technological) options for achieving energy and environmental sustainability in China. This is an important part of our firm's global research effort into topics related to sustainable development. The primary goal of this study is to create a consistent, detailed fact base to inform and support economically sensible strategies that will foster energy and environmental sustainability in China.

Sustainability is an extensive topic. Our study reflects the specific situation of China as the world's largest developing country, currently undergoing industrialization and urbanization at an unprecedented rate. It also reflects the Chinese government's agenda to conserve energy and cut greenhouse gas (GHG) emissions. Hence, in our report, we consider four major areas under the umbrella of sustainability:

- Enhancing energy security
- Reducing greenhouse gas emissions
- Curbing local pollution
- Conserving the (land) ecological system.

With regard to pollution control and ecological conservation, our report focuses on active prevention measures. These include, avoiding the generation of pollutants, recycling waste, and expanding and improving habitats of eco-systems (forests and grasslands). These activities normally are closely linked to energy and carbon. On the other hand, we did not examine "downstream" environmental interventions that control pollutants after they are generated (e.g., industrial wastewater processing, vehicle-exhaust-gas purification) or optimize eco-diversity (e.g., endangered-species protection programs). Although important, such measures are not in the scope of our report.

The core of our work is an analysis of the potential and the costs of over 200 technologies/ techniques to improve energy and environmental sustainability. We selected those technologies with the highest likely impact in China. However, quantifying the potential and the costs of the technologies is a complex task. It involves, for example, reconciling very different units of measurement. To reduce the complexity to a manageable level and develop a consistent view, we adopted GHG emission reduction (abatement) as a proxy for improving energy and environmental sustainability, measuring GHG abatement in tons of CO_2e and the cost of reducing GHG emissions in euros (€) per ton of CO_2e.

Using figures for GHG emissions also ensures a more complete picture thanks to the wide availability of reliable data. Moreover, GHG emissions correlate closely with key elements of energy and environmental sustainability. For instance, a cut in China's GHG emissions by reducing its consumption of coal and (imported) oil would improve the country's energy efficiency and energy security. By decreasing the emissions from coal-fired power generation and heating or from motor vehicles, China would improve local environmental conditions (e.g., lower air pollution). Other GHG emission reduction measures, such as an extension of forest coverage or the preservation of arable land and grassland, could also have a positive impact on the environment (e.g., ecosystem conservation).

Our report therefore structures and focuses the discussion and quantitative analyses around GHG emission abatement. We evaluate each technology / technique in terms of its abatement potential (i.e., how many tons of CO_2e emissions it can cut) and abatement cost (i.e., how much it costs for every ton of CO2e it reduces). We also consider the impact of the abatement options on energy, pollution and eco-system, particularly when the CO_2e abatement potential/cost alone does not provide the whole picture.

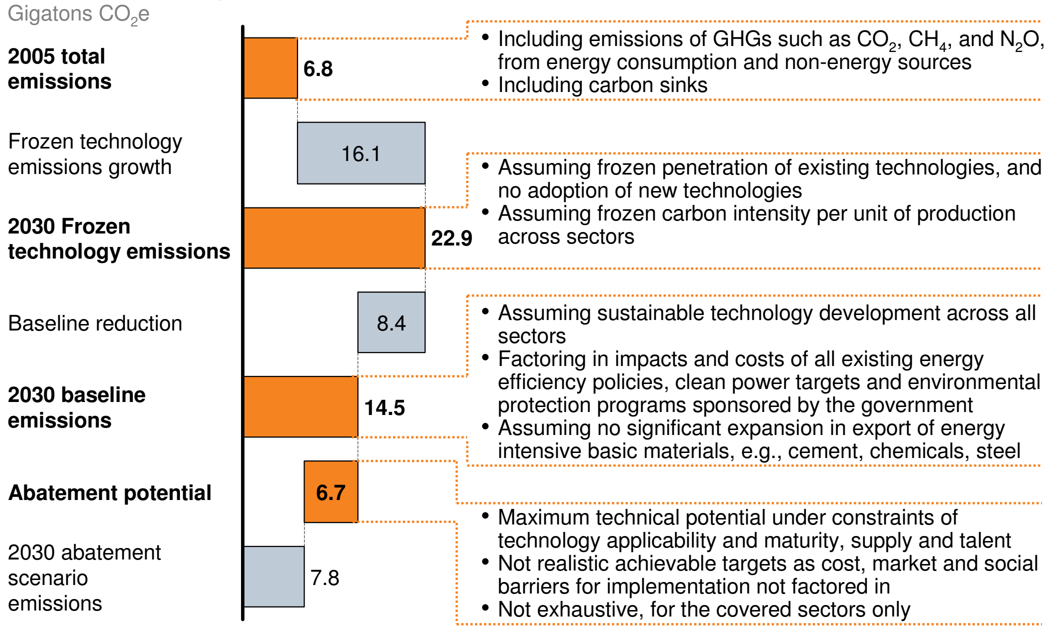
To estimate the potential and the costs of the various abatement options to reduce or prevent GHG emissions, we defined and quantified three development scenarios for China from 2005 to 2030: a "frozen technology" scenario, a "baseline" scenario, and an "abatement" scenario (Exhibit 1).

Exhibit 1

DEFINITION OF THE FROZEN TECHNOLOGY, BASELINE, AND ABATEMENT SCENARIO

Definition and description

Gigatons CO_2e



Source: McKinsey analysis

Our *frozen technology* scenario assumes that China adopts no new GHG-reducing technologies between 2005 and 2030. We also assume existing technologies are not further deployed and remain at their 2005 penetration levels. Hence, China's carbon intensity (i.e., carbon emissions per unit of production) would remain at 2005 levels for all industries. We then calculated the expected growth in production volumes of each industry to reflect the growth of and the structural changes in China's economy.

Our 2005–2030 *baseline* scenario builds on McKinsey's extensive study of a range of Chinese industries and the research findings of leading China institutes and experts. The baseline scenario is a bottom-up analysis of GHG emissions and absorption across ten industries: residential and commercial buildings (including appliances), road transportation[1], steel, cement, chemicals, coal mining, waste management, power generation, forestry, and agriculture. The baseline scenario assumes sustainable technological development across all these industries. We include a broad range of mature, proven technologies in the baseline scenario. This reflects the belief that China will steadily increase its products' quality and the efficiency of its industrial processes in the coming two to three decades. We also factored in the costs and benefits of all known, existing energy-efficiency improvement policies and clean power targets sponsored by the Chinese government. At the same time, we assume that China does not significantly expand the export of any energy-intensive basic materials, such as, steel, cement, and chemicals (Exhibit 2).

Exhibit 2

TECHNOLOGIES IN THE BASELINE SCENARIO VS. THOSE IN THE ABATEMENT SCENARIO

	Major technologies in baseline	Major technologies in abatement
 Power	• Super- and ultra super-critical • Hydro and natural gas power • Nuclear • Wind: onshore	• More nuclear • Wind: offshore and more onshore • Solar power • IGCC and CCS • Bio power: switch grass
 Road Transportation	• Conventional fuel efficiency marginal improvement measures	• Advanced ICE fuel efficiency improvement measures • Hybrid and pure electric vehicles • LC ethanol
 Emissions intensive industries	• Steel: BOF to EAF shift; better utilization of BF gas; APC • Chemicals: advanced motors; CHP; APC • Cement: shift from shaft kiln to pre-calciner kiln; improving quality and performance • Coal mining: high concentration CBM utilization • Waste: MSW/LFG power generation	• Steel: CCPP, CMC, DRI in Australia • Chemicals: catalyst optimization; fluorocarbon destruction • Cement: maximization of clinker substitution; co-firing of biomass • Coal mining: oxidization of low concentration CBM • Waste: MSW power generation
 Buildings and appliances	• Current efficiency building codes • CHP for district heating • CFLs • Efficient appliances	• Passive design with higher building energy savings • Heating controls • LEDs
 Agriculture and forestry	• Conservatory tillage • Grassland management • Forestation • Nutrient management	• More grassland management • More forestation • Livestock management • More nutrient management

Source: McKinsey analysis

1 Including emissions from the combustion of oil products in internal combustion engines of road vehicles across all industries, but excluding other energy consumption normally covered in the transportation sector by Chinese statistics. Aviation, rail and sea transport are not included.

The realization of the baseline scenario is no easy matter; it will depend on a concerted effort from the government and the private sector. In particular, given the nature of social benefits and the externalities of many abatement technologies, China will need to streamline market incentive systems, create consistent regulations and policies, and ensure their enforcement. In the private sector, on the other hand, progress often depends more on overcoming management issues than on technology.

The difference between the frozen technology and the baseline scenarios represents the reduction in greenhouse gases "embedded" in the current trends in regulation and market forces. The 2030 baseline GHG emissions figure shows the substantial impact of technologies and initiatives compared to our frozen technology scenario.

Nevertheless, we recognize that a further reduction in GHG emissions is possible. Our *abatement* scenario reflects this. It estimates the potential and the cost of more than 200 technologies/techniques to reduce or prevent GHG emissions beyond the baseline scenario estimates. The abatement options include improving energy efficiency, the destruction of non-carbon GHG (e.g., fluorocarbons) and carbon capture and storage, investing in clean energy and expanding carbon sinks. Our 2005–2030 abatement scenario does not assume any major technological breakthroughs. We focus on abatement measures that are already well understood and likely to be commercially available in the future. Furthermore, we took into account the likely evolution of living standards and consumer preferences as income levels rise, and did not factor in potentially disruptive changes due to concerns about climate change or fuel price changes.

For each abatement option, we attempted to estimate its technical potential to reduce emissions below the baseline scenario figure by 2030, given optimal government support, the applicability and maturity of the technology, and supply and talent constraints. We then calculated the incremental resource costs compared with the baseline technological solutions by applying the formula:

$$\text{Abatement cost} = \frac{[\text{Full cost of abatement option}] - [\text{Full cost of baseline option}]}{[CO_2e \text{ emissions from baseline solution}] - [CO_2e \text{ emissions from abatement option}]}$$

We quantified the potential and the cost of each option in five clusters: power, road transportation, emissions-intensive industries (including steel, basic chemicals, cement, coal mining and waste), residential and commercial buildings (including appliances), and agriculture and forestry. The team conducted more than 100 interviews and working sessions with industry experts, McKinsey's own global network of internal experts, and other leading thinkers to test and refine its work.

For each sector, we arrayed the abatement options from lowest to highest cost and constructed the sector abatement curve. We present each industry's abatement curve in an integrated fashion to eliminate any double counting. The industry abatement curves plot the estimated maximum technical abatement potential of each option and the realistic resource costs of implementing them. As such, each abatement curve is an analytical tool that provides fact-based support to prioritize the various abatement techniques in an industry.

Throughout our report, we refer to costs on a “societal basis.” We analyzed the net resource costs of an abatement option by examining its incremental initial investments, operating and maintenance costs, replacement costs and avoided costs relating to energy efficiency or other benefits. We applied a four-percent discount rate to account for the difference in time between the initial investment and the resulting savings. If we looked at costs from a “decision-maker’s perspective,” we would need to apply a higher discount rate. Naturally, this would increase our estimates of the costs of most of the abatement options, particularly those with high upfront capital investment needs.

Our analysis was constrained in several important aspects. Specifically:

- We focused on the emissions produced and the energy consumed by human activity within the borders of China and did not attempt an analysis of the impact of “imported” or “exported” GHG/energy
- We did not attempt to model the impact of the abatement options on energy prices and consumer behavior
- We analyzed technologies with predictable cost and development paths by sorting “credible” technological options from “speculative” ones. We based our decisions on evidence of maturity, commercial potential, and the presence of compelling forces at work in the marketplace:
  - — Most of the technologies (i.e., accounting for roughly 80 percent of the abatement potential we identified) are already working at a commercial scale. Any uncertainty associated with them primarily relates to issues of execution
  - — We examined a number of high-potential emerging technologies (e.g., carbon capture and storage, cellulosic biofuels, ICE fuel-efficiency improvement measures, plug-in hybrid vehicles, and light-emitting diode lights). They amount to some 20 percent of the total abatement potential. The consensus among experts is that these technologies are likely to reach a commercial scale by 2030
  - — Beyond this, we were conservative in our assessment of future technologies. It is likely that important breakthroughs in processes and technology will happen in the next 20–25 years. It is also highly probable that a concerted effort to abate emissions and conserve energy would stimulate innovation, leading to new opportunities for low-cost CO_2e abatement. We do not attempt to model such “disruptive” technologies in our study.

Furthermore, we do not attempt in our report to quantify positive and negative externalities such as:

- The broader social costs or benefits associated with improving energy and environmental sustainability (e.g., the cost of adapting to or the benefits of avoiding the adverse consequences of climate change)
- The environmental and other benefits associated with the development of a more sustainable economy (e.g., reduced healthcare costs as a result of lower levels of local and regional air pollution, or improved safety in coal mines). Instead, we integrate such considerations qualitatively in our findings.
- The policy-dependent social, structural and transactional costs (beyond direct capital, operating and maintenance costs) associated with pursuing specific abatement options. We focus on "techno-engineering" or "resource" costs. We do not attempt to estimate welfare costs (e.g., because of structural unemployment) or regulatory/compliance costs.

We do not intend our findings in any way as a forecast or as a target for CO_2e emissions abatement. Our estimates are of the *maximum* technical abatement potential of each option, i.e., the upper limit of a possible range. In addition, several factors could limit the realization of the abatement potential. These include, among others, employment considerations, budget constraints, environmental concerns, and the prioritization of technologies for reasons other than cost and potential. Moreover, as mentioned above, our analysis of costs only considers resource costs.[2]

Our analysis does not attempt to address any broad policy questions with regard to the regulatory regimes or incentive structures the Chinese government might consider. McKinsey & Company explicitly does not endorse any specific legislative proposals, or any specific mechanisms to foster sustainable growth. The purpose of our study of energy and environmental sustainability in China is solely to provide data and analyses and not to present any opinions or advice on behalf of any party.

The aim of this report is to facilitate the definition and prioritization of economically sensible approaches to address the challenges that China faces with regard to energy and environmental sustainability. Our hope is that this report will help policy makers, business leaders, academics and other interested parties to make more fully informed decisions.

2 The cost of an abatement option reflects its resource (or techno-engineering) costs – i.e. capital, operating and maintenance costs – offset by any energy savings associated with abating 1 ton of CO_2e per year using this option, with the capital investment spread over the lifetime of the option using a 4-percent real discount rate. The cost is incremental to the technological solutions embedded in the baseline. We excluded social costs, transaction costs, communication/information costs, taxes, tariffs, and/or subsidies. We also have not assumed any "price for carbon" (e.g., a carbon cap or tax) that might emerge due to legislation or the impact on the economy of such a carbon price. Hence, the per-ton abatement cost does not necessarily reflect the total cost of implementing that option.

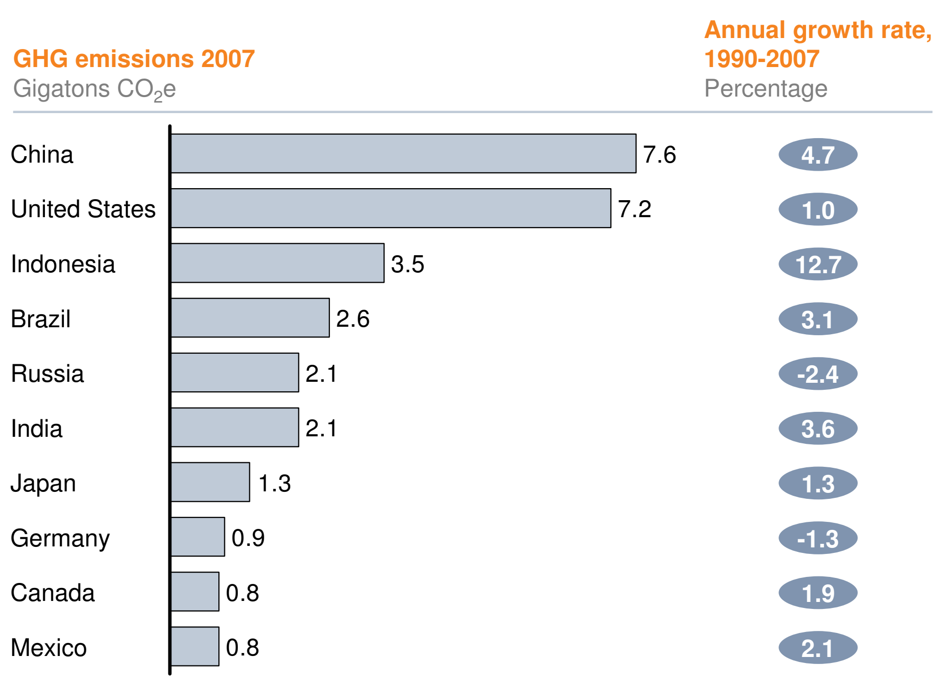
Chapter 1: The rising challenge of sustainability

China is home to a fifth of the world's population and, in 2007, consumed about 2.7 billion tons of standard coal equivalent (SCE) and emitted approximately 7.5 gigatons (Gt) of CO_2 equivalent (CO_2e). China has overtaken the US as the world's top emitter of greenhouse gases (Exhibit 1). Along with its substantial energy consumption and carbon emissions levels, local pollution in China is also increasing significantly. This is a direct result of the use of coal and other fossil fuels by industry and for power generation and heating, as well as vehicle exhaust gases and waste landfills. In the country's northern regions, desertification is threatening both arable land and grasslands. Across the country, water shortages are a growing problem. China faces serious challenges to its energy and environmental sustainability in the coming decades.

In this chapter, we examine energy and environmental sustainability in China. We also look at how the situation could develop according to our 2005–2030 baseline scenario. We use GHG emissions (tons of CO_2e) as our metric to enable a quantitative discussion. We complement this by considering energy supply and security, and other factors.

Exhibit 1

LEADING GHG EMITTERS IN THE WORLD – 2007

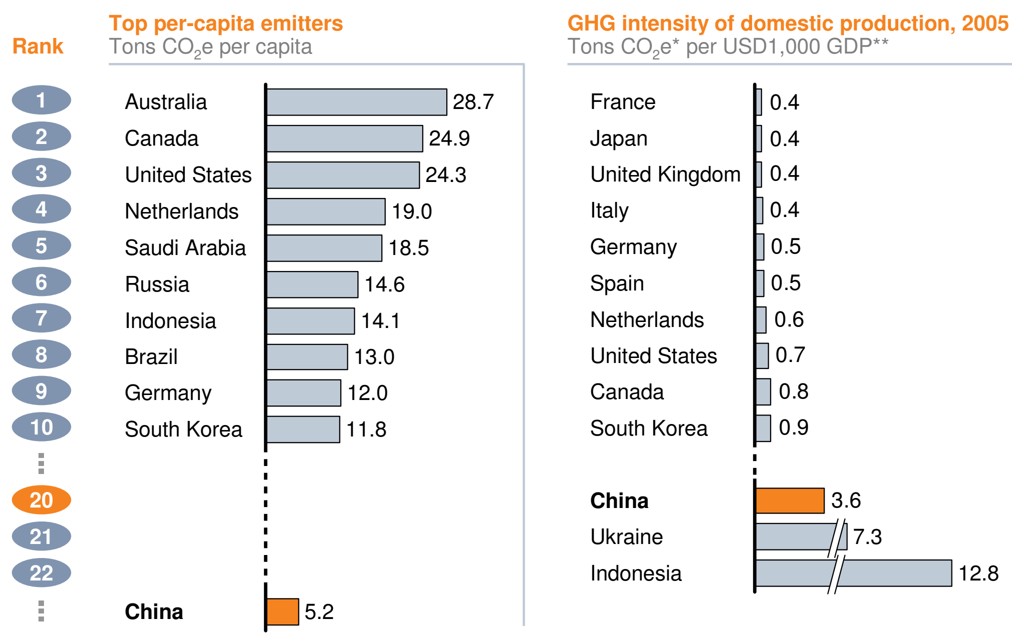


Source: IEA; EPA; WRI; UNFCCC; McKinsey analysis

China's per capita emission rate is low, owing to its large population. However, its carbon intensity (measured in tons of CO_2e per US$ 1,000 of GDP) is higher than in most developed countries as it is still in the earlier stages of economic development (Exhibit 2).

Exhibit 2

GHG EMISSIONS BY POPULATION AND GDP – 2005



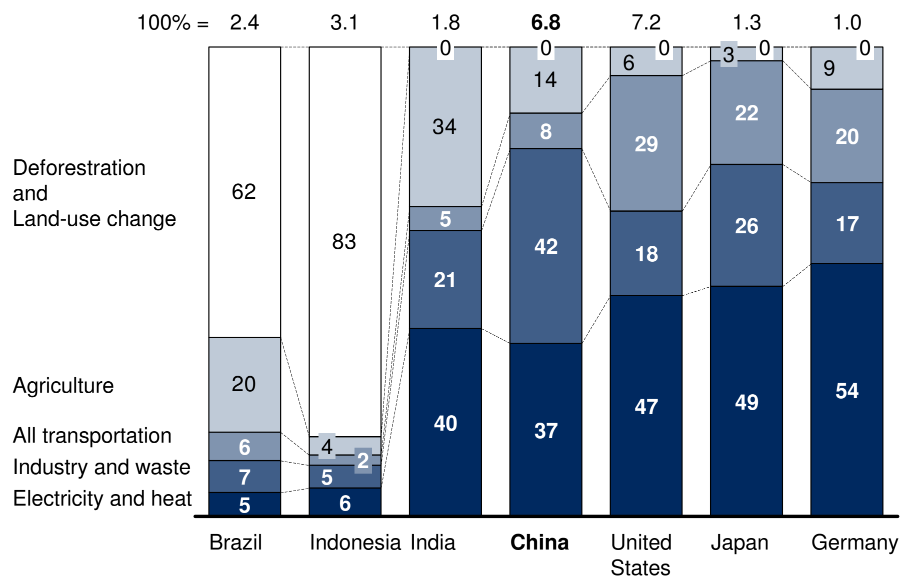
* Including emissions associated with deforestation and land-use changes
** Real USD in 2000
Source: UNFCCC; IEA; EPA; Global Insight; McKinsey analysis

China's status as a large developing country has left its mark on the country's emission profile (Exhibit 3). In many developing countries, the industrial sector is still relatively small, while many developed countries have a services-based economy. China, on the other hand, emits a greater portion of its GHGs from its industrial sector. This reflects the massive industrialization that China is undergoing, as well as the energy-intensive nature of recent economic development. Emissions due to power and heat supply (commercial and residential buildings consume most of the heat) are somewhat lower, but not far from the levels of developed countries. This is an indication of China's ongoing urbanization process and the corresponding change in living standards. Transport-related emissions are moderate and consistent with the current low penetration rate of motor vehicles (3 percent in 2005, compared to almost 60 percent in Japan and 80 percent in the US). As China develops, however, its emission profile will evolve accordingly.

Exhibit 3

GHG EMISSIONS PROFILES FOR SELECTED COUNTRIES – 2005*

Percentage, Gigatons CO_2e



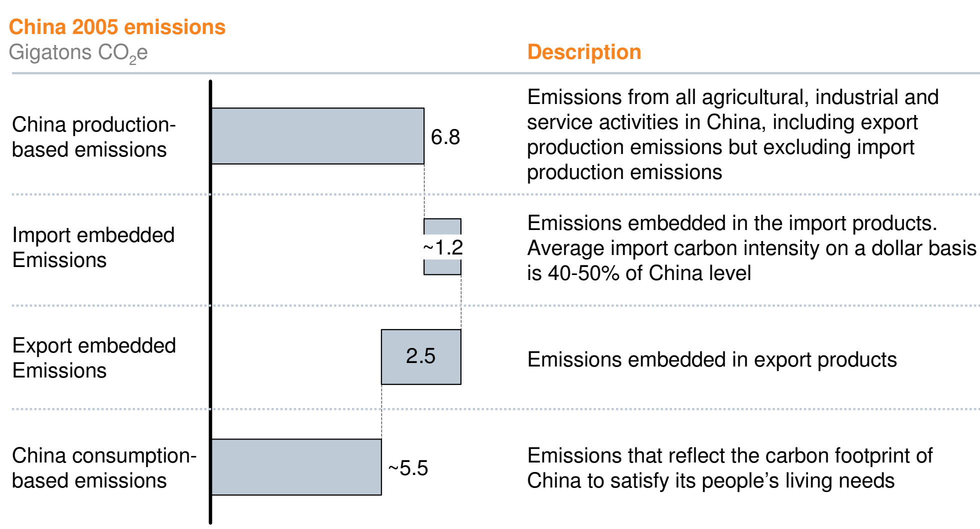
* Including emissions associated with deforestation and land-use change, excluding carbon sink

Source: UNFCCC; WRI; IEA; EPA; McKinsey analysis

Some 20 percent of China's GHG emissions occur in the production and transportation value-chain of net exported goods. Hence, consumption-based emissions were roughly 5.5 Gt of CO_2e in 2005 (Exhibit 4). The development of international trade is a key factor that will affect China's future emission levels.

Exhibit 4

PRODUCTION-BASED VS. CONSUMPTION-BASED EMISSIONS FOR CHINA – 2005



Source: Ye Qi "Accounting embodied carbon in import and export in China"; McKinsey analysis

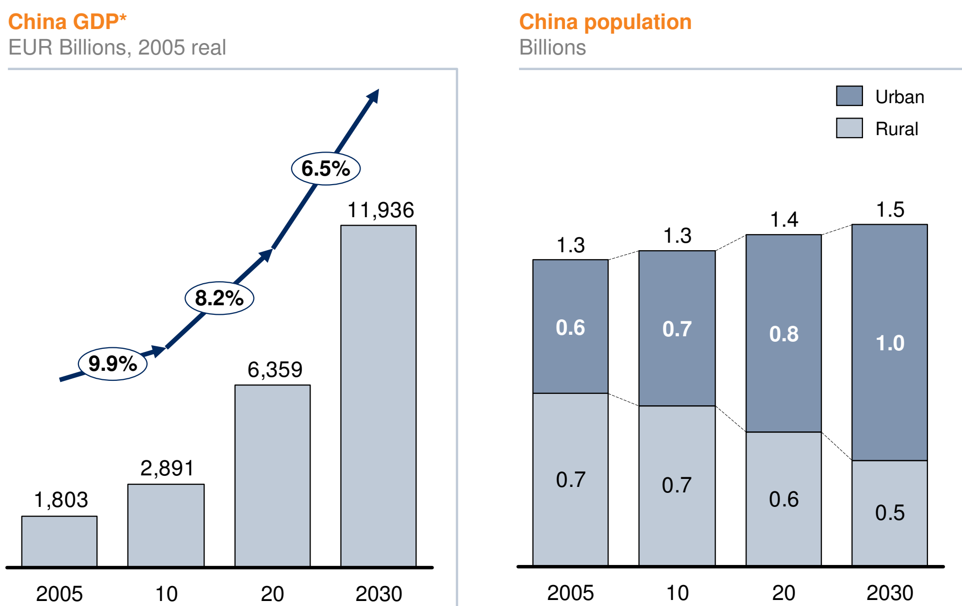
While GDP growth and urbanization will continue to drive up emissions, improving carbon efficiency, thanks to energy-efficiency improvements and other measures to reduce GHGs across different sectors, will slow down emissions growth.

DRIVERS OF RISING GHG EMISSIONS

The main drivers of growing GHG emissions in China are strong GDP growth and urbanization at an unprecedented scale (Exhibit 5).

Exhibit 5

CHINA GDP GROWTH AND URBANIZATION DEVELOPMENT



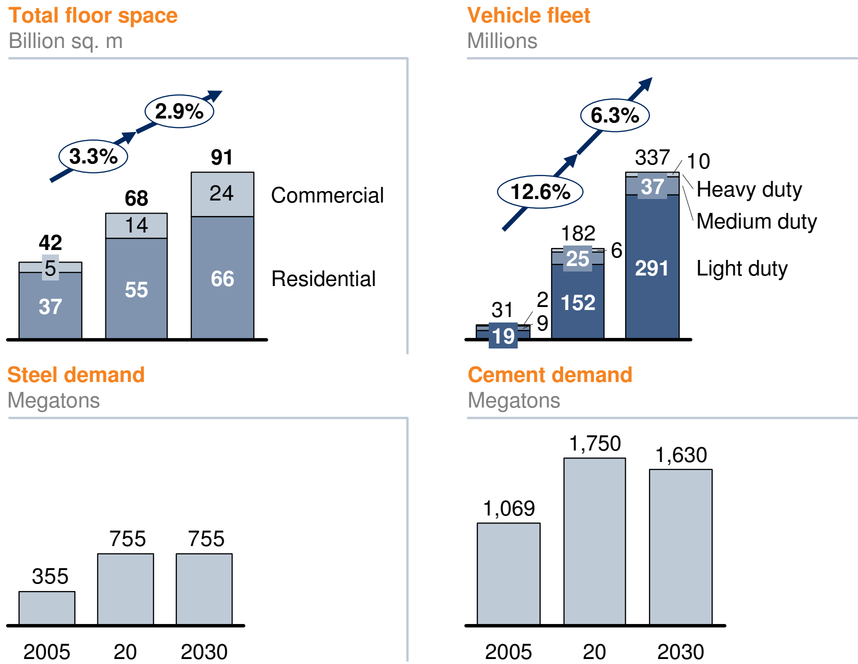
* Exchange rate in 2005 EUR1 = RMB10.1953

Source: expert interview; McKinsey analysis

Long-term projections estimate a 7.8 percent annual GDP growth rate for China. Sustainable investment, productivity gains, the development of a higher value-adding industrial sector, and the rise of the service sector are the locomotives of growth. The industrial sector will account for about 41 percent of total GDP in 2030 (down from 48 percent in 2005). This reflects an expected structural change in the country's economic development in line with the Chinese government's growth agenda. We expect the rapid urbanization process that China has experienced in the past decade to continue. By 2030, two-thirds of China's 1.5 billion people will live in urban areas. To cope with such a massive increase in its urban population, China plans to build 50,000 new high-rise residential buildings and 170 new mass-transit systems. (By comparison, Europe currently has just 70 such systems.) As the economy grows, urbanization progresses, and living standards evolve, carbon-related demand (e.g., commercial and residential space, vehicles and basic industrial materials) will rise (Exhibit 6).

Exhibit 6

DEMAND GROWTH IN BUILDING FLOOR SPACE, VEHICLES AND BASIC MATERIALS



Source: China industry year books; McKinsey analysis

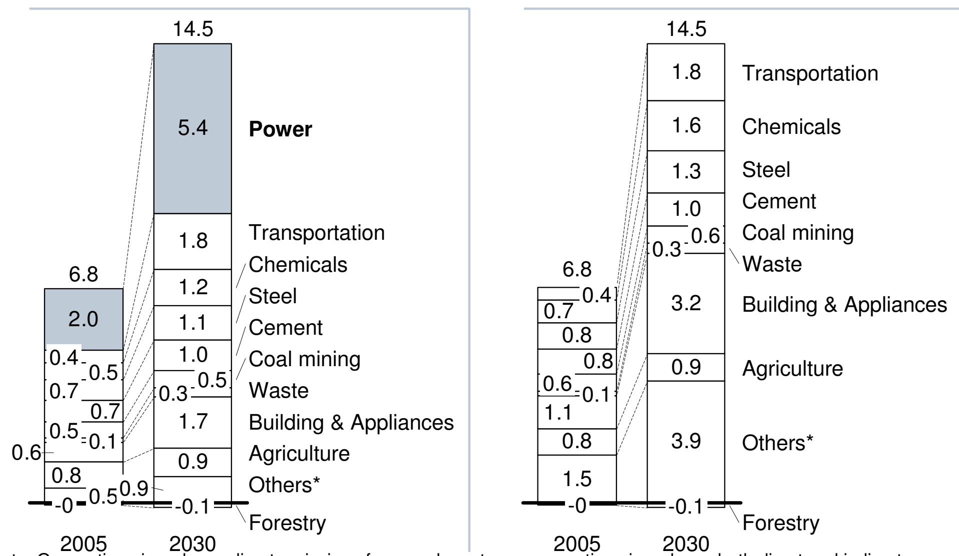
In our baseline scenario,[1] we calculate that China's GHG emissions will increase from 6.8 Gt of CO_2e per year in 2005 to 14.5 Gt in 2030. This represents an average annual growth rate of 3.1 percent (Exhibit 7). While the annual increase may appear small, it will mean a 113 percent rise in projected annual emissions by 2030. Emissions growth will occur in all sectors of the economy. However, the largest contributors will be power generation, road transportation, and buildings and appliances.

1 See Introduction for a description of the various scenarios and the assumptions underlying them.

Exhibit 7

BASELINE EMISSIONS SPLIT BY SECTOR IN 2005 AND 2030

Gigatons CO_2e per year



Note: Generation view shows direct emissions from each sector; consumption view shows both direct and indirect

* Including emissions from other manufacturing industries, construction industry, other mining industries, non-road transportation, and agriculture energy consumption; including auxiliary power consumption from the power sector

Source: China Energy Statistical Year Book; expert interview; McKinsey analysis

Emissions growth is sensitive to two factors: overall increases in GDP and the share of total GDP of the industrial sector.[2] For instance, our baseline scenario assumes an annual GDP growth rate of 7.8 percent per year. A sensitivity analysis shows that a 1 percent higher growth rate per year would increase emissions by about 14 percent. A 1 percent lower growth rate per year would lead to a fall in emissions of about 11 percent.

The changes in the country's economic structure, as projected in our baseline, are critical to a reduction in GHG emissions. If the structural changes do not materialize and industry's GDP share were higher than the 41 percent we assume in our baseline scenario, emissions would rise. For instance, if the industrial sector's share of GDP remained at its 2005 level of 48 percent, GHG emissions would be 5–16 percent higher than our baseline estimate. The final figure would depend on the GDP share of energy-intensive industries.

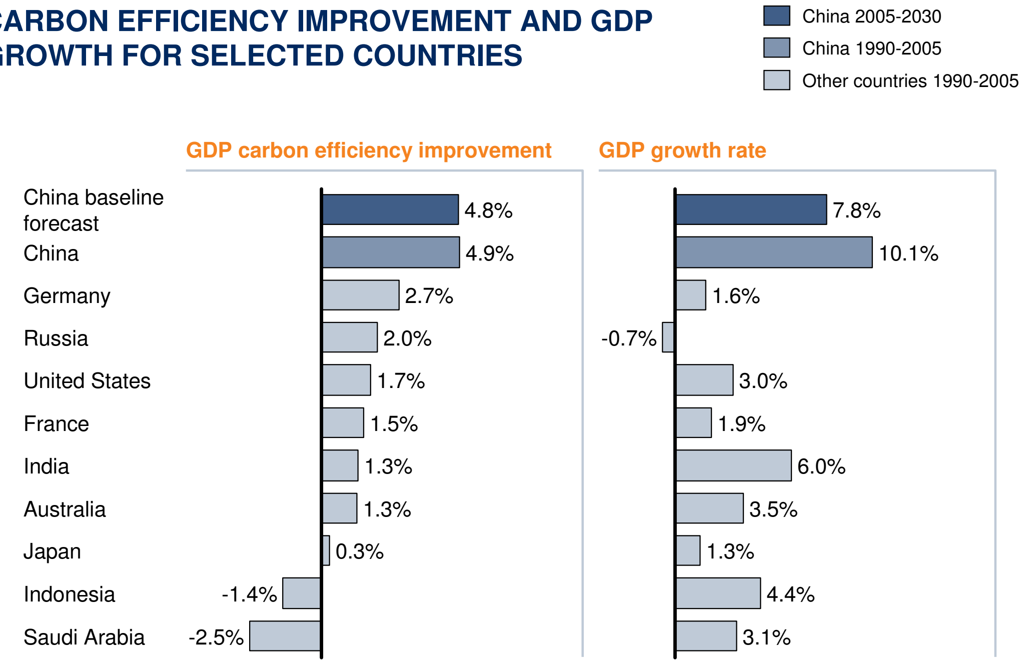
DRIVERS OF CARBON EFFICIENCY IMPROVEMENT

Carbon efficiency is the amount of GDP produced per unit of CO_2e emission. In our baseline scenario, we assume a 4.8 percent annual growth rate of carbon efficiency in China. Historically, China has maintained a 4.9 percent carbon-efficiency growth rate: the highest in the world in the past 20 years (Exhibit 8).

2 Our definition of the industrial sector follows that of "secondary industry" in the China Statistical Yearbook.

Exhibit 8

CARBON EFFICIENCY IMPROVEMENT AND GDP GROWTH FOR SELECTED COUNTRIES

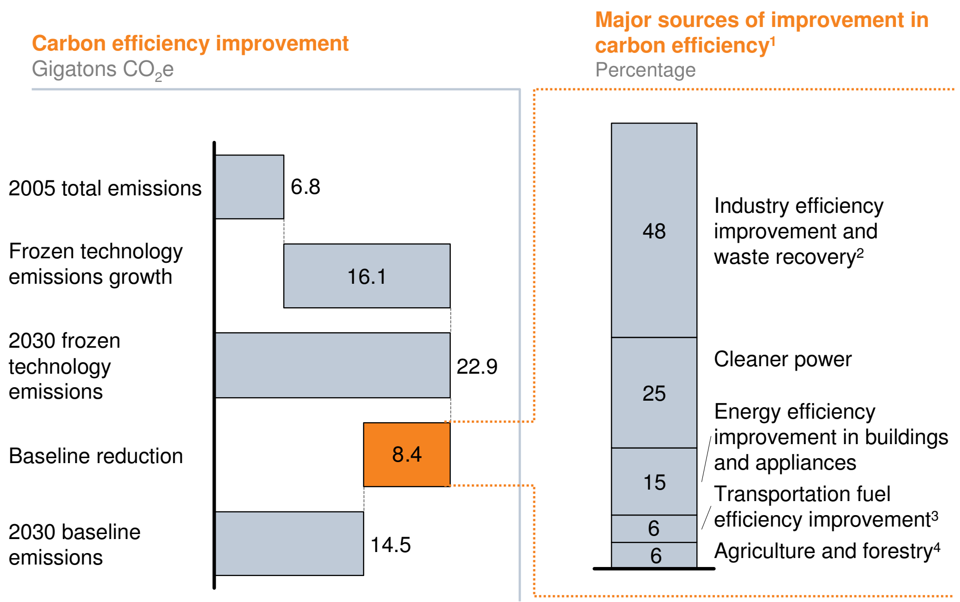


Source: IEA; expert interviews; McKinsey analysis

The forecasts underlying our baseline scenario assume that increased carbon efficiency (compared to our frozen technology scenario) will reduce emissions by 8.4 Gt of CO_2e between 2005 and 2030 (Exhibit 9). This differs from most developed countries, which have limited carbon-efficiency improvement opportunities in their baseline scenarios. We expect such efficiency gains to stem from lower energy intensity and better waste recovery in the industrial sector (48 percent), the increased use of nuclear and renewable energies and improved coal-power efficiency in electricity generation (25 percent), more energy-efficient buildings and appliances (15 percent), and the increased fuel efficiency of all forms of transportation (6 percent). The sectors this report studies in detail will contribute 75 percent of this emissions reduction.

Exhibit 9

GHG EMISSIONS REDUCTION EMBEDDED IN THE BASELINE SCENARIO



1 Improvement in end-user sectors including electricity emissions related with power reduction
2 Including other industries not analyzed in detail
3 Including all forms of transportation
4 Including energies consumed by agricultural activities

Source: McKinsey analysis

These efficiency gains are in line with the Chinese government's target of a 20 percent reduction in the country's energy intensity[3] during the Eleventh Five-year Plan period. The government is already putting in place comprehensive policy measures to realize its target, including:

- Enacting the Law on Energy Conservation, the Law on the Circular Economy, and the Renewable Energy Law
- Launching stricter high-efficiency building codes
- Raising fuel-efficiency standards for vehicles
- Establishing the National Coordination Committee on Climate Change (NCCCC) and the Energy Leading Group.

3 Energy intensity is a measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of GDP.

Based on a bottom-up analysis, we estimate a 17 percent reduction in energy intensity every five years in our 2005–2030 baseline scenario.

Realizing the efficiency gains included in our baseline is a challenge. On the one hand, it will require the rigorous enforcement and implementation of the government policies mentioned above. On the other hand, it depends on the country's ability to establish a streamlined market-incentive system to mobilize corporations and individuals. Failure to do this will endanger China's chances of improving its energy and environmental sustainability.

Most carbon-efficiency improvement opportunities are in relatively consolidated sectors, such as the industrial sector and the power generation sector. These two sectors together contribute more than 70 percent of the improvement opportunities. The key initiatives are improving the efficiency of energy-intensive industry and increasing the role of renewable energy sources and nuclear energy in power generation.

ENERGY SUPPLY AND SECURITY CHALLENGES

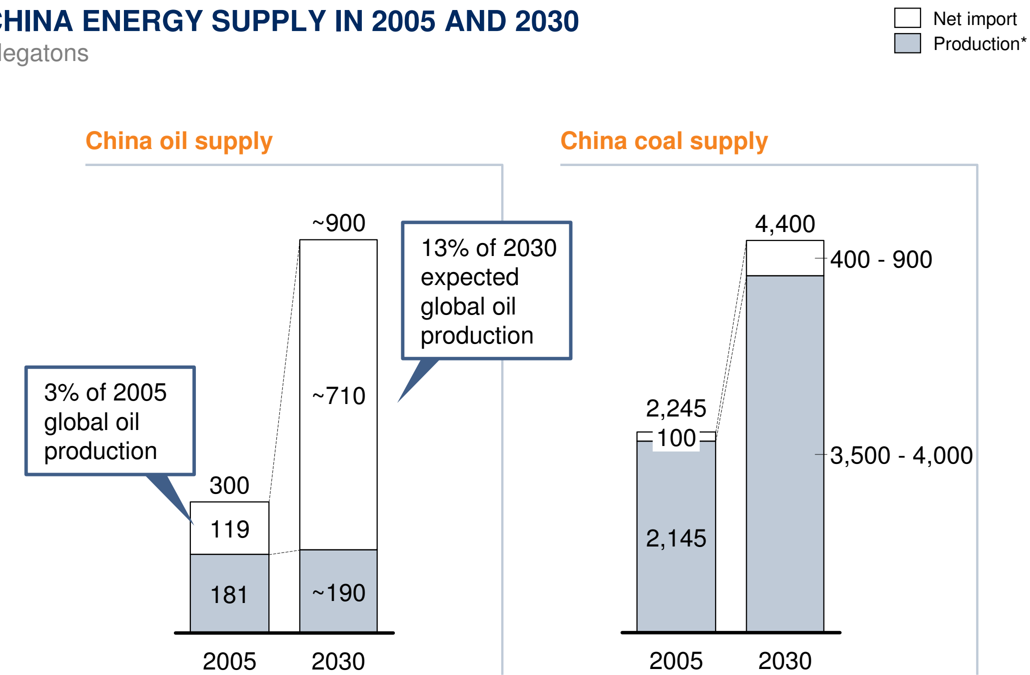
There is a close link between GHG emissions and energy consumption. Over 80 percent of emissions stem from energy consumption. The remainder comes from non-CO_2 sources (e.g., coal-bed methane leakage, agriculture and waste emissions, and process emissions from cement manufacture and some chemical processes). In our baseline scenario, we estimate a significant increase in total energy demand to reach 5.5–6 billion tons of standard coal equivalent (SCE) by 2030, more than double the 2007 level. For example, demand for crude oil would triple to approximately 900 million tons; demand for power would almost quadruple to over 9,200 billion KWh; coal demand would double to 4.4 billion tons; while demand for natural gas would increase eight times to around 420 billion cubic meters.

Such growth would put intense pressure on energy supply and security. We estimate that crude oil imports could climb to 700 million tons in 2030, equivalent to about 13 percent of projected world crude-oil production. China's oil-import dependency ratio would be close to 80 percent (currently, the US is at less than 60 percent). At the same time, China would need to import a minimum of 10 percent of its total coal demand in 2030. This would mean ensuring a supply of about 400 million tons of coal from, for example, Mongolia, Australia and other neighboring nations (Exhibit 10). Some experts are less optimistic about how much of its own coal China can extract. They point to environmental, safety and transportation bottlenecks that could reduce the upper supply limit. Hence, import requirements could even rise to 1 billion tons of coal in 2030 (i.e., over 20 percent of estimated total coal demand). In addition, if China wants to use natural gas to clean up its power mix, it will need to import most of it, either by sea (as liquefied natural gas) or through pipelines.

Exhibit 10

CHINA ENERGY SUPPLY IN 2005 AND 2030

Megatons



* 2030 production is based on gasoline, diesel and other oil product demand forecast

Source: EIA; IEA; expert interview; McKinsey analysis

LOCAL POLLUTION AND ECOSYSTEM CONSERVATION CHALLENGES

Rising energy consumption and carbon emissions imply worsening issues of local pollution and threats to the stability of ecosystems. For examples, we estimate:

- The vehicle fleet will grow tenfold from 2005 to 2030 with a corresponding increase in exhaust gases.
- Urban floor space will need to double to accommodate an increase of 350 million in the urban population. At the same time, living standards will evolve. To provide sufficient heating will mean burning almost 200 million tons more coal than in 2005. Moreover, managing the growing amount of urban waste will be a major challenge.
- Coal-based power-generation capacity will more than triple from 2005 to 2030. Proper environmental treatment (e.g., desulfurization) will require sizeable capital investments and extensive regulatory monitoring.
- Urbanization and rising living standards call for greater varieties of food. China will need to control desertification, overgrazing, the overuse of fertilizers, and over-logging in order to preserve (and, potentially increase) its arable land and grasslands and ensure their productivity.

BASELINE SCENARIO EMISSION LEVELS BY SECTOR

The launch of a national energy conservation and emission control program has led in recent years to greater awareness of the risks to sustainability. The result has been a significant slowing in the growth of China's energy and GHG footprint. However, projections based on an analysis of important sectors in the national economy indicate that China's GHG emissions will continue to grow.

Buildings and appliances

To cope with the demands of urbanization, we expect the commercial and residential building stock to continue to grow strongly in the next 20 to 25 years. Along with increasing energy consumption due to rising living standards, this will push GHG emissions in 2030 to three times their 2005 level.

- *Commercial buildings:* Total floor space for commercial buildings will increase from 5 billion square meters to 24 billion square meters, with a corresponding rise in emissions from 0.3 Gt to 1.3 Gt of CO_2e.
- *Residential buildings:* Total floor space for residential buildings will increase from 37 billion square meters to 66 billion square meters, with a corresponding rise in emissions from 0.7 Gt to nearly 1.9 Gt of CO_2e.

In our baseline scenario, we take into consideration existing energy-efficiency measures and sustainable technology development. Hence, higher-efficiency building codes and upgrades to lighting systems (e.g., switching from incandescent to compact fluorescent lamps) will help to offset some of the emissions growth. As a result, in our baseline scenario, we forecast that emissions in the sector will decrease by 1.3 Gt of CO_2e compared to the frozen technology scenario.

Road transportation

As urbanization increases and incomes grow, the number of vehicles (primarily, light-duty vehicles or LDVs) in China is set to increase by a factor of ten. By 2030, 290 million LDVs will be on the road, each traveling an average of 10,000 kilometers per year. As a result, we forecast the sector's share of emissions to grow by 6 percent annually from 0.4 Gt of CO_2e in 2005 to 1.8 Gt in 2030.

Expected improvements in fuel efficiency will partially offset this increase. The fuel efficiency of LDVs will improve by 27 percent up to 2030, and we expect sizable improvements for heavier-duty vehicles, too. Hence, in our baseline scenario, we expect a reduction of 0.4 Gt in GHG emissions compared to the frozen technology case. (Note that we do not include electric vehicles in our baseline scenario. We see important barriers to the wide-scale penetration of such vehicles. Indeed, to kick-start and maintain their adoption will require significant government intervention.)

Emissions-intensive industries

The continued high demand for basic materials in China will also push up emissions. Demand for steel, for instance, will rise by 116 percent. By 2030, steel production will have grown to over

750 million tons from 355 million tons in 2005. Overall, emissions-intensive industries (i.e., steel, cement, chemicals, and coal mining) and the waste management sector will increase their emissions by 63 percent from 3.0 Gt of CO_2e in 2005 to 4.8 Gt in 2030. The biggest increase will be in the chemicals industry (125 per cent, mainly due to growth in the production of ethylene and its byproducts), followed by the steel industry and waste management.

Across the sector, we expect a one-third improvement in energy efficiency. This will stem from a broad range of efficiency programs, and waste recovery and reuse initiatives promoted by the government and the private sector. Consequently, in our baseline scenario, we forecast a reduction of 2.2 Gt of CO_2e for the sector compared to the frozen technology scenario.

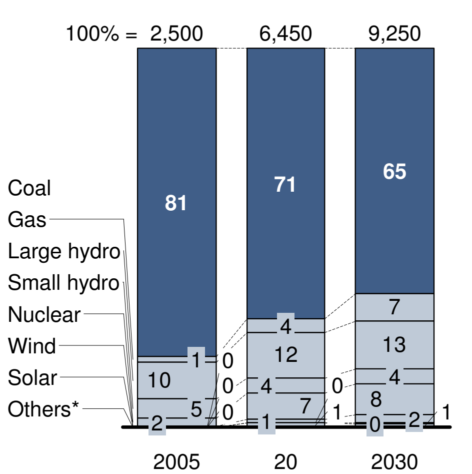
Power

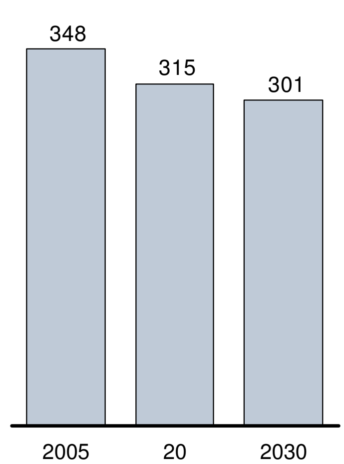
To meet the increasing energy demand of the buildings sector and industry, we expect power supply to exceed 9,200 billion KWh in 2030 – almost three times higher than in 2005. Currently, coal-fired power plants produce more than 80 percent of the electricity generated in China. The power-generation sector produced 29 percent of all emissions in 2005 – more than any other sector.

In our baseline scenario, China's generating capacity grows from 519 gigawatts (GW) to over 2,000 GW. However, emissions from the power-generation sector will increase by just one-and-a-half times, thanks to a fall in the share of coal-based electricity generation from 81 percent to 65 percent. More hydroelectric generation and a 15-percentage-point increase in the share of gas, nuclear and renewable energy from 2005 to 2030 will plug the power-generation capacity gap (Exhibit 11).

Exhibit 11

EVOLUTION OF THE POWER SECTOR IN THE BASELINE SCENARIO





* Includes geothermal, CBM, MSW, LFG and biomass

Sources: McKinsey analysis

China's power sector is already significantly improving its fuel efficiency and lowering its carbon intensity. We expect the average fuel efficiency of coal to increase by almost 15 percent as an increasing number of supercritical and ultra supercritical coal-fired plants come on stream. Because of the growth of cleaner energies and higher coal efficiency, in our baseline scenario, we forecast a reduction of 2.1 Gt of CO_2e compared to the frozen technology scenario. Nevertheless, the sector's overall share of GHG emissions will increase substantially to 5.4 Gt CO_2e by 2030.

***

China faces an energy and environmental sustainability challenge. The country needs to find answers to its energy security and GHG emissions problems, and deal with issues of local pollution and ecosystem preservation.

China imported 3 percent of the world's crude oil production in 2005. Its self-sufficiency rate was over 60 percent. In our baseline scenario, it will import up to 13 percent of the world's crude oil production by 2030 and will be dependent on foreign oil for close to 80 percent of its needs. Even China's abundant coal reserves will fall short of demand, requiring the import of anywhere between 400–1,000 million tons by 2030, representing 10–20 percent of total coal demand in that year.

As energy demand and emission levels rise, so too will local pollution and the threat to ecosystem conservation. It is therefore critical that China explores options to improve sustainability (i.e., GHG abatement measures) beyond those included in our baseline scenario. In particular, the country needs to embrace technological measures that will create a future of low-carbon emissions and energy security without compromising the economic growth of the nation and the living standards of the Chinese people.

Chapter 2: Overview of China's sustainability improvement opportunities

In this chapter, we will discuss key aspects of our methodology and the findings of our analysis of China's sustainability improvement (GHG abatement) opportunities. Throughout this report, we focus on a quantitative assessment of GHG abatement potential (measured in tons of CO_2e) as a proxy for improvements to energy and environmental sustainability. We complement this by considering other sustainability factors.

I. METHODOLOGY: HOW DID WE ESTIMATE THE SIZE AND COST OF THE SUSTAINABILITY IMPROVEMENT (GHG ABATEMENT) OPPORTUNITIES?

We estimated each abatement opportunity in three steps. First, we established the current penetration rate of each abatement technology/technique along with its abatement efficiency, cost, and its underlying drivers and constraints. Then, we projected the growth curve of each abatement technology's penetration rate and abatement efficiency, taking into account how the technology and its constraints would likely develop. Based on this, we calculated the technical potential of each abatement technology, i.e., how many tons of CO_2e would the technology remove from emissions. Lastly, we estimated the future cost, allowing for such factors as the learning curve to adopt a specific technology and the possibility of producing it in China (Exhibit 12). At all stages of our analysis, we drew on the opinions and insights of over 100 experts and institutions inside and outside China.

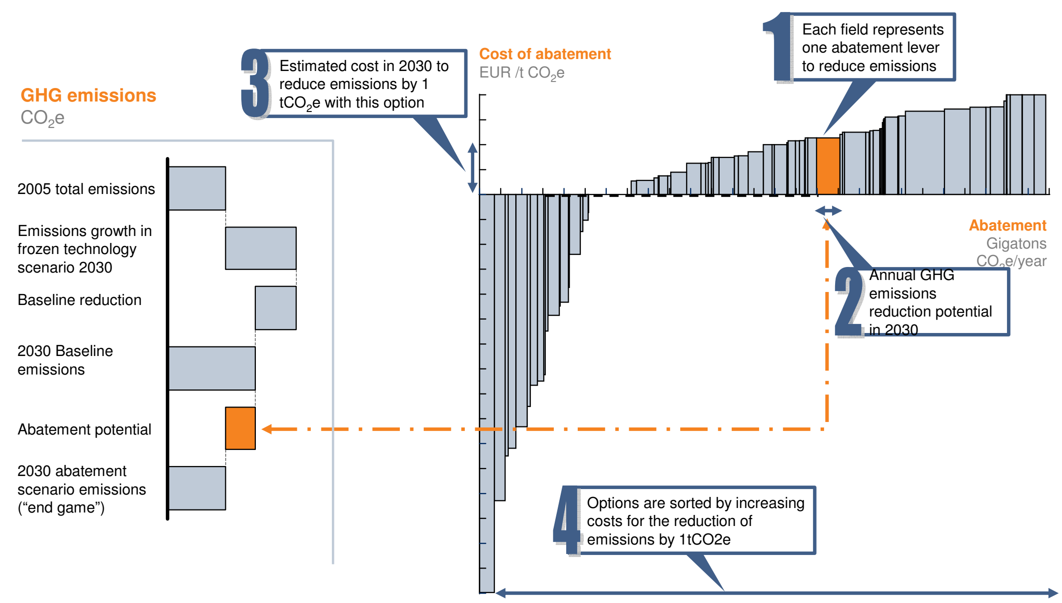
Defining and estimating the technical abatement potential

In each case, we estimated the maximum technical abatement potential of each abatement technology. To this end, we assumed optimal governmental support to develop and implement the technologies. We also assumed no constraining factors (e.g., high capital investments) that would restrict the application of the technology with the exception of four "hard constraints": technical applicability, technical immaturity, material supply, and talent availability.

- *Technical applicability.* All technologies have limits to their applicability (and, therefore, penetration rate) due to engineering, process-related or equipment constraints. For instance, combined cycle power production (CCPP) only applies to large-scale steel plants because it requires a large volume of coal gas. In addition, some coal-fired power plants' equipment is too old to install carbon capture and storage (CCS) technology. Moreover, to maintain the stability of the electricity grid, variable power sources, such as wind or solar energy, should not exceed 20 percent of a local network's total power generation.[1] However, future technological advances and better knowledge of a technology's applicability could mitigate such constraints. Hence, the abatement potential of some technologies could increase over time.

Exhibit 12

THE COST CURVE DISPLAYS ABATEMENT POTENTIAL, AND CORRESPONDING COST, FOR EACH ABATEMENT LEVER RELATIVE TO A "BASELINE" SCENARIO



Source: McKinsey analysis

- *Technical maturity.* Certain emerging technologies have a long lead-time to develop into a solution suitable for large-scale implementation. For instance, we assume that CCS technology will take another ten years to develop sufficiently and its widespread application will begin only after 2020. Similarly, the commercialization of advanced high-efficiency measures for internal combustion engines (ICE) will start after 2015.

- *Material supply.* The scarce supply of resources will constrain the adoption and application of technologies that rely on them. For instance, China's supply of agricultural bio-waste (e.g., straw and husks) will not meet the needs of several competing abatement technologies, such as cement co-firing, LC (lignocellulose) ethanol production and power generation, by 2030. Until 2020 the amounts of slag produced by steel plants and fly ash by power plants will also fall short of the cement industry's maximum demand, thus temporarily limiting the impact of clinker substitution.

- *Talent constraints.* Most technology needs sufficient talent to support its development and implementation. In our analysis, we consider talent constraints only when it involves more than five years of "nurturing." For example, training a generation of qualified

1 There have been debates on what should be taken as future grid stability limits. More optimistic experts believe the share of variable power sources could be higher than 20 percent, especially given the anticipated advances in grid and power technology. In our analysis, we adopted a conservative approach. If grid stability were higher, the technical abatement potential of renewable power would increase.

architects in passive design principles would require a minimum of six years, including four years' college education and two years' work experience. At the same time, a lack of time and resources makes it challenging to implement large-scale training schemes for experienced architects.

The maximum technical abatement potential does not take into account any economic, market or social barriers for implementation. Hence, we do not intend it as a forecast of a realistically achievable GHG emission abatement potential. Rather, it is the upper limit of a technology's abatement potential range. Furthermore, we based our estimates on our best current knowledge of the technologies and techniques in question. Of course, any new and currently unforeseen technological developments would require us to recalculate our estimates.

Defining and estimating the abatement cost

The cost of an abatement option reflects its resource (or techno-engineering) costs – i.e., capital, operating and maintenance costs – offset by any energy or other savings associated with abating 1 ton of CO_2e per year using this option. To account for the time value of upfront capital investment, we spread the investment over the lifetime of the option using a 4 percent real discount rate. This rate is taken from a "societal perspective," and may be lower than the required return on capital investment in many industries from a "decision-maker's perspective."

The cost is incremental to the technological solutions included in our baseline scenario. We calculated it using the formula:

$$\text{Abatement cost} = \frac{[\text{Full cost of abatement option}] - [\text{Full cost of baseline option}]}{[CO_2e \text{ emissions from baseline solution}] - [CO_2e \text{ emissions from abatement option}]}$$

For example, the abatement cost of nuclear power is the difference between the cost of building and running a nuclear power plant compared to that of a same-sized coal-fired plant. Our rationale for such a comparison is that, even without taking GHG emissions abatement into consideration, the coal-fired power plant would have to be built to satisfy the demand for electricity.

The abatement cost can be positive or negative. A negative cost indicates a net benefit or saving to the economy (compared to our baseline scenario) over the lifetime of a specific abatement technology. A positive cost means that capturing the abatement potential would incur incremental costs (compared to our baseline scenario) over the technology's lifetime.

The per-ton abatement cost does not necessarily reflect the total cost of implementing a specific abatement option or the price needed to stimulate the capture of a specific abatement potential. Of necessity, we excluded certain factors that could be important in actual decision making. We excluded taxes and tariffs, existing or future subsidies, and existing or future carbon prices (e.g., a carbon tax or cap) to avoid their distorting effects. We also left out social and transaction costs, as well as communication and information costs. In addition, our cost calculations do not factor in the impact on the economy of implementing specific abatement technologies (e.g., the benefits stemming from technology leadership, the impact on GDP growth, and changes in employment structure and dynamics).

We applied a long-term oil price of USD 60 per barrel and a long-term coal price in the USD 70–80 per ton range. It is important to note that we did not attempt to model demand feedback for energy price changes. (The costs of various abatement technologies are linked to the energy savings brought about by their use. Hence, higher energy prices would mean lower abatement costs, and vice versa.)

II. KEY FINDINGS

1. How big are the sustainability improvement (GHG abatement) opportunities and the required investments?

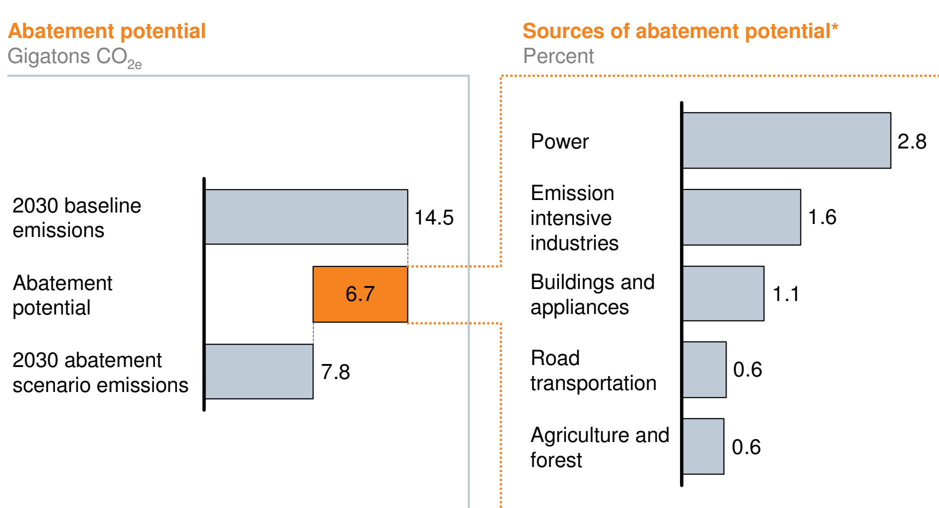
Our baseline scenario forecasts total GHG emissions of 15 Gt of CO_2e in China in 2030. We estimate that the maximum technical abatement potential of the over 200 abatement options we analyzed is 7 Gt of CO_2e. Hence, in our abatement scenario, China's total GHG emissions are 8 Gt of CO_2e.

The abatement opportunities are widely spread across the five key sectors in our analysis. All the same, the power generation and emissions-intensive industry sectors account for nearly two-thirds of the total maximum abatement potential. The high abatement potential (1.1 Gt of CO_2e) in the buildings and appliances sector reflects the expected increase in energy consumption driven by urbanization and rising living standards (Exhibit 13).

We do not claim that our findings are an exhaustive estimate of the GHG emissions abatement potential in China. Our estimates reflect only the upper technical limit of the potential of the abatement technologies covered in our analysis. Not only is there additional abatement potential in other sectors of the national economy, but also new abatement solutions are likely to emerge in the sectors we analyzed.

Exhibit 13

TECHNICAL ABATEMENT POTENTIAL ACROSS 5 CLUSTERS – 2030



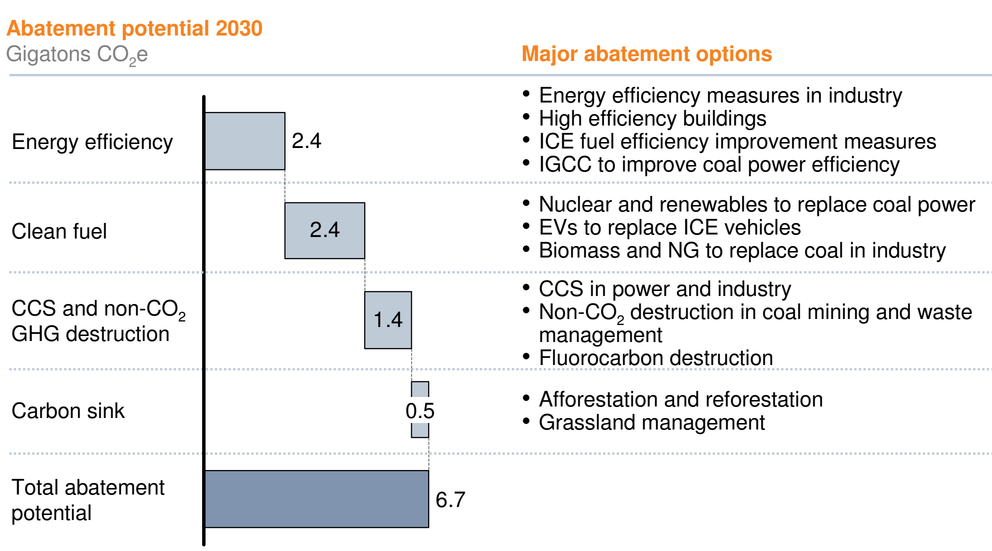
* Improvement in end-user sectors including reduced indirect (electricity generation) emissions
Source: McKinsey analysis

The major drivers of GHG emissions abatement are energy efficiency and clean fuel. Together, they represent over 70 percent of the total abatement potential in China. CCS and non-CO_2 GHG management measures (e.g., coal mine methane and waste methane management) provide just over 20 percent of the potential. A further 7 percent stems from carbon sink enhancement in the forestry and agriculture sectors (Exhibit 14). These figures show the close alignment of GHG emissions abatement and the Chinese government's agenda to promote energy savings and security, protect the environment and ecosystems, increase safety in the mining industry, encourage land conservation, and ensure food safety. It is further confirmation of the utility of using GHG emissions as the focus and common unit of measurement in the discussion about sustainability.

Achieving the substantial improvements outlined in our abatement scenario will require considerable investment incremental to the baseline scenario. We estimate that China will need up to 150-200 billion euros on average each year in incremental capital investment over the next 20 years. According to our analysis, capital requirements will increase over time, driven by higher penetration of abatement technologies in later years and the implementation of high cost technologies such as CCS. In 2030, incremental capital needs are expected to reach 1.5-2.5 percent of total GDP. Although this capital cash outlay can be offset to a great extent by cash income from energy savings, mobilizing the sizeable resources to satisfy the large financing needs will nevertheless pose a great challenge for China (Exhibit 15).

Exhibit 14

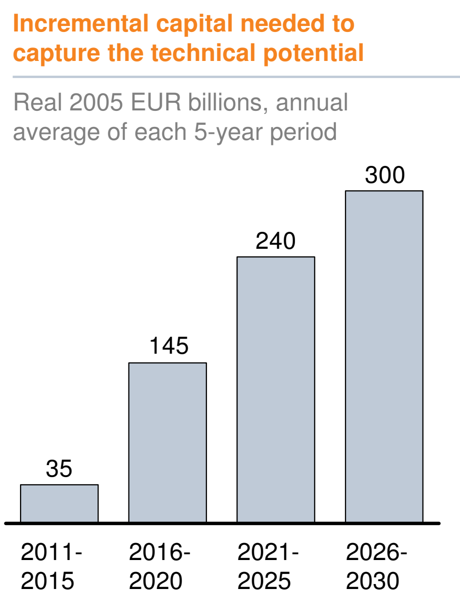
ABATEMENT POTENTIAL BY CATEGORY – 2030



Sources: McKinsey analysis

Exhibit 15

INCREMENTAL CAPITAL INVESTMENT NEEDED FOR IMPLEMENTING ABATEMENT OPTIONS, FROM 2010-2030



Key findings

- **Capital requirements increase over time mainly driven by**
  - Higher implementation shares of abatement levers over time
  - Implementation of high cost technologies such as CCS
- **Up to EUR 150-200 billion on average is needed in incremental capital investment each year from 2010-2030**
- **Capital investment needed in 2030 represents 1.5-2.5% of forecast China GDP in that year**
- **Capital investment cash needs will be largely offset by energy savings**

Source: McKinsey analysis

2. How did we assess the time sensitivity and uncertainty of the sustainability improvement (GHG abatement) opportunities?

Our estimates of the maximum technical potential of the abatement technologies are subject to various factors. Our figures could change significantly if our assumptions do not materialize.

Time sensitivity

The ability to capture the full potential of the abatement opportunities in 2030 at our estimated costs depends critically on when actions begin. We have assumed that most abatement options will become operational in 2010–2015 and ramp up to very high penetration levels in 5–10 years. The exceptions are CCS, offshore wind power, ICE efficiency improvements, and electric vehicles (EVs). The technological maturity of these options is still low and they require long development lead times. Nevertheless, the preparations for these technologies (e.g., research and development, pilot projects, site and construction planning, and talent cultivation) must start now.

For our time horizon, we developed “snapshots” of the situation every five years from 2010 to 2030. Certain actions are possible from as early as 2010. Hence, there is a significant total abatement potential at an early stage: 1.2 Gt of CO_2e in 2015, 2.7 Gt in 2020, and 4.6 Gt in 2025. These figures represent almost 20 percent, 40 percent, and two-thirds, respectively, of the total abatement potential in 2030.

The abatement opportunities involve a wide range of economic activities and many stakeholders. Hence, coordinating a timely and comprehensive plan to capture the abatement potential is a significant challenge. Any delay to the implementation of the abatement options would lead to a decrease in the abatement potential and an increase in the abatement costs at any given time. A reduction in abatement potential is mainly due to "lock-in" effects and the slower penetration rates of immature technologies.

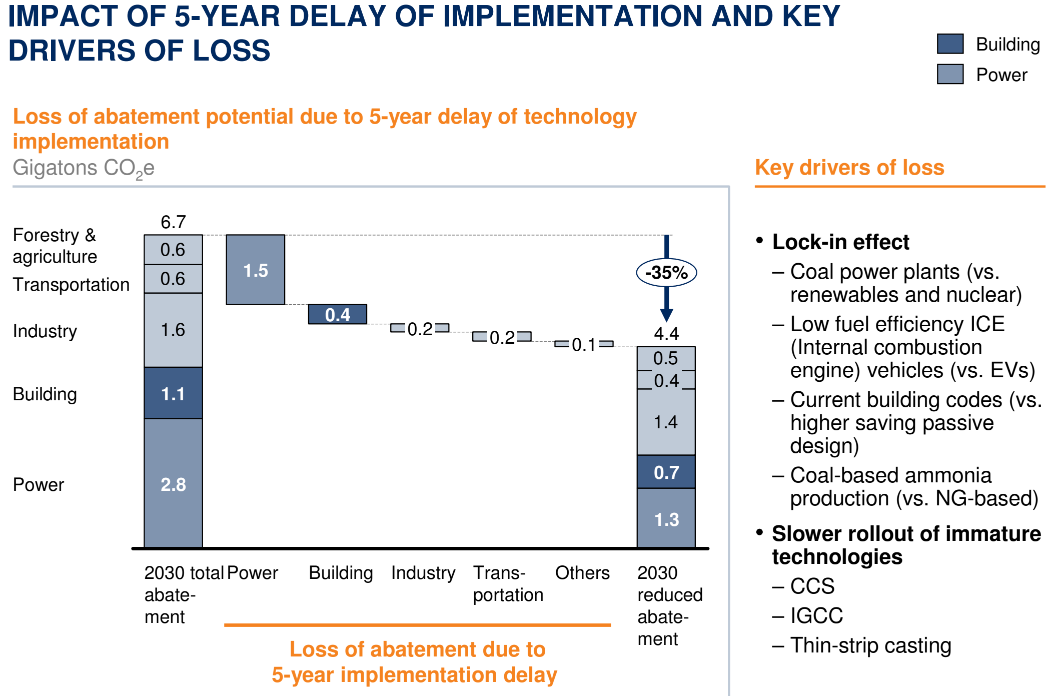
- *Lock-in effects.* Many abatement options would replace existing technologies and production formats. Typically, high costs prohibit the replacement of capital-intensive, long lifecycle production formats (e.g., coal-fired power plants, blast-furnace steel plants, and low-efficiency motor vehicles and buildings) before they reach the end of their respective lifecycles. For example, a coal-fired power plant, once built, has to run for some 30–40 years to provide the required return on capital investment. Hence, any new investment in "clean" alternatives (nuclear and renewable energy) needs to arrive before any major expansion of coal-based power generation. Preempting the lock-in effect is critical for China given its stage of economic development and the scale of its population. Over the coming decade, as China continues to rapidly expand its industrial capacity, stock of commercial and residential buildings, and its fleet of vehicles, it will be important to learn from the errors as well as the achievements of other countries if it hopes to contain and reduce GHG emissions.

- *Slower penetration rates of immature technologies.* Some relatively immature technologies, such as IGCC and CCS, depend on significant near-term investment in research and development, running pilot projects and building up infrastructure. Problems in getting implementation permission or liability issues could mean they will not reach commercial viability by 2020, which will affect their wider diffusion.

Based on sensitivity analyses, we estimate that a 5-year delay in implementing the abatement technologies would cut the total maximum abatement potential in 2030 by 2.4 Gt of CO_2e. This represents one-third of the estimated total abatement potential in 2030 in our abatement scenario (Exhibit 16). A 10-year delay in implementation would increase the missed opportunity to 60 percent of the total abatement potential. The power generation and building sectors would account for the biggest share of the fall in potential abatement due to their significant lock-in effects.

Exhibit 16

IMPACT OF 5-YEAR DELAY OF IMPLEMENTATION AND KEY DRIVERS OF LOSS



Source: McKinsey analysis

Uncertainty

We analyzed GHG emissions abatement opportunities in a broad range of economic activities over more than 20 years. Such a large-scale, long-term forecast enables the creation of a fact-based platform for multi-sector, multi-year sustainability initiatives. Nevertheless, there are inherent uncertainties in our forecasts with regard to technological evolution, abatement-technology penetration, cost and international GHG emissions abatement regimes.

- *Technological evolution.* We cannot forecast precisely how technology will develop in the next 20 years; for instance, a significant breakthrough in solar or wind power technology could increase their use dramatically. On the other hand, some technologies currently deemed more viable than others may disappoint in the future.

- *Abatement-technology penetration.* Unforeseeable factors could affect the penetration of abatement technologies; for instance, we base our assumptions about CCS technology penetration on existing estimates of the available space in China for storing captured CO_2. We may have to change our assumptions significantly in light of more accurate estimates.

- *Cost.* Our projections of the costs of the various abatement technologies depend heavily on an assumed learning rate over the next 20 years. Sophisticated and extensive study has identified the most likely learning rate for each technology, but these are still subject to uncertainty. Moreover, there is a feedback loop between a technology's penetration and the learning rate. One affects the other, thus influencing whether a technology can achieve an economically viable scale. Hence, uncertainty about technology penetration rates leads to uncertainty about cost. For example, we assume a 16 percent learning rate with regard to solar power. We base this on the historical learning curve of the power industry and draw a parallel with the semi-conductor industry (as both are silicon-based industries). At the same time, solar power is an international market, so we use maximum global solar penetration as the basis on which to apply the learning rate. Consequently, we estimate that solar power would cost only 50 percent more than coal power in two decades. Of course, changes in the learning rate might alter our forecast. Furthermore, at a "macro" level, it is difficult to predict accurately the cost of energy, labor and land.

- *International GHG emissions abatement regimes.* It is unclear how international efforts to combat GHG emissions will affect the costs of abatement technologies. For instance, global policy on technology transfers will have a substantial, direct impact on the cost of technologies that China currently has to import or expects to import in the future.

3. What are the implications for energy supply and energy security?

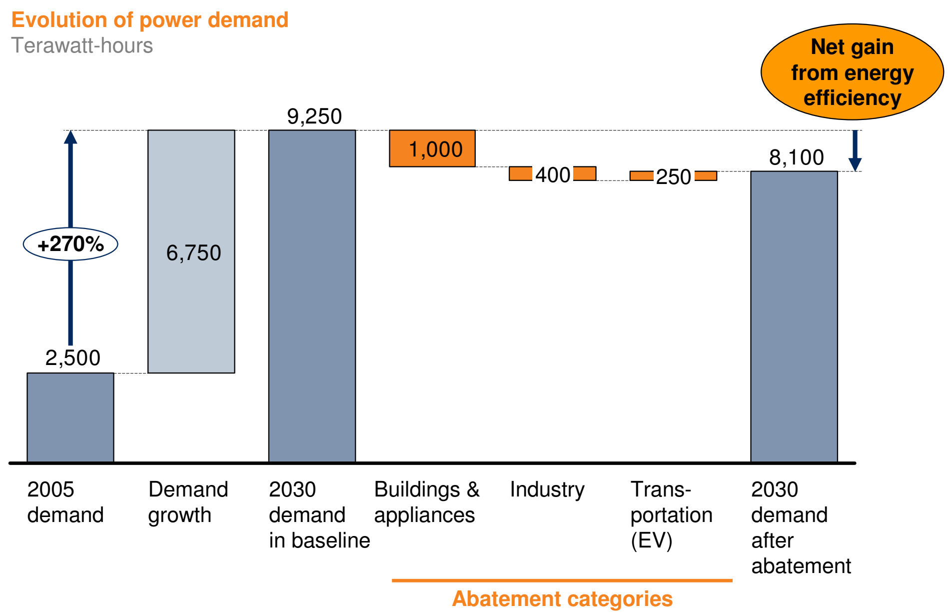
Energy savings are at the core of our research. Many of the abatement options we consider take effect by improving energy efficiency and reducing CO_2 emissions from the use of primary (e.g., coal, natural gas and oil) and secondary energy sources (e.g., electricity). The full implementation of the abatement options would lead to a significant reduction in demand for power, coal, and oil products (gasoline and diesel). For example, we estimate that the net effect of energy efficiency gains in the buildings and appliances sector and industry sector would offset over 10 percent of the projected baseline demand for electricity in 2030 (Exhibit 17). This reduction in end-user demand could help decrease coal-based power generation and reduce the volume of coal demand in 2030 by 500 million tons.

In addition, the large-scale rollout of nuclear and renewable energies, coupled with energy efficiency gains in the buildings and appliances sector and industry sector, would cut coal consumption in 2030 to approximately 2,650 million tons – almost the same as the 2007 consumption level (Exhibit 18). This will ease the pressure on domestic coal production and the need to secure coal imports.

Furthermore, fully applying EV technologies and advanced ICE efficiency improvements has the potential to cut gasoline demand by more than 70 percent and diesel demand by around 10 percent in 2030. These efficiency gains in the road transportation sector could reduce oil imports by 200–300 million tons, i.e., 4–6 percent of expected global oil production in 2030. This represents, for example, five to eight times the output of the Daqing oilfield (Exhibit 19). Such a reduction would shrink China's imported-oil dependency ratio from close to 80 percent to 60–70 percent.

Exhibit 17

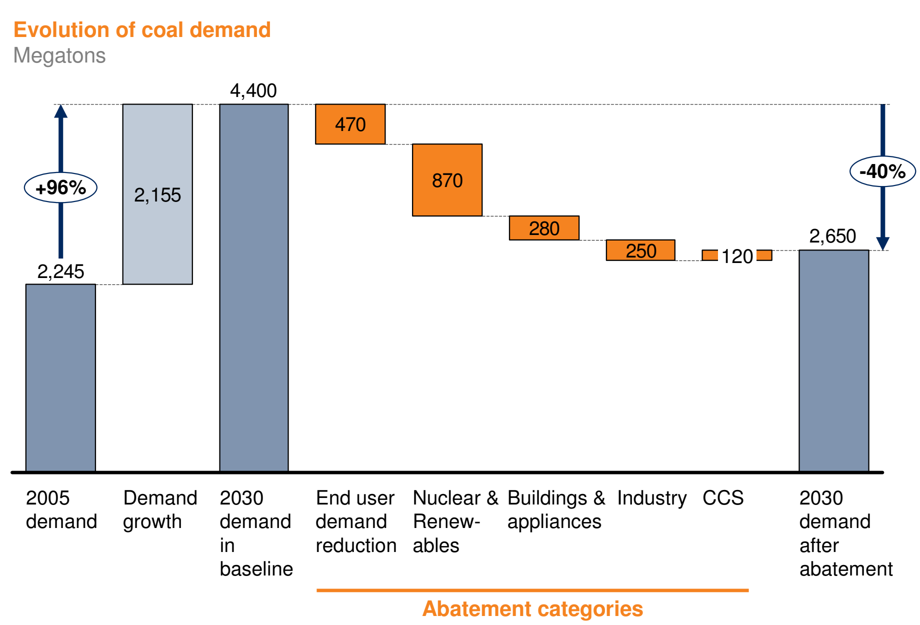
CHINA POWER DEMAND REDUCTION IN THE ABATEMENT SCENARIO



Source: China Energy Statistical Year Book; McKinsey analysis

Exhibit 18

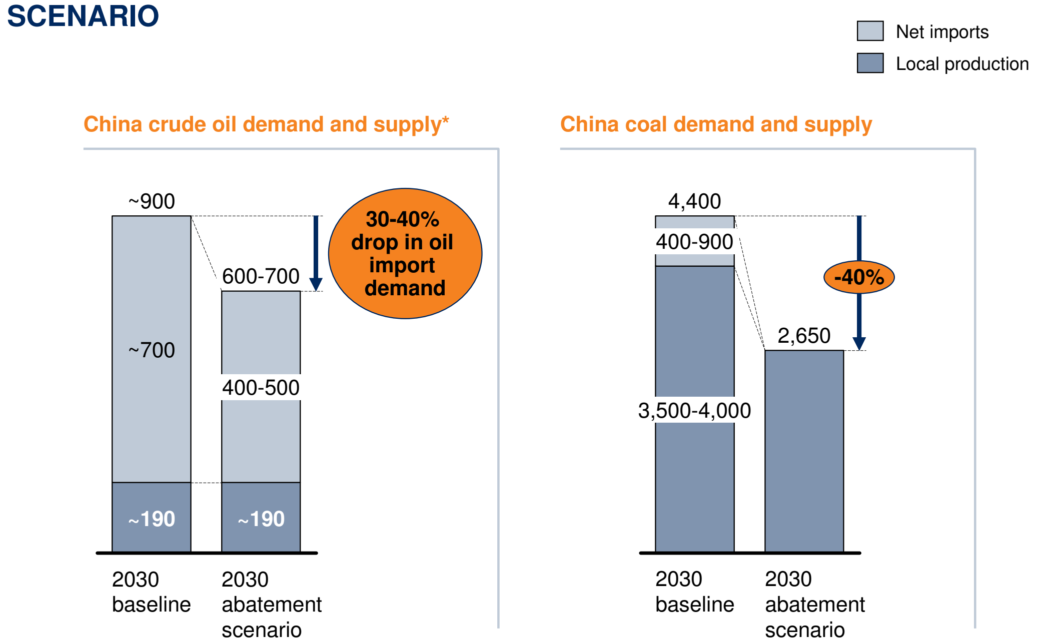
CHINA COAL DEMAND REDUCTION IN THE ABATEMENT SCENARIO



Source: China Energy Statistical Year Book; McKinsey analysis

Exhibit 19

CHINA OIL AND COAL DEMAND AND SUPPLY IN THE ABATEMENT SCENARIO



* 2030 crude oil demand is based on forecasts of gasoline, diesel and other oil products

Source: EIA; IEA; expert interview; McKinsey analysis

4. How will the abatement opportunities affect energy infrastructure?

Capturing the full abatement potential would also have an appreciable impact on the nation's energy infrastructure.

- *Power generation infrastructure.* We expect a significant slow down in the construction of coal-fired power plants. Coal-based power generation would drop from 6,000 billion KWh in our baseline scenario to less than 3,000 billion KWh in our abatement scenario. At the same time, nuclear power plants and renewable energy facilities (e.g., wind and solar farms) would need to expand rapidly. Comparing capacity in our baseline scenario with the abatement scenario, nuclear power would grow from 100 GW to 180 GW, wind capacity from 100 GW to over 300 GW, and solar capacity from 10 GW to over 300 GW.

- *Energy distribution network.* Power transmission and distribution grid upgrades are indispensable for enabling the large-scale rollout of renewable energy and electric vehicles. Integrating renewable energy sources (primarily wind and solar) into the nation's electricity supply would require a significant expansion of the grid. The massive adoption of EVs would need a dense and convenient recharging infrastructure to support it. To manage the complexity of an expanded grid, efficiency and system control upgrades (e.g., well planned grid deployment, high-efficiency grid equipment, and smart-grid technologies) are essential. In addition, deploying CCS technology in coal-fired power plants would mean building CO_2 pipelines to transport some 900 megatons of CO_2 in 2030.

- *Automotive industry.* If China were to completely shift its automotive manufacturing capacity to the production of electric vehicles and advanced ICE efficiency technologies, 90 percent of the country's passenger vehicle fleet could be running on these technologies by 2030. This will require significant changes to automotive manufacturing processes, as well as to the refueling infrastructure for these vehicles (e.g., EVs would require a network of battery charging and instant battery exchange services).

5. What are the implications for local pollution and ecosystem conservation?

Capturing the full GHG emissions abatement potential should have a significant favorable impact on local pollution levels and efforts to conserve ecosystems. A number of examples will illustrate this. For instance, if a sizeable proportion of the vehicle fleet is electric or adopts high-efficiency ICE technologies, car exhaust gases will diminish. Buildings equipped with appropriate insulation, windows and roofs will require less heating. The amount of coal burned for heating China's urban floor space in 2030 would be no more than in 2005. Beijing, for example, would benefit from noticeably cleaner air, especially in winter, and the railway system would no longer face the intense pressure of transporting heating coal in the winter months. Overall, coal-based power generation capacity would increase only moderately by 2030, thus helping to protect the environment in cities, railway areas, and coal mining regions.

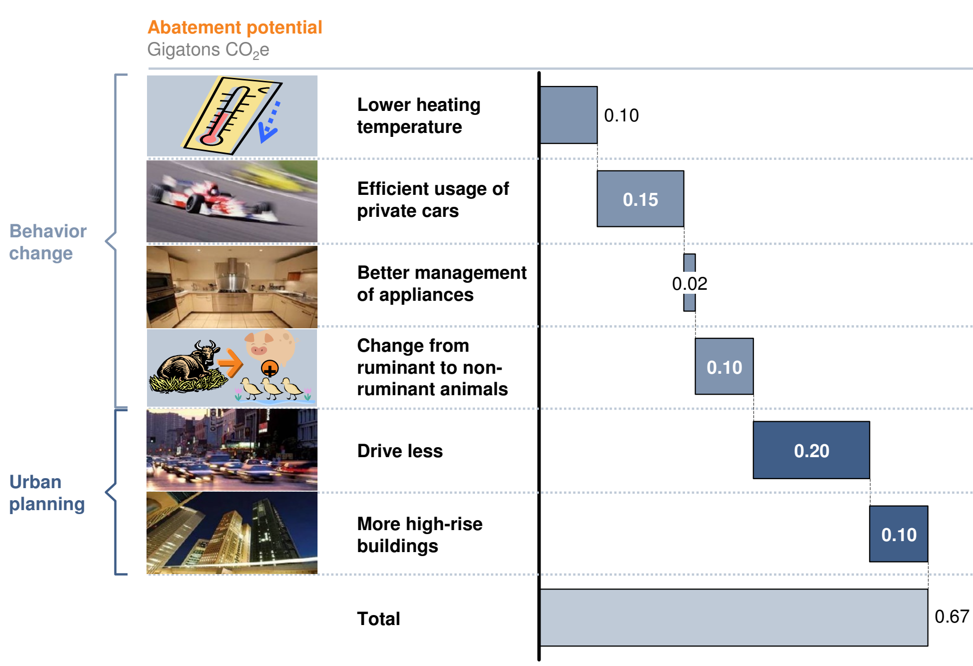
GHG emissions abatement would lead to a substantial increase in forest coverage, and contribute to preserving or recovering extensive grasslands. The amount of arable land and its productivity will also rise, providing valuable support to ensure the security of China's food supply.

6. How big are the sustainability improvement (GHG emissions abatement) opportunities beyond the technological options?

On top of the technological abatement options, savings in GHG emissions are possible from changes in consumer behavior and urban planning (Exhibit 20).

Exhibit 20

ABATEMENT POTENTIAL FROM NON-TECHNOLOGY OPTIONS



Source: China Building Energy Efficiency Annual Report; NSB; expert interview; McKinsey analysis

Environmentally conscious behavior changes mainly comprise a more efficient use of motor vehicles, appliances, and heating, ventilation and air-conditioning (HVAC) systems. Such improvements could deliver an abatement potential of 300-400 million tons of CO_2e. All such changes are minor, driven by shifts in preferences and priorities that do not significantly affect people's living standards. For example, a recent survey indicates that people do not need constant room temperatures of 23°C year-round to feel comfortable. The Chinese government has already mandated a lower minimum room temperature of 20°C and a higher maximum of 26°C, which would cut heating and cooling requirements. There are also simple and effective ways to use cars and appliances to the same extent while consuming less energy, e.g, car pooling and elimination of stand-by uses.

Lastly, planning for denser urban areas calls for more high-rise buildings, which are generally 10–15 percent more energy efficient than their low-rise counterparts. In addition, denser cities could also cut private car use in favor of public transportation systems (as is the case in Tokyo and Hong Kong). We estimate the abatement potential of increased urban density is some 300 million tons of CO_2e.

***

China has substantial potential to improve energy and environmental sustainability beyond the levels in our baseline scenario. China's maximum technical abatement potential in the five sectors we analyzed amounts to 7 Gt of CO_2e, compared to 15 Gt in our baseline scenario. Capturing the full potential of the various abatement options across a wide range of industries will be a major challenge. Moreover, one must consider a number of uncertainties, including implementation time, when assessing the full abatement potential. By implementing the abatement opportunities, China can not only combat GHG emissions, but also ensure future energy supplies, curb local pollution, and conserve its ecosystem. Nevertheless, realizing the full benefits to sustainability of many GHG emissions abatement technologies will require substantial changes to the country's energy infrastructure.

In the next chapter, we outline the GHG emissions abatement potential and its cost, along with the details of the key abatement technologies, for each of the five sectors we analyzed.

Chapter 3: Five clusters of sustainability improvement potential

We analyzed GHG emissions abatement options in a comprehensive range of sectors across the entire Chinese economy. For the purposes of this report, we have clustered our findings as they apply to five major economic sectors. The combined maximum abatement potential of these five clusters amounts to 6.7 Gt of CO_2e.

The five economic sectors (and their specific abatement potential) are:

- Buildings and appliances (1.1 Gt of CO_2e)
- Road transportation (0.6 Gt of CO_2e)
- Emissions-intensive industry (1.6 Gt of CO_2e)
- Power generation (2.8 Gt of CO_2e)
- Agriculture and forestry (0.6 Gt of CO_2e)

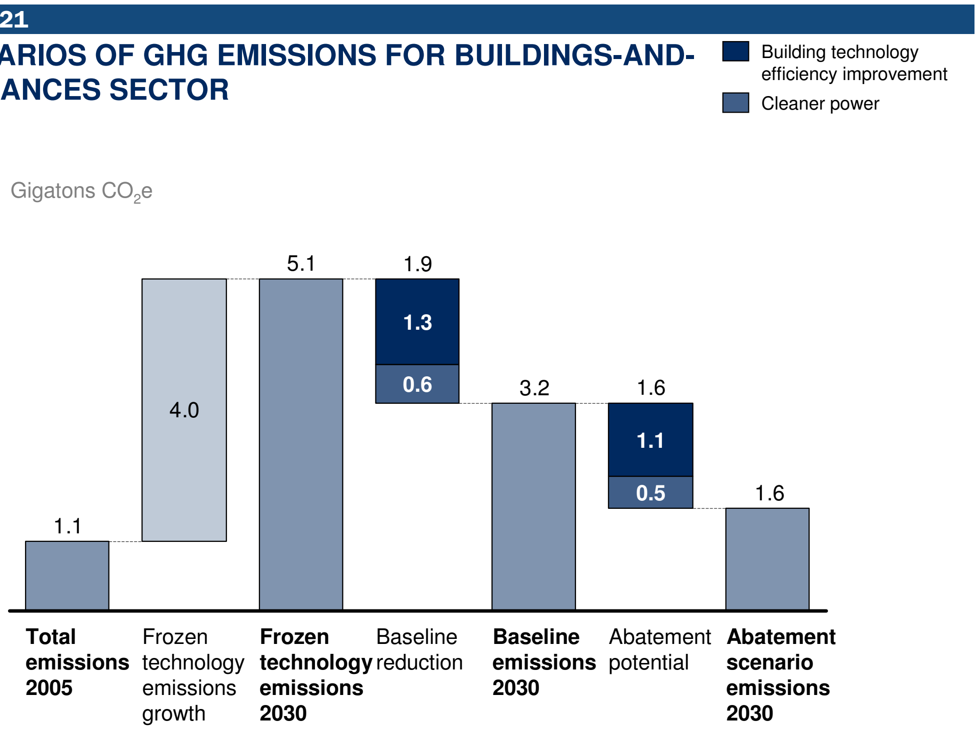
Buildings and appliances sector: Increasing the energy efficiency of residential and commercial properties

China's building boom and rising living standards are driving an increase in the share of the country's total energy that is consumed by the buildings (both residential and commercial properties) and appliances sector. In our 2030 baseline scenario, this sector accounts for 25 percent of the China's energy consumption, up from 17 percent in 2005. At the same time, we expect GHG emissions from buildings and appliances to grow by an average of 80 million tons a year – the equivalent of eighteen 1,000 MW coal-fired power stations – to reach 3.2 Gt of CO_2e by 2030.

Nevertheless, our analysis shows a potential to cut power demand in this sector by one-third and coal demand by a half – resulting in a 50 percent reduction in GHG emissions to 1.6 Gt of CO_2e. The buildings and appliances sector itself would contribute 1.1 Gt of this total reduction, with the remainder attributable to improved carbon efficiency in the power generation sector (Exhibit 21). To achieve this abatement potential requires a focus on improving energy efficiency in the sector and the use of several economically viable and readily deployable techniques. The reduction in coal usage will help efforts to lower local air pollution. Moreover, it would alleviate pressure on the transportation system, especially in the peak winter months for coal shipments in China.

Exhibit 21

SCENARIOS OF GHG EMISSIONS FOR BUILDINGS-AND-APPLIANCES SECTOR



Source: McKinsey analysis

However, the window of opportunity to realize the GHG emissions abatement potential is closing fast. “Lock-in” effects pose a significant risk in the sector. Delays in adopting the required abatement technologies would have significant ramifications for China’s energy security . Therefore, it is critical to factor in time sensitivity when taking decisions in this sector.

BASELINE SCENARIO

In our baseline scenario, we estimate that buildings and appliances in China will emit 3.2 Gt of CO_2e in 2030, a 200 percent increase in emissions compared with 2005 levels. This represents about 750 million tons of standard coal equivalent (SCE) in primary fuels and 2,700 billion KWh of electricity. Overall, residential buildings account for almost two-thirds of total energy consumption, but commercial buildings consume more electricity than residential buildings.

Driving the growth in GHG emissions and energy appetite are a doubling of total floor space over the next 25 years, and the accompanying changes in living standards and consumption patterns that lead to higher utilization of cooling and heating units, appliances, and electronics. However, shifts in fuel sources, HVAC and appliance efficiency improvements, and enhanced compliance with building codes will to some extent offset the rise in energy consumption. National policies to improve building energy efficiency levels are major driving forces for such changes. As a result, emissions are 1.9 Gt of CO_2e lower in our baseline scenario than in our frozen technology scenario.

Floor space

We estimate that total floor space will expand from 42 billion square meters (m^2) in 2005 to 91 billion m^2 in 2030. Commercial floor space will reach 24 billion m^2 by 2030 (growing almost three times as fast as residential floor space). Total urban residential floor space will almost triple from 15 billion m^2 to 42 billion m^2 by 2030. The urban population will expand in this period by 75 percent. An urban resident in China will have on average 42 m^2 of residential living space in 2030, a gain of 60 percent from 2005. This is a level comparable to Taiwan and South Korea today, and significantly less than that of the United States. Total rural residential floor space, on the other hand, will remain flat.

Consumption patterns

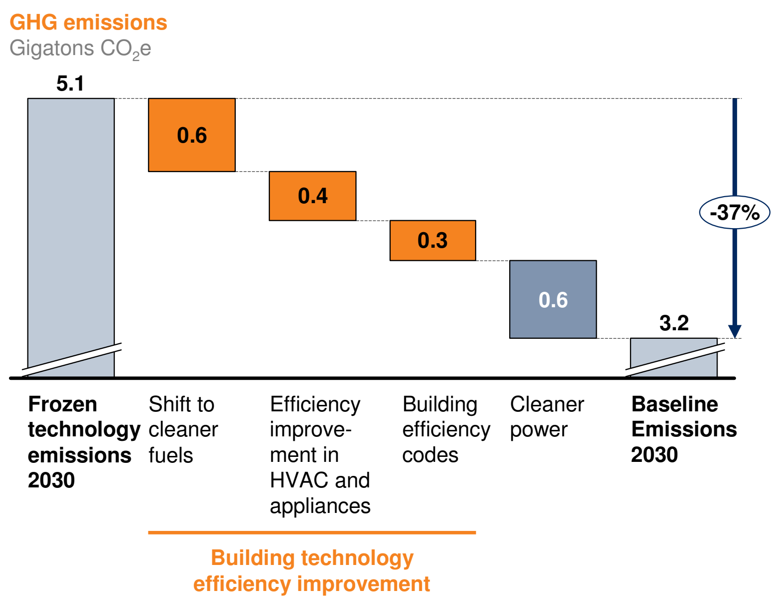
As standards of living rise, so does energy consumption. Rising income levels and more affordable appliances and consumer electronics will lead to greater use of heating units, air conditioners, and electrical appliances in China. By 2030, we expect the penetration rates and consumption patterns of most appliances and heating, ventilation, and air conditioning (HVAC) systems to equal those of developed Asian economies today. Consequently, we expect energy consumption to rise. We also expect China to follow global rather than regional consumption patterns with regard to appliances. For instance, refrigerators will evolve from the current 120-liter average to an average of 400 liters. We also expect rapid growth in the use of large-screen plasma and LCD televisions, and automatic washing machines (along with an increase in wash frequency and load size). All of these changes will add to the energy load in China.

Emission-reducing opportunities

In our baseline scenario estimates of energy demand and GHG emissions, we took into account four opportunities to reduce GHG emissions: energy-efficient fuels, energy-efficient appliances, tighter compliance with building efficiency codes, and higher power-generation efficiency. The overall GHG emission abatement potential of these opportunities (compared with our frozen technology scenario) is 1.9 Gt of CO_2e in 2030 (Exhibit 22). This represents a decrease of 500 million tons in the demand for coal and a decrease of 500 billion KWh in the demand for power. Government policy will play an important role in capturing the potential of each of these abatement opportunities.

Exhibit 22

GHG EMISSIONS REDUCTION IN THE BASELINE SCENARIO – 2030



Source: Ministry of Housing and Rural Development; "Building Energy Savings Yearbook 2008"; Lawrence Berkeley Laboratory; expert interviews; McKinsey analysis

The first three opportunities fall under the umbrella of general improvements in building efficiency. The fourth opportunity derives from the power generation sector and is not specific to the buildings and appliances sector.

- *Shift to energy-efficient fuels.* We expect a major change in the primary energy source for heating residential and commercial buildings as natural gas and combined heat and power plants (CHP) replace coal and diesel. In China's northern regions, the government has set a target of installing 56 GW of CHP capacity for urban heating by 2010 and 100 GW by 2020, triggering a rapid expansion in such plants.[1] In addition, we expect natural gas, which is less carbon-intensive, to displace coal and LPG for cooking and water-heating purposes.

1 It is important to note the limits of CHP expansion; barriers include proper sizing, engineering competence, and the high cost of grid connectivity.

- *Energy-efficient appliances.* Although the use of appliances, electronics and heating systems will rise, they will become more energy efficient and thus reduce private energy consumption. For example, we expect most refrigerators in 2030 to consume less than 80 KWh per year. The Chinese government has also enforced firm energy-efficiency ratings on a par with European Grade A standards for all the main white and brown goods. It has also rolled out a subsidy plan to encourage a shift from inefficient incandescent lamps to more efficient fluorescent lighting.

- *Building efficiency codes.* The government has passed a series of building codes – the most relevant being the Building Energy Efficiency Code – that detail mandatory efficiency improvements to building envelopes, and lighting and heating systems. The abatement potential of such measures is over 300 million tons of CO_2e. In addition, the Ministry of Housing and Urban and Rural Development will launch a Green Building Labeling System. This is a voluntary incentive system to enable consumers to choose "greener," less wasteful buildings, thus giving real-estate developers an incentive to develop such properties.

- *Power-generation efficiency improvements.* Although not specific to the buildings and appliances sector, a general improvement in power-generation efficiency will reduce GHG emissions by 600 million tons of CO_2e. We describe the government's role in this important change in a later chapter of this report on the power-generation sector.

ABATEMENT OPPORTUNITIES

The two decades from 2010 to 2030 will prove critical for reducing emissions from buildings and appliances and, hence, improving sustainability. These two decades will see the peak of building-space expansion and a massive rise in energy consumption by Chinese consumers in homes and offices. At the same time, there is an opportunity for China to set new precedents in building design, construction and energy consumption. In all, we identified a range of GHG emissions abatement options with a combined abatement potential of 1.1 Gt of CO_2e (Exhibit 23). This corresponds to energy savings of 300 million tons of coal and 1,000 billion KWh of electricity (i.e., 12 times the electricity output of the Three Gorges hydroelectric power plants in 2008).

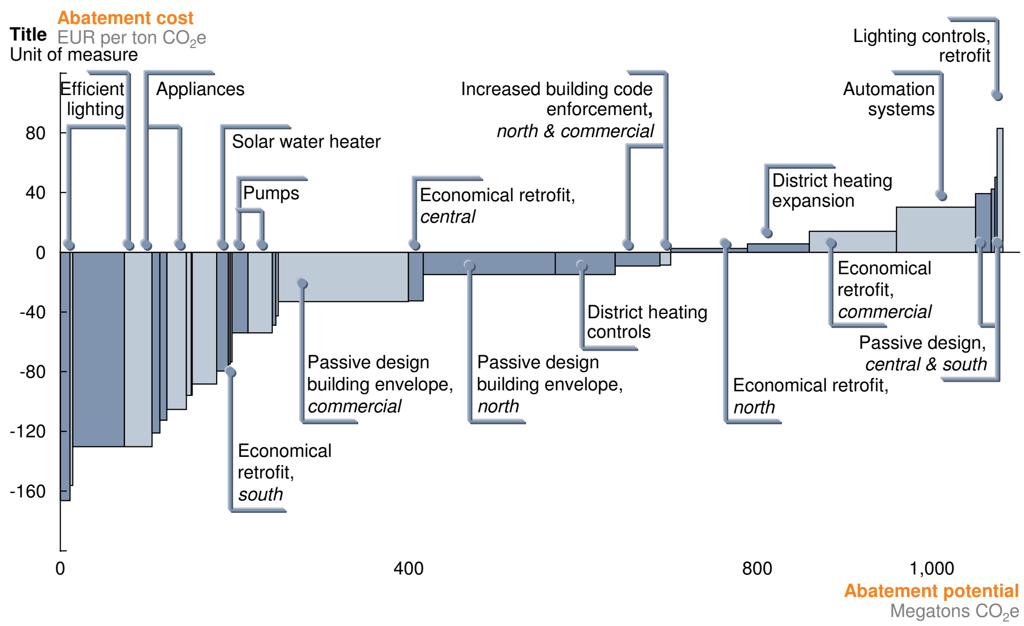
Of all the sectors we analyzed, abatement techniques in the building sector have the lowest costs overall. We estimate that about 70 percent of the abatement potential has a negative cost. The biggest abatement opportunities are efficient building envelopes, efficient HVAC systems, and energy-efficient lighting (Exhibit 24).[2]

2 We also analyzed technological improvements to appliances and water heating. We do not elaborate on them here as they make a relatively small contribution to total abatement, and there is no debate as to their utility and the benefits of continuing to expand access to them.

Exhibit 23

COST CURVE FOR BUILDINGS AND APPLIANCES SECTOR IN 2030

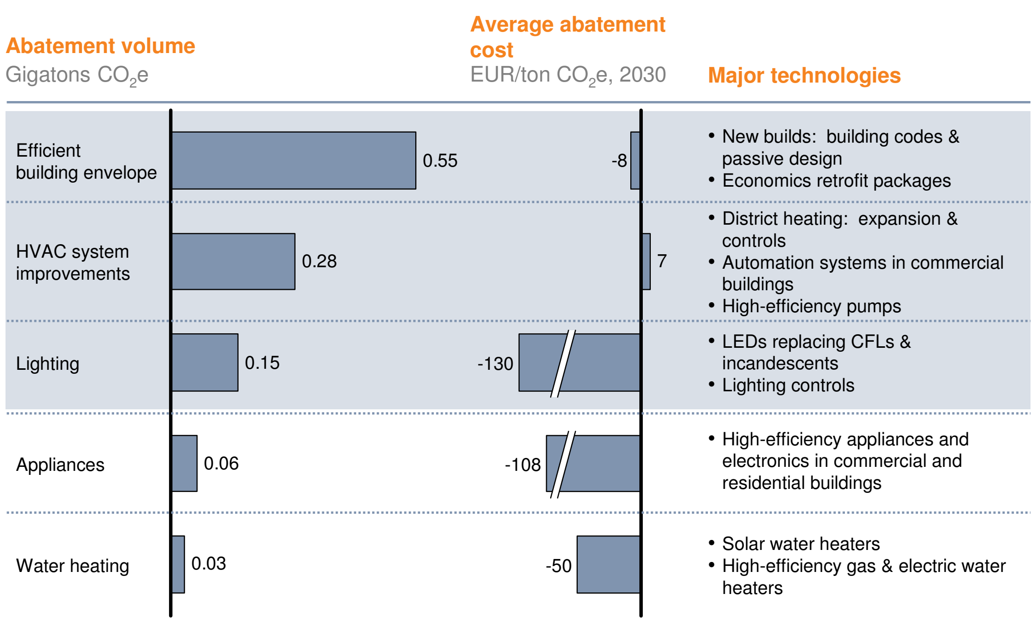
Technology applied to building type
Commercial
Residential



Source: McKinsey analysis

Exhibit 24

ABATEMENT OPTIONS – BUILDINGS AND APPLIANCES SECTOR – 2030



Source: McKinsey analysis

Buildings are not standardized products. Hence, there may be wide variations in the impact and cost of any abatement techniques. To address this, we ran in-depth analyses of actual cases and consulted numerous experts to arrive at reasonable averages. While we recognize there is no "one-size-fits-all" solution for every building, we have identified several techniques that represent the bulk of cost-efficient improvements to the energy efficiency of buildings.

1. Efficient building envelopes

A building's envelope primarily affects its heating and cooling capacity. Improving a building's envelope is possible by enforcing current energy-efficiency building codes for new builds, applying the principles of passive design to new builds, and using "retrofit packages" for existing structures. Overall, these three measures have a GHG emissions abatement potential of 550 million tons of CO_2e. The largest abatement potential is in commercial buildings throughout China and residential buildings in northern China, due to their high energy-consumption levels. Moves to enforce energy-efficiency building codes should prioritize these areas (Exhibit 25).

Defining the baseline scenario

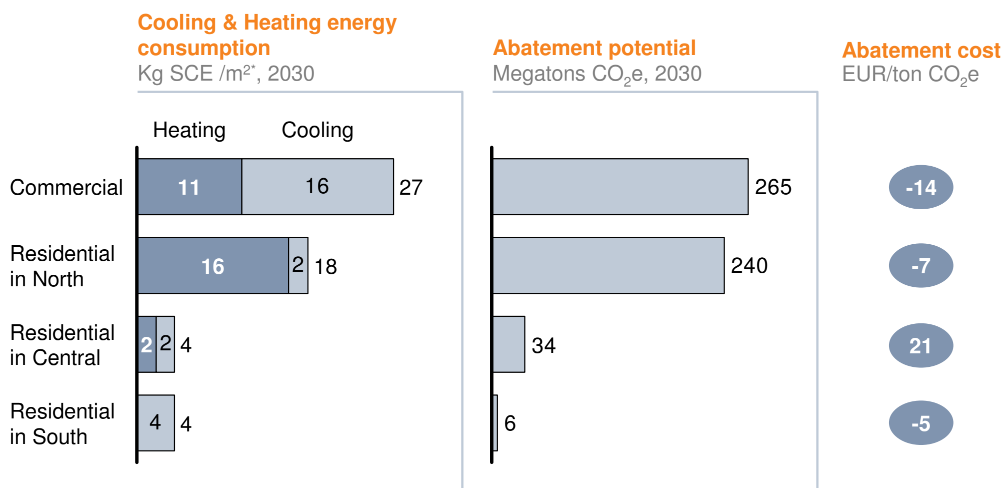
In our baseline scenario, we differentiated the energy consumption of residential buildings according to three "climatic regions." The north has cold winters and mild summers (e.g., Beijing and Tianjin). The central region has hot summers and cool winters (e.g., Shanghai and Sichuan). The south has hot summers and warm winters (e.g., Shenzhen and Yunnan).

Due to the substantial difference in heating and cooling needs, homes in northern China have higher energy consumption per m^2 than those in central and southern regions. We estimate that, in 2030, a house in northern China will consume 16 kg of standard coal equivalent (SCE) per m^2 for heating. This is eight times the amount consumed in central areas, while homes in the south need almost no energy for heating. The high use of primary energy (e.g., coal) for heating far exceeds the secondary energy (e.g., electricity) used for cooling across the country.

If we convert primary and secondary energy into one unit, commercial buildings consume almost six times more energy than homes in central and southern China. By contrast, we categorized commercial buildings as "modern" and "traditional," rather than by climatic region. Estimates suggest that modern buildings use anywhere from 30 percent to 80 percent more energy than traditional ones. This is because modern buildings have centralized heating and cooling systems (as opposed to individual units), as well as thicker walls and other building features (e.g., non-opening windows) that do not allow natural heating or cooling.

Exhibit 25

ENERGY CONSUMPTION AND ABATEMENT OPPORTUNITY BY BUILDING TYPE



* Power consumption is translated into comparable primary energy units by coal equivalent calculation methodology

Source: Yi Jiang, "Energy Efficiency Yearbook 2008"; EuroMonitor; CEIC; expert interviews; McKinsey analysis

Enforcing current energy-efficiency building codes

China's energy-efficiency codes for buildings are nationwide standards that stipulate energy conservation levels for lighting, HVAC systems and the building envelope. Increasing compliance to these building codes beyond the levels assumed in our baseline scenario offers an abatement potential of 55 million tons of CO_2e. Improvements in residential buildings in northern China and commercial buildings throughout the country account for about 93 percent of this potential at a negative cost of EUR -9 per ton of CO_2e. The remainder stems from reducing emissions in homes in the central and southern regions. However, the abatement cost in these regions is higher at EUR 165 (central) and EUR 260 (south) per ton of CO_2e.

The cost differential is due to two main reasons. First, as mentioned above, energy savings are higher in absolute terms for commercial buildings and homes in the north as their energy consumption is higher.[3] Second, the additional costs of compliance are the same in the north and south (EUR 9 per m^2) but higher in the central regions (EUR 12 per m^2). This is

3 In summary, the enforcement of the building code offers the following savings from building envelope improvements: 45 percent in the north, 30 percent in the central and southern regions, and 20 percent for commercial buildings. National policy mandates that building improvements produce energy savings of 65 percent in the north, and 50 percent in the central and southern regions and in commercial buildings. As these savings incorporate energy savings from lighting and heating / cooling systems, the actual figure is about 20 percent less than total purported savings for residential buildings and about 30 percent less for commercial buildings.

because the average home in the central regions needs more investment to comply with the building code.[4] Compliance enables homes in the north to save 8 kg of SCE per m^2, whereas the reduction in homes in the central and southern regions is just 1 kg of SCE per m^2.

At the same time, it would cost an additional EUR 20 per m^2 to ensure that commercial buildings throughout China comply with the code, and the savings potential is 5–6 kg of SCE per m^2. Compared with residential buildings, commercial buildings rely more on electricity. As electricity costs more than coal, energy savings in commercial buildings have higher financial savings and thus a lower abatement cost.

Passive design for new builds

Passive design is the most significant GHG emissions abatement measure in the buildings sector, but it is the least ingrained in modern building techniques. Passive design is an integrated approach to building. It focuses on reducing a building's energy consumption for heating and cooling by optimizing its insulation, ventilation, orientation and shade. Passive design has an abatement potential of 290 million tons of CO_2e in 2030 (i.e., 27 percent of the total abatement potential in the sector). Passive design is economical to apply in all residential and commercial buildings, although it offers a quicker payback when applied to commercial buildings and homes in the north. The costs are negative (i.e., savings) for commercial buildings (EUR –33 per ton of CO_2e) and for homes in the north (EUR –14 per ton of CO_2e). The costs are positive (i.e., expenditure) for homes in central China (EUR 28 per ton of CO_2e) and in the south (EUR 9 per ton of CO_2e).

4 Based on real case studies, initial building costs for the north, central and south areas are EUR 140 per m^2, EUR 120 per m^2, and EUR 115 per m^2 , respectively. The variance in additional costs is due to differences in initial costs and building components in the three regions. Initial building costs in the north are the most expensive because insulation is already included as a basic building component (even though the basic insulation does not meet the current building code's standards). The initial building costs in central and southern regions are much lower because houses do not originally include insulation or high-efficiency windows. To meet the efficiency code, buildings in the south need to add better quality windows. In contrast, central area homes will need to increase both insulation and the number of high-quality windows, which adds 10 percent to the initial costs.

Passive design – reviving traditional approaches to overcome modern-day challenges

Passive design is not new. Traditional Chinese architecture embodies certain principles of passive design that attempt to harmonize the human-built and the natural environments. Applying such principles to modern buildings requires that architects rethink their approaches to the specific components of a building, e.g.

- Orient or position the building to absorb solar heat in cold regions and optimize solar heat in hot regions
- Build windows that open to reduce dependency on air conditioners, fans, and heaters
- Use smaller heaters or coolers, given that passive design reduces the need for them

There are two challenges to the application of passive design. The first is to embed the approach in the mindset of professionals in the buildings sector. Today, new building designs in China (and elsewhere) tend to overlook environmental considerations. Buildings rely, for example, on active (rather than "natural") heating and cooling systems. Moreover, buildings have to meet the demands of a newly affluent population that does not always consider the implications of its lifestyle choices.

The second challenge is to overcome a lack of effective dialogue between architects and civil engineers. In China's schools of architecture, energy efficiency is never (or rarely) on the curriculum. Hence, architects may not think twice about erecting curtain walls or putting in sealed windows. On the other hand, civil engineers, who may be more aware of energy-efficiency considerations, tend to focus on executing a design and rarely get involved in the decisions that led to it.

The outlook for passive design in China is still unclear. Some experts say it will take a couple of years to integrate passive design principles fully into new buildings; others say it will take decades.

For China, passive design represents an ideal building approach founded on three cornerstones:

- Maximizing natural light, ventilation and shade
- The smart integration of building components to complement the design (i.e., proper-sized cooling units, windows that open, and insulation where necessary)
- Cooperation between engineers and architects for successful execution.

Passive design has emerged as the best alternative to standard building practices (which rely on a building's internal components to compensate for any shortcomings in design). Passive design can realize higher savings from improvements to the building envelope than those prescribed in the current building code. A comparative analysis of the US and China building codes reveals that the US code has an additional savings potential of 15–20 percent owing to passive design elements.

Passive design for residential buildings offers 15 percent extra energy savings on top of those realized by enforcing compliance with the building code. In absolute terms, for homes in northern China, the primary energy savings from heating represent 10 kg of SCE per m^2 annually. The secondary energy savings from cooling and a slight share of heating are 3 KWh per m^2. The extra cost (compared to the existing building codes) in the north is under EUR 1 per m^2. In the central areas, savings amount to 1 kg of SCE per m^2 in primary energy consumption and 5 KWh per m^2 in electricity. In the southern areas, savings of 9 KWh per m^2 can be realized. The additional cost is also EUR 1 per m^2.

With regard to commercial buildings, passive design typically applies to newer modern constructions that tend to consume more energy than traditional buildings. In this case, the expected additional savings amount to some 20 percent. This equals an annual saving of 6 kg of SCE per m^2 in primary energy and of 29 KWh per m^2 in electricity. The additional cost is EUR 10 per m^2.

We believe passive design concepts could be incorporated into 12 percent of residential buildings in China by 2020 and 60 percent by 2030. As commercial architecture is more open to “cutting edge” design ideas, we estimate passive design concepts could penetrate 15 percent of all commercial buildings by 2020 and 70 percent by 2030.

“Retrofit packages”

Retrofitting aspects of the building envelope in existing buildings has an abatement potential of 200 million tons of CO_2e at a relatively low cost. Retrofitting traditional commercial buildings represents half of the potential, at a cost of EUR 14 per ton of CO_2e. Most of the remaining abatement potential stems from retrofits to residential buildings in northern China, with an abatement cost of EUR 3 per ton of CO_2e. Cheap and simple abatement solutions also exist for residential buildings in the southern and central regions. These would reduce GHG emissions by 13 million tons of CO_2e at a negative cost.

In our analysis, we tailored such retrofit packages to the climate and the building types to generate the highest return on the necessary investments. Where energy consumption is high (e.g., commercial buildings and homes in northern China), adding insulation with superior u-values[5] has a very high impact as part of a retrofit package. Moreover, inexpensive additions (e.g., replacement windows, devices to provide shade, and door and window strips to minimize air-conditioning “leakage”) can provide further significant savings. Retrofit packages for homes in the central and southern regions comprise such inexpensive components.

The importance of retrofits depends on its penetration rate and the building stock eligible for retrofitting. The eligible building stock comprises the existing stock in 2005 (assuming a demolition rate of 1.3 percent per year) and stock built after 2005 that does not conform to the building code or to passive design principles. While China has few retrofitting companies today, more will emerge in the next 20 years. We forecast that retrofitting will reach 70 percent of eligible residential buildings and 90 per cent of commercial buildings (due to a combination of preference and government enforcement) by 2030.

5 A measure of heat transmission through a building part (a wall or window) or materials of a given thickness

We expect energy savings of 40 percent from retrofitting northern homes. This represents 6 kg of SCE per m^2 in primary energy and 2 KWh per m^2 in electricity. The expected energy savings from retrofitting all commercial buildings are 20 percent (i.e., 2 kg of SCE per m^2 and 11 KWh per m^2). The initial investment to retrofit homes in northern China is only about one-third of the cost for commercial buildings. Using simple retrofitting techniques in the south and central areas would yield energy savings of 20 percent at a cost of only EUR 4 per m^2.

2. Efficient HVAC systems

Increasing the energy-efficiency of HVAC systems yields a total maximum abatement potential of 280 million tons of CO_2e. The abatement costs vary from highly negative to highly positive. Despite this, implementing the measures both in residential and commercial buildings will contribute substantially to energy savings.

Residential sector

For homes in northern China, the principal improvements involve the expansion of district heating and district heating controls.[6] The former involves replacing low-efficiency community boiler systems with large network coal-boiler systems. We assume that coal-based heat-only plants will substitute 90 percent of community boilers by 2030. Replacing them completely is not practical due to the difficulties of connecting remote communities to a district heating network. This measure offers energy savings of 25 percent, amounting to an abatement potential of 71 million tons of CO_2e by 2030.

Eliminating the excess heat generated by current systems can double the savings. District heating controls could reduce emissions by a further 69 million tons of CO_2e at a (negative) cost of EUR –15 per ton. However, the widespread implementation of district heating controls requires well-insulated buildings and a reform of the heating system. The latter is critical given the rate of new residential construction in China. Currently, residents have limited control of their heating. For instance, they cannot control the amount of heat delivered. Moreover, heating charges are at a flat rate per square meter of floor space and not based on actual consumption.

Commercial sector

Most of China's commercial buildings operate with inadequately commissioned and poorly managed building automation systems (BAS). A properly calibrated and managed BAS can cut energy consumption by 20 percent, saving a total of 16 million tons of SCE of primary energy and 93 billion KWh of electricity. The GHG emissions abatement potential is 91 million tons of CO_2e.

We estimate the cost of retrofitting a BAS at EUR 66 per square meter, including the costs of retro-commissioning and employing trained building-system managers. This leads to a substantial abatement cost of some EUR 30 per ton of CO_2e. Most experts, however, remain

6 In the district heating system, a heating supply plant burns coal to heat water distributed by pipes to a routing point (substation). This is the primary heating network. In addition to maintaining water pressure, the substation channels heated water to buildings. This is the secondary heating network. Lastly, a system of pipes at the building entrance circulates heated water to rooms. This is the tertiary heating network. Heating controls, which regulate the flow and volume of heat through the system, may be integrated in both the secondary and the tertiary (i.e., the end-user level) heating networks.

optimistic about the impact of BASs. They believe that, although costly, a centralized control system is necessary in modern buildings in China. Given the limited capacity to undertake retro-commissioning today, we assume BASs will not achieve full penetration by 2030.

Commercial as well as residential buildings can also benefit from using high-efficiency pumps in their HVAC systems and water supply/drainage systems. The abatement potential of energy-efficient variable-speed pumps is 46 million tons of CO_2e by 2030. The abatement cost is negative at EUR –54 per ton of CO_2e, thanks to a low capital investment of EUR 0.4 per m^2.

3. Energy-efficient lighting

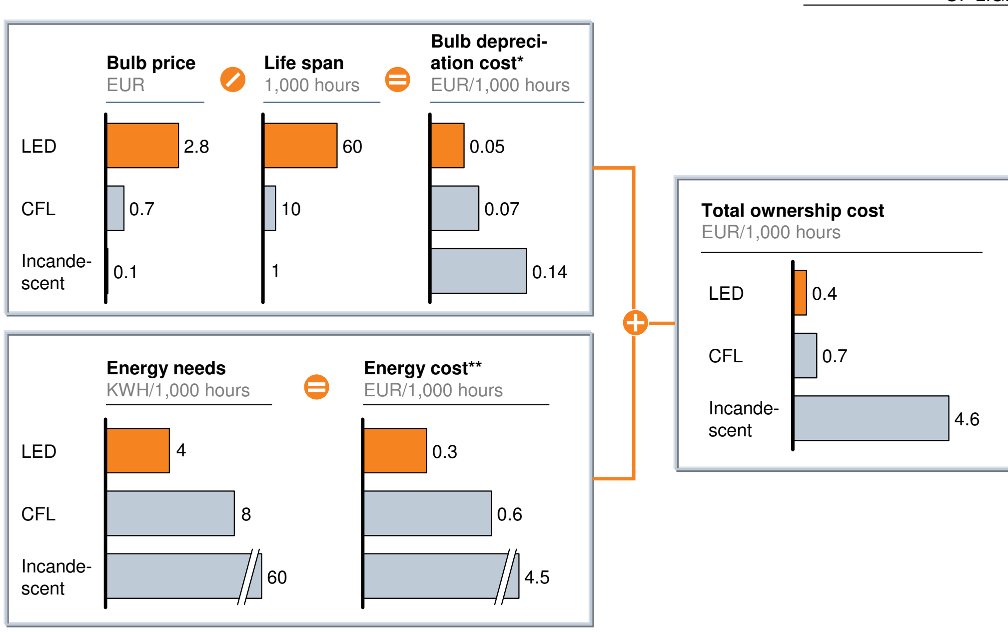
By replacing less efficient lighting with light emitting diodes (LEDs), China could reduce emissions by 145 million tons of CO_2e at an average (negative) abatement cost of EUR –124 per ton.

The Chinese government is aware of the need to move to more energy-efficient lighting and encourages the use of compact fluorescent lamps (CFLs). In our baseline scenario, we estimate that CFLs will represent 48 percent of residential lighting and 20 percent of commercial lighting. However, replacing all CFLs and the remaining incandescent lighting by LEDs would yield energy savings of up to 190 billion KWh of electricity (i.e., 2 percent of total power demand in 2030 in our baseline scenario). We calculate that replacing the incandescent lamps in China with LEDs would contribute 84 percent of the energy savings. LEDs are up to 14 times more efficient than incandescent lamps and twice as efficient as CFLs. As a result, for the same luminosity and time, LEDs' total cost of ownership (i.e., depreciation plus the cost of electricity) is half that of a CFL and one-tenth that of an incandescent lamp (Exhibit 26).

Exhibit 26

TOTAL OWNERSHIP COST OF DIFFERENT LIGHTING TECHNOLOGIES – 2030

FOR LIGHT BULBS WITH THE SAME OUTPUT OF LIGHT



* Discount rate = 0 for simplicity
** Assuming power cost in 2030 of EUR0.08/Kwh
Source: IEA; isuppli; expert interviews; literature research; McKinsey analysis

The costs of LEDs should fall by more than 80 percent by 2015 to EUR 3–4 per lamp bulb. Moreover, we expect LEDs to become more consumer-friendly over the next ten years (e.g., producing a warmer light and offering solutions for a range of applications currently covered by CFLs and incandescent lamps).

In addition, lighting controls installed in commercial buildings would cut usage by 50 percent (in new buildings) and by about 30 percent (in older buildings). This represents energy savings of 62 billion KWh of electricity.

SUSTAINABILITY IMPROVEMENTS IN THE CONSTRUCTION PROCESS

In addition to making buildings and appliances more energy efficient, there is a significant opportunity to improve sustainability by intervening in the construction process. For example, technologies such as prefabrication hold great potential for China. Prefabrication is the practice of transporting preassembled building components to a construction site. Prefabrication is widespread in Europe and in developed Asian cities. The preassembly system optimizes construction operations, thus lowering overall resource usage and the level of particulate matter (e.g., PM10) in the air.

Over the entire construction process, estimates show that prefabrication can cut resource consumption significantly (e.g., power by 30 percent, water by 60 percent and wood by 90 percent) and reduce waste production and pollution by 10 percent. Using less power and wood also produces a tangible carbon abatement of 17 kg of CO_2e per m^2 of floor space – but at a very high cost of EUR 360 per ton of CO_2e.

The energy savings and corresponding GHG emissions reduction come at a high cost due to the heavy initial investments required to switch to prefabrication building techniques. However, GHG emissions abatement does not capture the full impact of prefabrication on the environment and sustainability. The substantial reductions in resource usage make prefabrication one of the most critical technologies for improving sustainability in the sector.

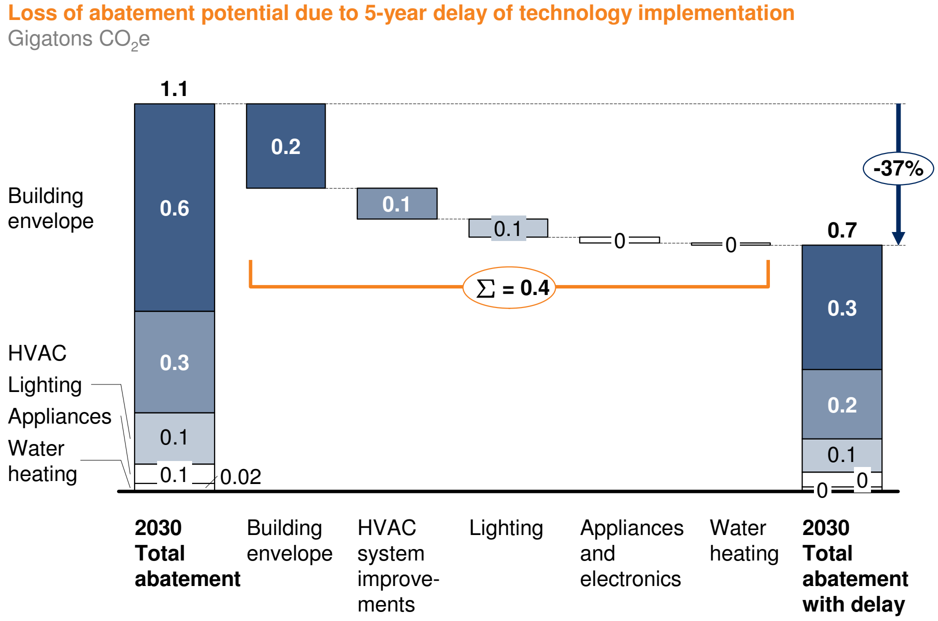
BARRIERS TO IMPLEMENTATION

The GHG emissions abatement potential of the buildings and appliances sector is very sensitive to delays in implementation. Our sensitivity analysis shows that a delay of only five years would reduce the total maximum abatement potential by 400 million tons of CO_2e (i.e., one-third) due to lock-in effects (Exhibit 27). If the delay were 10 years, the abatement potential would decline by over 50 percent.

Without quick and decisive action, China will lose opportunities as new building development peaks. Later intervention would cover only a fraction of new floor space. Retrofitting finished buildings to achieve the same level of energy savings would cost EUR 175 billion more than implementing the improvements in buildings under construction.

Exhibit 27

IMPACT OF 5-YEAR DELAY IN IMPLEMENTATION – BUILDINGS AND APPLIANCES SECTOR – 2030



Source: McKinsey analysis

Furthermore, these sustainability improvements entail significant social, administrative and transactional costs, which could hinder their implementation.

- *Building envelopes – the "agency/principal" barrier.* Although developers pay the extra upfront cost to improve building envelopes, they often cannot pass on their costs to end users (who are the direct beneficiaries of the energy savings). An effectively enforced, mandatory building code could resolve this by "pushing" developers to comply without the need for a "pull" incentive. Naturally, this will incur administrative costs for building-quality regulators and require evaluation mechanisms to enforce the building code. In addition, there are costs to train a new generation of architects and engineers in passive design techniques.

- *Lighting – the "consumer preference" barrier.* The diffusion of energy-efficient lighting, (e.g., CFLs) is proving slow. Despite awareness programs and government subsidies, the penetration of CFL bulbs has reached only around 10 percent, a decade after their introduction. The primary reason is that consumers do not perceive the long-term payoff from using relatively expensive CFLs. One potential solution is to implement mandatory measures to ensure the removal of incandescent lamps from the market, as has happened in Australia, for example.

- *HVAC – "heating-reform cost" barrier.* More stringent energy efficiency standards for heating controls and pumps risk driving inefficient local players out of the market. More important, there is a social cost to wide-scale reform of heating systems and pricing: heating may become unaffordable for lower-income groups. The Chinese government has to decide whether to include such standards in the building code and roll out heating reform. If it does, it must also consider how to address the needs of low-income families.

It is not enough to consider only the tradeoff between the GHG emissions abatement potential and the abatement costs. China also needs to factor in the higher cost of the new coal-fired power plants it will need to heat, cool and light its ever growing – but energy-wasting – building stock. Moreover, as we have pointed out, burning more coal places a considerable strain on the countries' energy supplies, transportation systems and local pollution levels.[7]

***

Overall, the sustainability improvement opportunities in the buildings and appliances sector are backed up by sound economics. Taking the necessary steps now will help to meet the increasingly severe problems of energy security facing many Chinese cities. The challenge is for China to take swift and decisive action to implement the technologies and techniques to improve energy and environmental sustainability as the country gears up to build its future cities.

7 Beijing, for instance, requires 30 million tons (and growing) of coal every winter. Moreover, transporting coal has become a massive burden on the rail and road networks feeding Beijing. The strains on the coal supply chain led to a shortage of power as well as heating disruptions in the winter of 2007.

Road transportation sector: Improving fuel efficiency and reducing oil dependency

As purchasing power increases, people aspire to better living standards. For many Chinese, owning a car is part of that aspiration. Between 2002 and 2007, the size of the vehicle fleet in China more than doubled. We expect the growth in demand for cars to continue so that by 2030 the total vehicle fleet will be ten times larger than in 2005. At this size, oil consumption and GHG emissions will be close to four times higher than the 2005 level. The explosion in vehicle ownership will strain the country's infrastructure and energy security.

As well as emitting greenhouse gases, motor vehicles are a major source of air pollution, particularly in urban areas. The volume of chemical and particulate pollutants from vehicle exhaust has increased exponentially in China in recent years. Pollution from vehicle exhaust results in poor visibility in many cities, and poses a significant threat to the public's health and the environment. Noise is another form of vehicle pollution that is drawing increasing attention. In some cities, estimates put the level of urban noise attributable to motor vehicles at up to 75 percent. Thus, creating a "greener" and more energy-efficient vehicle fleet is an urgent challenge to achieve sustainable urbanization in China.

We analyzed more than 20 different technologies to reduce oil consumption and GHG emissions in the road transportation sector.[8] These include fuel efficiency improvements in conventional internal combustion engines (ICE), electric vehicle (EV) technologies, as well as bio-fuel technologies.[9] Overall, such technologies provide an abatement potential of approximately 600 megatons of CO_2e in 2030 across all classes of vehicles (light, medium, and heavy duty). This represents a reduction of about 200–300 million tons in demand for gasoline and diesel in China.

ICE efficiency improvements and electric vehicles are the two major technological routes toward reducing energy dependency and GHG emissions in the road transportation sector in China. ICE improvements generally offer better economics, but uncertainty regarding the technologies remain, and we do not expect their commercialization before 2015. EV technologies, on the other hand, are more mature, but are also more costly. Nevertheless, when we consider national energy security, local pollution alleviation and the potential for technology leadership, EVs are a more attractive option for China.

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8 For practical reasons (i.e., to reduce complexity and scope to manageable levels), we only considered road transport in our analysis as it consumes most of the energy and produces most of the GHG emissions in the transportation sector. We do not cover the potential opportunities for GHG emissions abatement and/or sustainability improvements in the aviation, rail and sea transportation industries.

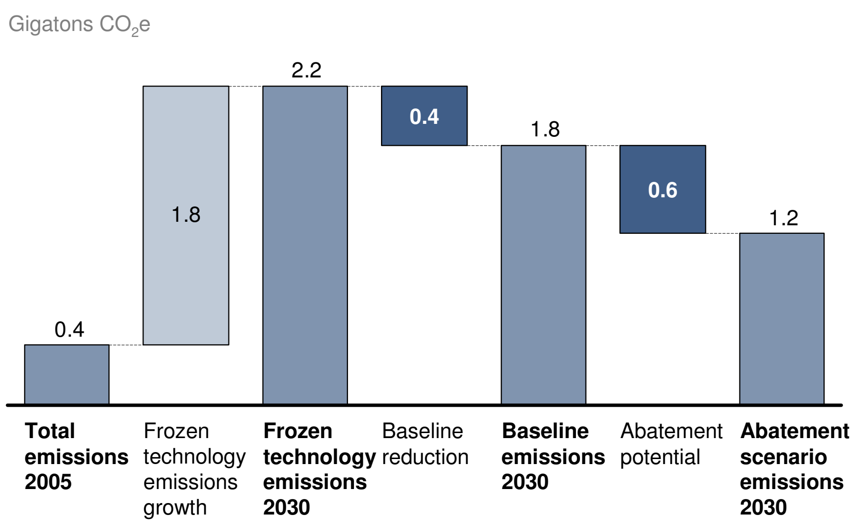
9 First-generation bio-fuel technology uses starch (from food or non-food plants) to produce ethanol. It is inefficient in abating GHG emissions due to its high energy requirements and significant process emissions. Second-generation bio-fuel technology, which is still under development, uses cellulosic material (e.g., straw) to produce ethanol. It has a potential to help reduce GHG emissions. (See the discussion of agricultural waste as part of our report on the emissions-intensive industry sector.)

BASELINE SCENARIO

We estimate annual emissions in the road transportation sector will grow from about 0.4 Gt of CO_2e in 2005 to around 1.8 Gt in 2030 (Exhibit 28). Furthermore, gasoline and diesel consumption will increase from 110 million tons in 2005 to almost 500 million tons in 2030. This increase reflects an expected tenfold increase in the number of vehicles on the road, as privately owned cars become more accessible to people in China and medium-to-long-distance road freight develops. The growth of China's fleet of light-duty vehicles (LDVs) to some 290 million vehicles will account for about 90 percent of the increase in vehicles. In 2030, vehicle ownership in China (as measured by the number of vehicles per 100 people), will be similar to that in Taiwan in 2005.

Exhibit 28

SCENARIOS OF GHG EMISSIONS FOR TRANSPORTATION SECTOR



Source: McKinsey analysis

As mandated by the government, the average fuel efficiency of for new passenger vehicles will improve from about 10.1 liters per 100 km now to roughly 8.6 liters per 100 km. We expect a further improvement to 7.4 liters per 100 km by 2030 as technology evolves (i.e., a 25 percent improvement on the 2005 level). The incremental upfront investment needed for this efficiency gain will be just EUR 140 per vehicle according to industry experts. The savings from increased fuel efficiency would more than offset the initial investment within five years (i.e., the typical ownership period for passenger vehicles). Therefore, consumers should be willing to pay the premium for higher efficiency vehicles, even without the government mandating it. We expect less significant fuel efficiency improvements in medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs).

As a result of these improvements, we estimate a baseline carbon reduction in the road transportation sector of about 0.4 Gt of CO_2e (i.e., compared to our frozen technology scenario in which we assume no changes in vehicle fuel efficiency).

ABATEMENT OPPORTUNITIES

The principal abatement options in the road transportation sector (improving ICE vehicles and developing EVs) are competitive and mutually exclusive. Therefore, we have adopted a marginal (incremental) approach to evaluating both potential and cost.

Marginal (incremental) potential and cost approach

The two competing abatement technologies (ICE and EVs) and their specific technical levers are mutually exclusive. To estimate the full technical abatement potential and costs, we sequenced the abatement opportunities in the transportation sector and adopted a marginal (incremental) approach.

We calculated independently the standalone GHG emissions abatement potential and costs of the ICE and EV options by assuming full penetration of the respective technologies in all new vehicles in a given year. We then ranked the specific options by potential and cost. Options with lower potential and higher cost (e.g., the two LDV gasoline-ICE bundles that provide the highest fuel efficiency) do not appear on our cost curve as they have inferior fuel- and carbon-reduction efficiency levels. We sequenced the remaining options in order of increasing cost. On our abatement cost curve, each option's potential and cost are incremental to the option to its left. However, our analysis reveals that, in general, ICE fuel-efficiency improvement levers have lower abatement potentials at lower costs. Therefore, on this sector's cost curve, we position the ICE levers on the left, applying their full potential and real costs. We then calculated the EV levers potential and costs as marginal (incremental) to the ICE levers.

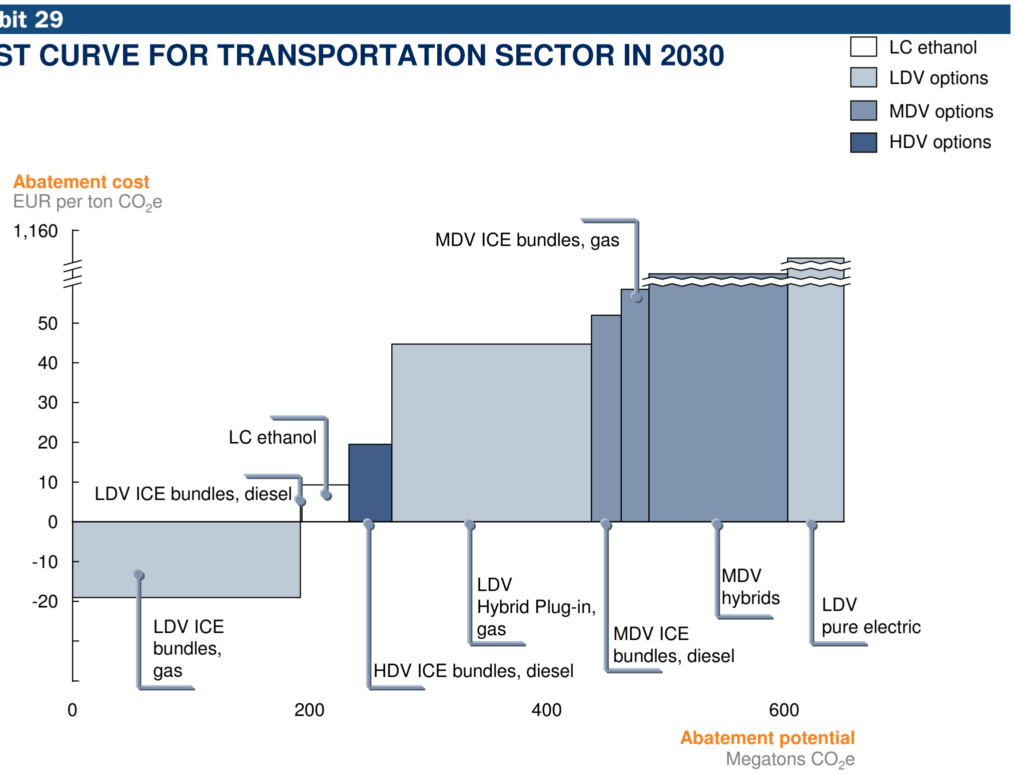
Hence, our cost curve reflects the true maximum technical abatement potential in the transportation sector. Our sector cost curve does not represent the standalone potential and costs of the EV technology route, but signifies the high opportunity cost of pursuing the additional abatement potential by pursuing EV rather than ICE technologies. (e.g., the standalone cost for PEV is EUR 134 / ton of CO_2e, its marginal (incremental) cost is much higher at over EUR 1,000 / ton of CO_2e).

ICE efficiency improvements have a total GHG emissions abatement potential of roughly 270 megatons of CO_2e at a cost ranging from EUR –19 to about EUR 50 per ton of CO_2e. The cost depends on the type of vehicle and the level of efficiency gains. We estimate that ICE efficiency improvements would reduce oil consumption by up to 100 million tons. ICE efficiency measures for LDVs account for more than half of the potential and offer particularly good economics (i.e., an average negative cost of EUR –19 per ton). This is because the upfront investments in the technology are low and fuel savings over a vehicle's lifetime more than offset them. For MDVs and HDVs, the abatement potential from ICE improvements is lower and costs are higher. This is due, in part, to the limited margin of improvement offered by the diesel technology widely used in MDVs and HDVs.

Electric vehicles, including plug-in hybrid vehicles (PHEVs) and pure electric vehicles (PEVs), have a marginal (incremental) GHG emissions abatement potential of 330 megatons of CO_2e at an average marginal (incremental) cost of nearly EUR 450 per ton. We estimate that EVs would reduce oil consumption by about 130 million tons (i.e., in addition to the ICE efficiency improvement measures outlined above). The high abatement cost reflects the substantial upfront investments required. Whereas PEVs have a higher marginal (incremental) abatement potential than PHEVs, they also have far higher costs. Hence, plug-in hybrid LDVs offer the best economics as an EV solution with marginal (incremental) abatement costs of around EUR 45 per ton of CO_2e (Exhibit 29).

Exhibit 29

COST CURVE FOR TRANSPORTATION SECTOR IN 2030



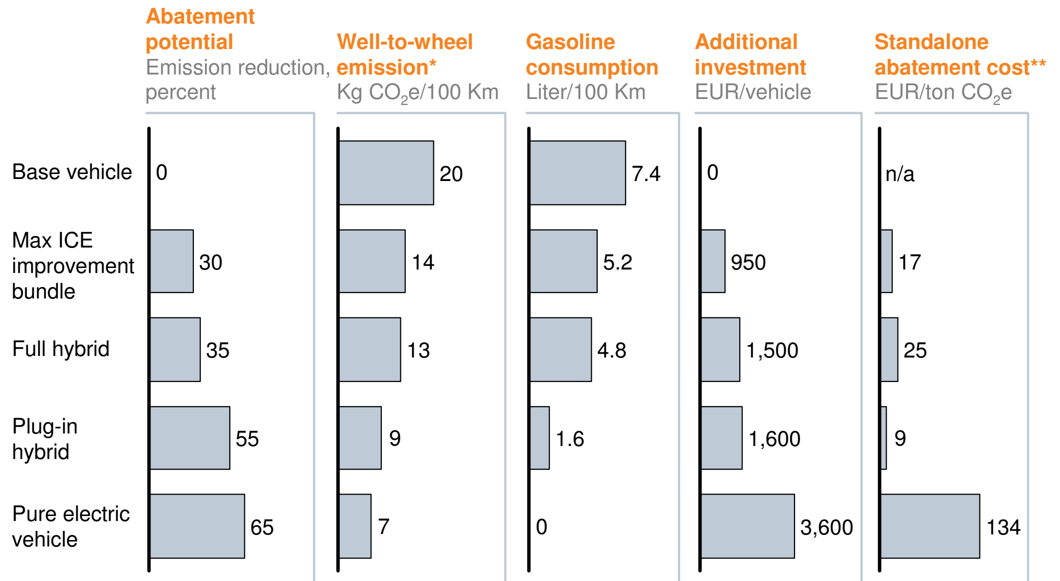
Source: McKinsey analysis

The marginal (incremental) approach is suitable for taking a “macro” perspective because it focuses on the maximum technical potential and takes into account the opportunity cost of choosing one technology over others from a pool of mutually exclusive technologies. However, given the uncertainty of technological evolution, most automobile manufacturers are developing several technologies simultaneously. Industry experts recognize that vehicles coming to market in the future are likely to adopt multiple technologies. It is therefore important to have a perspective on the “standalone” abatement potential and costs of the competing technologies mentioned above. Without making any predictions of the future penetration rates of the various technologies, we can compare the standalone abatement potential and cost of the technologies for LDVs[10] on a unit basis (Exhibit 30).

10 LDV is the dominant category that EV technologies can be applied to

Exhibit 30

LDV – ABATEMENT POTENTIAL AND COST ON A STANDALONE BASIS – 2030



* Emission is calculated based on 2030 power mix assumed in our baseline, where coal power share is 65 percent

** Pure electric vehicle electricity consumption 9 KWh/100 Km, plant to battery efficiency 85%; Battery-to-wheel efficiency 81%; hybrid car with 66 percent electric share

Source: DRIVE; expert interviews; McKinsey analysis

1. ICE fuel-efficiency improvements

Various measures, including reducing tire friction, vehicle weight and fuel leaks, can improve the fuel efficiency of ICEs in all vehicle types. According to industry experts, commercialization of the necessary technologies could begin in 2015. Because these technical measures work in combination to maximize the efficiency improvement, we categorized the ICE efficiency options in technology "bundles." Overall, these bundles have a GHG emissions abatement potential of 270 megatons of CO_2e.

The abatement cost of fuel efficiency improvements for conventional ICE vehicles includes lifetime fuel savings. Usually, vehicles have several owners over their average 15-year lifetime. The actual fuel savings achieved by an individual owner will depend on how long he or she owns the vehicle. Consequently, for any individual owner of a vehicle, the abatement cost of ICE fuel-efficiency improvements may be positive (i.e., the cost is higher than the fuel savings), even though it would be negative (i.e., lifetime fuel savings are greater than the cost) for society as a whole.

We base our ICE fuel-efficiency options on the realistic estimates of industry experts. Some automobile manufacturers are testing cutting-edge technologies (e.g., new types of light materials to reduce vehicle body weight) that are currently far from reaching full commercialization. If such technologies were to prove viable, we could expect further improvements in fuel efficiency and, thus, higher abatement potential and lower costs.

Light-duty vehicles

We identified several options to improve the fuel efficiency of ICE-powered LDVs that burn gasoline or diesel. Overall, these options have an abatement potential of some 190 megatons of CO_2e, at a negative average cost. Some of the most notable options are variable valve controls, air-conditioning modifications, tire-pressure control systems, aerodynamic efficiency improvements, transmission optimization, and engine-friction reductions. Although each of the technologies makes its own contribution, we had to analyze the options in bundles to avoid any double counting of efficiency gains. These bundles of options also allow for balancing performance and efficiency and are consistent with best-practice vehicle design.

The ICE fuel-efficiency bundles would add some EUR 330–950 to the cost of a LDV and improve fuel efficiency by 13–30 percent (compared to our baseline scenario) by 2030. This would mean that an average new gasoline-powered car in 2030 would burn fuel at a rate of 5.2–6.4 liters per 100 km. An average new diesel-powered vehicle would achieve 4.3–5.3 liters per 100 km in 2030. It is worth noting that the cost efficiency of further reductions in ICE oil consumption and carbon emissions diminishes as fuel efficiency improves. The two ICE efficiency bundles that provide the highest gasoline-engine fuel-efficiency improvements have such high abatement costs that hybrid plug-in vehicles provide better economics. These two bundles, therefore, do not appear on the cost curve.

As mentioned above, most ICE abatement options would have a negative cost because fuel savings offset the incremental costs of fuel efficiency over the lifetime of a vehicle. The savings would increase if the long-term price of oil were to climb above the US$60 per barrel assumed in our baseline scenario.

Medium-duty and heavy-duty vehicles

For MDVs and HDVs, ICE fuel-efficiency improvements are costlier than for LDVs. We analyzed measures such as improving rolling resistance (rolling friction) and enhancing vehicle aerodynamics, among others. Technology bundles for MDVs and HDVs would improve fuel efficiency (compared to our baseline scenario) by 8–13 percent (MDVs) and 4–10 percent (HDVs) by 2030. They would add EUR 340–670 to the cost of a vehicle. The total GHG emissions abatement potential is 47 megatons of CO_2e (MDVs) and 35 megatons of CO_2e (HDVs).

2. Electric vehicles

Electric vehicles include plug-in hybrid vehicles (PHEVs) and pure electric vehicles (PEVs).

PHEVs have rechargeable batteries and a higher power capacity than full hybrids, while a smaller proportion of their propulsion comes from a conventional ICE. PHEVs can be both light and medium duty vehicles. Light duty PHEVs have a marginal (incremental) abatement potential of 165 megatons of CO_2e at a marginal (incremental) abatement cost of EUR 45 per ton of CO_2e. PEVs, on the other hand, run solely on battery power and are mainly light duty vehicles. PEVs have a marginal (incremental) abatement potential of 46 megatons of CO_2e, but a high marginal (incremental) abatement cost of over EUR 1,000 per ton.

PHEVs and PEVs are more expensive than the efficiency improvement measures for ICE-driven vehicles. By 2030, the incremental initial investment needed for a passenger PHEV (about EUR 1,600) or a passenger PEV (about EUR 3,600) would be substantially higher than for ICE-driven vehicles (even after accounting for the potential to cut costs by localizing R&D and production in China). Against this, PHEVs would consume 70 percent less gasoline, while PEVs would need none. With regard to GHG emissions, PHEVs and PEVs would generate, respectively, about 35 percent and 50 percent less CO_2 emissions than the most fuel-efficient ICE vehicles by 2030.[11] PHEVs' standalone abatement cost is low at EUR 9 per ton of CO_2e, as they are more affordable and quite efficient in cutting oil consumption and GHG emissions. PEVs, however, still have a long way to go: the fuel savings of a PEV do not offset the initial investment needed. PEVs' standalone cost is thus much higher at above EUR 100 per ton of CO_2e.

PHEVs and PEVs differ significantly from "full hybrid" vehicles, which run primarily on gasoline. In a full hybrid vehicle, an electrical drive system is packaged in parallel to the ICE drive system and is calibrated to run when conditions best suit electrical driving. The full hybrid battery is charged by the drive cycle of the vehicle (e.g., regenerative braking), hence the vehicle draws most of its power from an ICE. Full hybrids are less efficient than EVs in cutting fuel consumption and GHG emissions. Estimated GHG emissions from full hybrids are 45 percent higher than PHEVs and 85 percent higher than PEVs. Globally, Japanese carmakers are leaders in the full hybrid market. In China, EV technologies have attracted far more investment than full hybrid technology. Consequently, we assume full hybrid vehicles offer less potential than PHEVs for cost reductions (mainly through large-scale and timely localization) in the future. Given its limited abatement potential and high cost, we do not consider full hybrid technology as a focus of discussion in our report. Obviously, our assumptions and analyses are subject to change depending on the future dynamics of the automotive market and technological developments.

The abatement cost of EVs is sensitive to oil prices and China's power mix (i.e., the combination of energy sources used to generate electricity). The higher the oil price, the lower the abatement cost because a higher oil price offsets more of the initial investment cost for EVs through fuel savings. Moreover, a "cleaner" power mix (i.e., less power generated from coal and more from cleaner energy sources) would lower the abatement cost as the CO_2 abatement levels of EVs would increase (Exhibit 31). Sensitivity analysis shows that when the price of oil climbs above USD 110 per barrel, the standalone abatement cost of PEVs drops below zero.

Although the high initial investments weaken the economics of EVs, China has other incentives to develop its own EV technology, such as ensuring national energy security and technology leadership. In terms of energy security, deploying EV technology after 2015 would cut gasoline demand in 2030 by up to 70 percent (compared to our baseline scenario). This would reduce China's oil imports by 30–40 percent and improve the country's oil self-sufficiency ratio from just over 20 percent to about one third (Exhibit 32).

11 Our figures take into account the lifetime GHG emissions from gasoline ("well to wheel") and electricity ("plant to wheel").

Exhibit 31

IMPACT OF OIL PRICE AND POWER MIX CLEANNESS ON PEV'S ECONOMICS – 2030

PEV standalone abatement cost

EUR/ton of CO_2e, 2030

Oil price 2005 real USD/ barrel, 2030	**Power mix cleanness** **2030 baseline power mix***	**2030 abatement power mix****
60	134	97
90	35	25
120	-64	-47

* Coal generation share 65%, CCS = 0

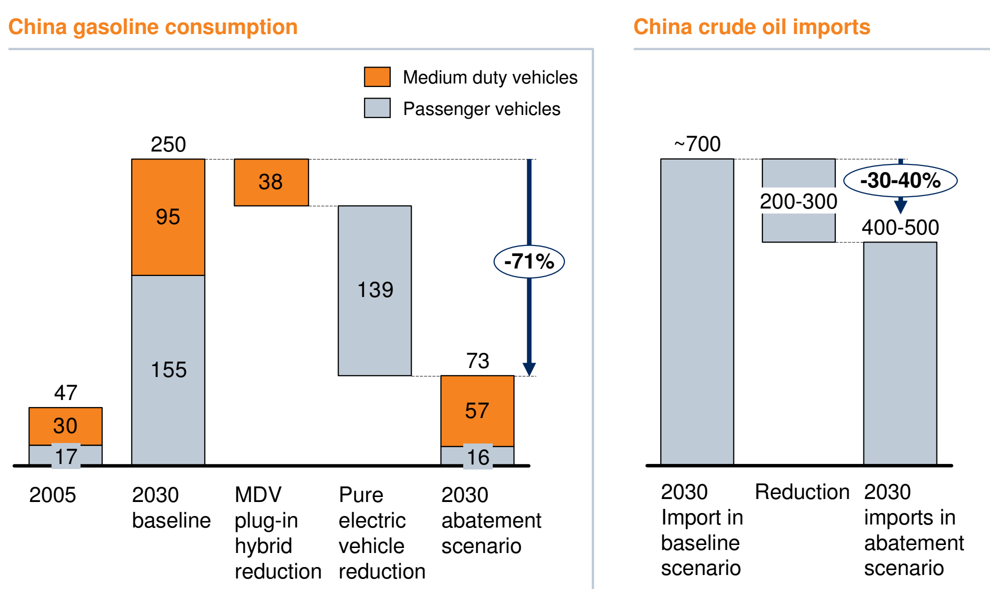
** Coal generation share 34%, CCS = 25% of coal power capacity

Source: McKinsey analysis

Exhibit 32

IMPACT OF ELECTRIC VEHICLE DEPLOYMENT ON GASOLINE CONSUMPTION AND OIL IMPORTS

Megatons



Source: EIA; IEA; China Energy Statistical Year Book; McKinsey analysis

With regard to technology leadership, China is the world's leading manufacturer of rechargeable batteries (after all, it has the world's largest electric bicycle and electric motorcycle fleets). The Chinese government's promotion of the "independent innovation" of intellectual property is driving several initiatives to foster investments in EV R&D. In December 2008, for example, a Chinese carmaker launched the world's first passenger PHEV that does not require a dedicated charging station for recharging.

China's technology leadership in EVs

China is a world leader in battery technology and well-positioned to move into electric vehicles. Chinese automobile manufacturers like BYD and the Wanxiang Group have high aspirations for EVs, and both are developing their own technology to avoid relying on foreign technology.

BYD, for example, is one of the world's largest battery makers. Established in 1995, BYD is a high-tech private enterprise listed in Hong Kong with production sites in Guangdong, Beijing, Shanghai, and Xi'an. Its total workforce is over 130,000. Since entering the automobile industry in 2003, BYD has made strides in whole-car manufacturing, especially EVs.

BYD is innovating in electric vehicles and rechargeable batteries. In 2006, it released its first pure electric concept car, the F3e, at the Beijing Auto Show. The F3e combines BYD's latest developments in rechargeable battery technology, core automobile components and manufacturing technology. The F3e has zero pollution, emissions and noise. It has a top speed of over 150 km per hour and acceleration of zero to 100 km per hour in less than 13.5 seconds. Its electric power consumption is lower than 12 KWh per 100 km, with a driving range of up to 350 km per charge. The battery's lifecycle is about 2,000 recharges/600,000km. BYD is planning to launch the F3e in China by the end of 2009, and has announced plans to market its electric vehicles in the US and Europe.

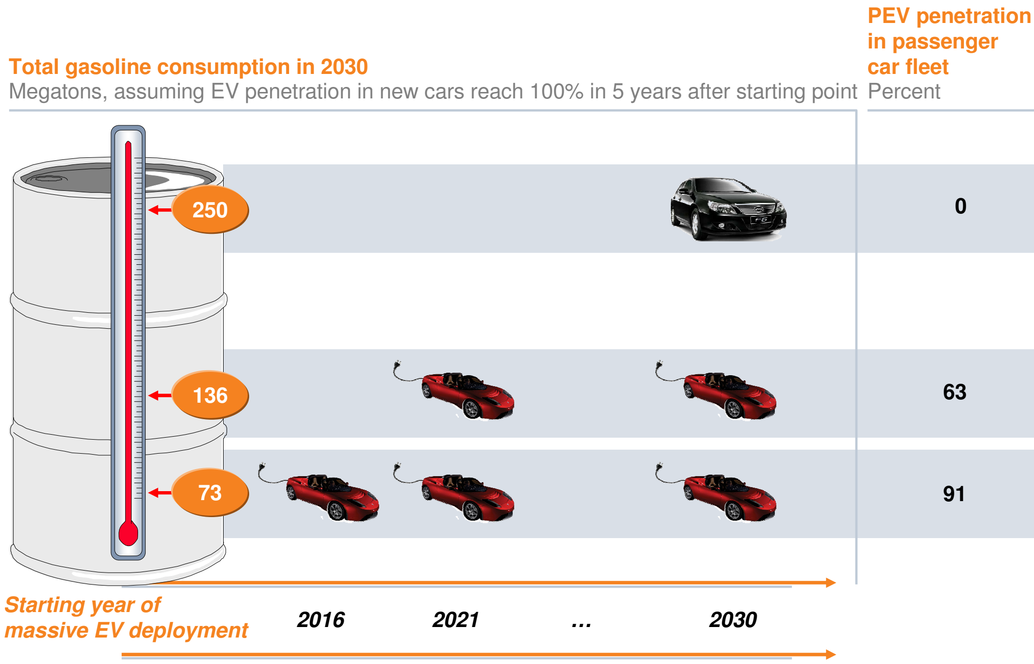
The US, Europe and Japan dominate the traditional ICE vehicle sector. Japanese firms, such as Toyota and Honda, lead in the full hybrid vehicles market. However, no clear leader has emerged to date in electric vehicles. By investing in R&D and capitalizing on its large supply of low-cost labor, its fast-growing automobile market, and its proven success in rechargeable battery technology, China could emerge as a technological leader in electric vehicles.

In addition, EVs can recharge in off-peak periods and therefore be applied like distributed power storage to match the load of wind and solar electricity. This will lead to a higher sold rate of renewable energy and a more streamlined load balance.

An early rollout of EVs is crucial to avoid lock-in effects and capture the full potential to reduce gasoline consumption. If a massive deployment of PEVs started in 2016, they could make up over 90 percent of passenger vehicles by 2030. Total gasoline demand could fall to approximately 70 megatons. A delay of five years (i.e., deployment starting in 2021) would result in higher gasoline demand of 140 megatons in 2030. Delaying the introduction of PEVs until after 2030 would result in gasoline consumption of 250 megatons. At this level, China's imported oil requirement would equal 13 percent of world oil production and its imported-oil dependency ratio would be almost 80 percent. Clearly, securing sufficient oil supplies in such a case could pose serious concerns (Exhibit 33).

Exhibit 33

SCENARIOS OF EV DEVELOPMENT AND GASOLINE DEMAND



Source: McKinsey analysis

CHALLENGES TO IMPLEMENTATION

China faces several challenges to capturing the potential of GHG emissions abatement and sustainability improvements in the road transportation sector. The country will need to take action to overcome the barriers and realize the full environmental and economic benefits of GHG abatement.

- *Perceived cost barriers.* The successful deployment of fuel-efficient ICE-driven vehicles and/or EVs has to overcome potential buyers' perceptions of the extra cost of such vehicles. Although the lifetime fuel savings from improved ICEs and from PHEVs offset or, almost equal their higher initial costs, buyers may hesitate to pay the extra upfront investment. Most buyers do not take a long-term view of the cost-benefit trade-off as the period in which they own a vehicle is usually shorter than the vehicle's lifetime. This suggests the need for some form of government intervention. For example, the authorities could establish higher fuel-efficiency standards (as recently introduced for all new passenger cars in China). This would allow carmakers to build in fuel-saving features for which customers would pay a premium.

  The lifetime fuel savings from PEVs are not sufficient to cover the high initial cost of such vehicles. Hence, PEVs may need financial incentives to encourage their adoption (e.g., rebates on fees or tax breaks for manufacturers and consumers). For instance, the

Chinese government announced recently a "green" tax to encourage people to switch to smaller, cheaper and more fuel-efficient cars. Taxes on cars with an engine capacity over 4 liters were increased to 40 percent, whereas taxes on cars with an engine capacity under 1 liter were reduced to 1 percent. A similar policy for EVs would reduce their effective cost and improve their perceived value, giving the EV industry a boost.

- *Infrastructure barriers.* Electric vehicles need a network of facilities to recharge or replace their batteries conveniently and securely. Installing a sufficiently dense battery-recharging infrastructure is critical. A recent McKinsey study estimates the cost of installing the necessary recharging facilities in China at RMB 5 billion–10 billion by 2020. The high cost of setting up recharging stations will require a joint effort by the government and the private sector.

- *Battery technology barriers.* The performance and cost of EV batteries is a major hurdle to their wide-scale use. In China, passenger cars are used mainly as a means of urban transport. In the cities, vehicles drive shorter distances and at slower speeds. Current EV battery capacity is sufficient to drive about 100 kilometers at an average speed of 50 kilometers per hour between charges. However, the large-scale introduction of EVs depends on much improved battery performance and lower battery costs, as well as smart technical solutions for (battery-draining) vehicle heating and cooling systems. Therefore, continued public and private investment in R&D is vital to push the development of battery technology.

- *Electric vehicle standards.* Specifying and implementing EV standards for technical specifications would lower the technical entry barriers and costs for companies and academic institutions investing in EV research.

***

With a projected tenfold increase in China's vehicle fleet by 2030, the road transportation sector is clearly of high importance in the effort to reduce not only GHG emissions and oil consumption, but also air and noise pollution. What people drive in China and how much diesel and gasoline their vehicles consume are critical to GHG abatement, environmental protection, energy security, infrastructure planning and industrial growth.

Two technological routes are open to China: improving the fuel efficiency of conventional ICEs and introducing EVs on a large scale. Although the costs are high and there are significant implementation hurdles to address, EVs yield a GHG emissions abatement potential double that of ICE measures. EVs would also contribute to alleviating pressure on oil supplies and provide a significant opportunity for Chinese technology leadership in a strategically important industry.

The emissions-intensive industry sector: Driving energy efficiency and waste recovery

For the purposes of this report, we have grouped five major industries, based on their emissions volumes, into what we call China's emissions-intensive industry sector. The industries are steel making, chemicals production, cement manufacture, coal mining and waste management. To manage the complexity of our analysis, we have not studied in similar detail other energy- or water-intensive industries (e.g., non-ferrous metal manufacturing or the pulp and paper industry). Some technologies (e.g., advanced process control) discussed in this section are also applicable to other industries. On the other hand, not all technologies important to the industry sector have been accounted for. Their potential to achieve sustainable development, though not in this report, should not be overlooked.[12]

The emissions-intensive industry (EII) sector plays a crucial role in China's sustainable development. The sector's energy consumption in 2005 was over 700 million tons of SCE energy (primary and secondary energy combined). At the same time, GHG emissions were 3.0 Gt of CO_2e. EII represented about one-third of China's total energy consumption and 44 percent of China's total annual emissions that year.[13] EII is also one of the major sources of air and water pollution in China.

In our baseline scenario, we estimate that the sector's energy consumption will reach 1,250 million tons of SCE in 2030. GHG emissions will increase to 4.8 Gt of CO_2e. Despite this, the sector's share of national emissions will decrease to just one-third of the total. Faster growth in other sectors will partly account for this fall in the share of total emissions in China. However, the main driver will be anticipated improvements in energy efficiency. Gains in energy efficiency reflect the substantial existing efforts by the Chinese government and the private sector to discontinue inefficient plants and foster the use of mature technologies to improve efficiency. The impact of such measures is not only on energy consumption and GHG emissions (as measured in our report), but also on a broad range of environmental indicators, such as water and air pollution levels.

Going beyond our baseline scenario, our analysis shows that GHG emissions abatement opportunities in the EII sector would yield a total maximum abatement potential of 1.6 Gt of CO_2e by 2030. At this stage, the recovery and reuse of by-products and waste becomes a crucial driver of GHG emissions reduction (e.g., the use of blast furnace slag as a clinker substitute in cement manufacture, power generation from burning municipal solid waste, and the recovery of coal-bed methane in coal mining). Further improving energy efficiency will also remain important in specific industries (e.g., steel and chemicals). Overall, there are GHG emissions abatement opportunities across all of the industries, processes and energy-related applications in the EII sector.

12 As our analysis focuses on GHG abatement opportunities, we do not claim to account for all technologies relevant to energy and environmental sustainability in the EII sector. The omission of a particular technology is purely on practical and methodological grounds, and does not reflect the potential impact of a particular method.

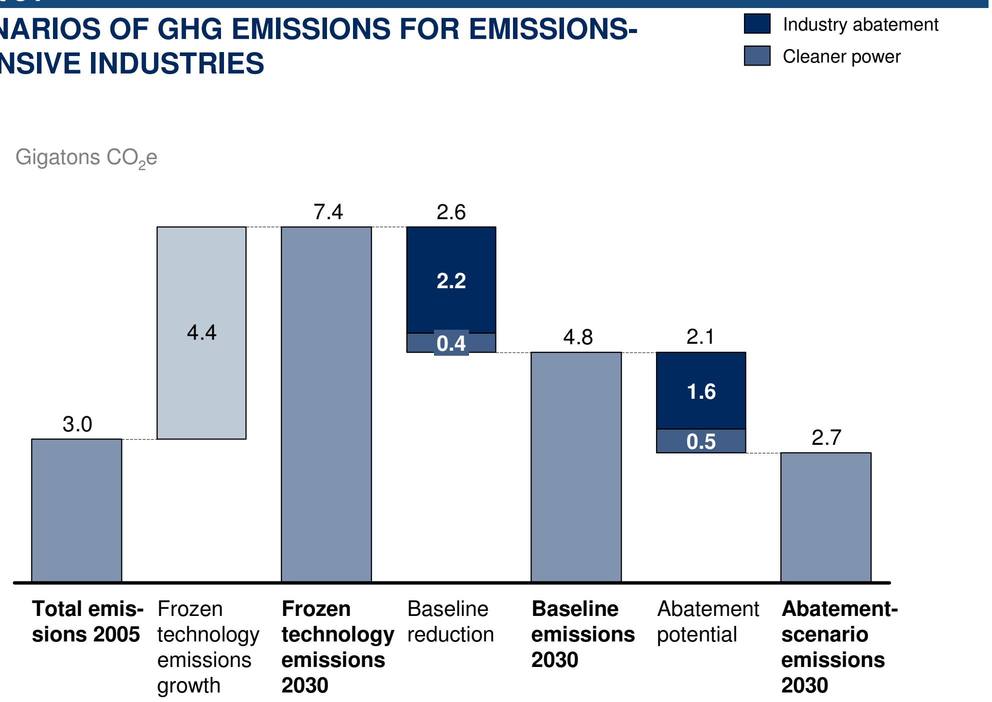
13 The figure includes emissions attributable to generating the electricity consumed by the sector

BASELINE SCENARIO

As mentioned above, by 2030, we estimate that energy consumption in the emissions-intensive industry sector will reach 1,250 million tons of SCE. It will produce 4.8 Gt of CO_2e, which represents a 60 percent increase from the sector's 2005 emissions level (Exhibit 34).

Exhibit 34

SCENARIOS OF GHG EMISSIONS FOR EMISSIONS-INTENSIVE INDUSTRIES



Source: McKinsey analysis

The major drivers of industry emissions growth are industrialization and urbanization, and the expansion of production in several industries. In particular, steel, chemicals and cement production will grow as China expands its industrial, transportation and urban infrastructure. We expect rapid growth in these industries over the next five to ten years. After 2020, we forecast production of steel, some chemicals and cement to stabilize or decline as demand drops off (as was the case in the US and in Japan, for example). We estimate that steel production in China will total 750 million tons in 2020 before stabilizing. Ammonia production will reach a peak of 75 million tons in 2030. We expect cement consumption to peak in 2020, when cumulative cement consumption per capita will be 20–25 tons (similar to the trend shown in Japan and Taiwan).

In our baseline scenario, we consider the impact of energy efficiency and carbon reduction initiatives *that are already in place or known and planned*, including government policies and private sector efforts.[14] By comparison, in our frozen technology scenario, we assume China does not introduce any carbon reduction initiatives and the energy efficiency of industry remains at its 2005 levels. In this case, emissions would increase 150 percent by 2030.

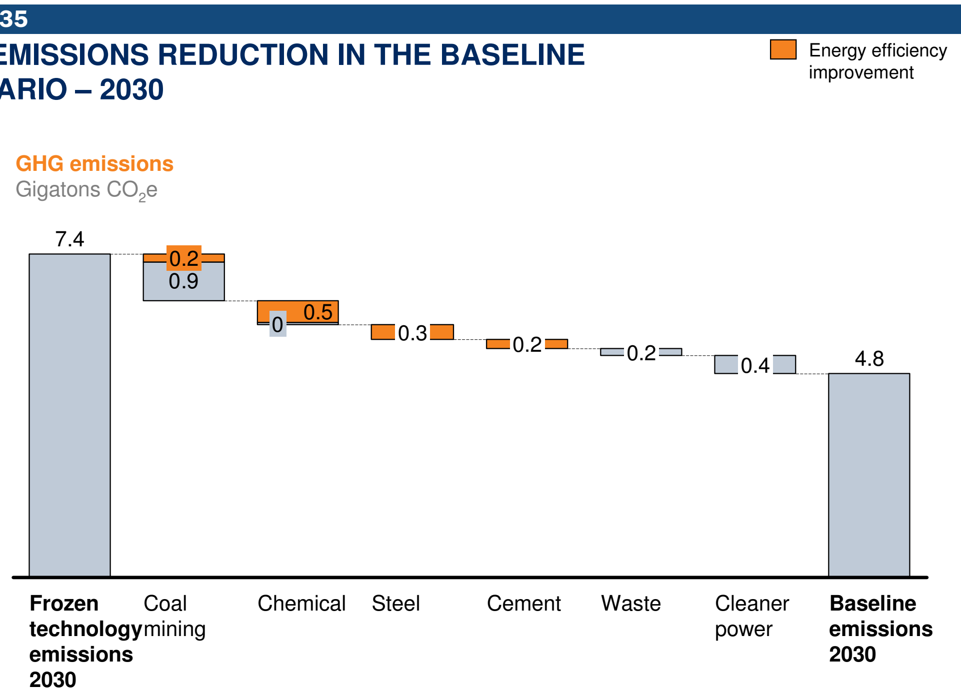
14 We considered only actual policies, rather than "aspirational" targets. For instance, we took into account the government's policy to shut down blast furnaces smaller than 300 cubic meters before 2010, but not the national target of cutting energy consumption per GDP by 20 percent before 2010.

The difference between our frozen technology scenario and our baseline scenario is the "baseline carbon reduction." The baseline carbon reduction in the EII sector is 2.2 Gt of CO_2e. Energy efficiency measures account for 60 percent of the carbon reduction. This is in line with the country's push to increase the efficiency of core processes in industry. In addition, our baseline includes some impact from waste recovery and reuse measures.

The Chinese government has initiated several energy-efficiency efforts in the industrial sector (Exhibit 35). One example is the nationwide "Top 1,000 Enterprises Energy Saving Project." This initiative covers 998 energy-intensive companies with a combined energy consumption of over 800 million tons of SCE in 2006.[15] China has also taken steps to shut down or consolidate subscale, inefficient facilities in the steel, cement, chemicals and coal mining industries. China's Eleventh Five-year Plan also sets targets to eliminate inferior capacity of up to 100 million tons in steel, 250 million tons in cement, and 400 million tons in coal mines. At the same time, stricter approval procedures will ensure that new plants conform to global best practices.

Exhibit 35

GHG EMISSIONS REDUCTION IN THE BASELINE SCENARIO – 2030



Source: McKinsey analysis

Our baseline scenarios for the industries in the EII sector are:

Steel

We expect the Chinese steel industry to press forward with advanced technologies already in use in developed countries. Overall, such technologies amount to a baseline carbon reduction (see above) of some 330 million tons of CO_2e. They include top pressure recovery turbines (TRTs), pulverized coal injection (PCI), oxygen-enriched PCI, coke dry quenching (CDQ) plants,

15 "Energy Utilization Report," Top 1,000 Enterprises Energy Saving Project, National Development and Reform Commission (NDRC), 2007

process automation, improving the use of blast furnace gas, and substituting basic oxygen furnaces (BOFs) by electric arc furnaces (EAFs) as scrap supplies increase. Most of these technologies save energy, making them economically viable in the long term. We expect their implementation in China in the next 20 years. Many of these technologies benefit the environment and the supply of natural resources, too. For instance, they help to reduce SO_x pollution and lower the demand for limited resources, (e.g., coking coal). China's National Climate Change Program emphasizes the importance of developing and implementing many of these technologies. Hence, as a result of their implementation, we estimate average energy efficiency in the steel industry will improve from about 750 kg of SCE per ton of steel in our frozen technology scenario to 570 kg of SCE in our 2030 baseline scenario.

A major driver will be a shift from BOFs to EAFs, which will reduce emissions by 200 million tons of CO_2e. An EAF consumes far less energy than a blast furnace or a BOF. However, the lack of scrap supplies to feed EAFs limits their use in China. EAFs accounted for only 12 percent of steel production in China in 2007, compared with 58 percent in the US and about 30 percent in both Germany and Japan. By 2030, we estimate steel production in China will reach 755 million tons. EAFs will produce around 240 million tons, i.e., 30 percent of the total. Meanwhile, scrap supplies will grow from 70 million tons in 2005 to 290 million tons in 2030. In such a case, we assume that China plans sufficient EAF capacity to exhaust its scrap availability in each year. This is clearly an optimal situation, which requires proactive, forward-looking capacity planning and monitoring by the government.

In addition, better utilization of blast furnace gas will help reduce another 40 million tons of CO_2e. Currently, China's major steel plants have a reported 93 percent utilization rate of blast furnace gas. We estimate an average national utilization rate of 85 percent. It is challenging to use blast furnace gas in power co-generation because of its very low heating value. Consequently, sub-scale mills often release blast furnace gas directly into the atmosphere where it adds to environmental pollution. However, by 2030, we expect China's utilization rate to improve to 95 percent, largely due to the closure of sub-scale mills.

Chemicals

In the chemicals industry, we estimate a baseline carbon reduction of 550 million tons of CO_2e. This is due, for example, to a switch from coal-based to natural gas-based ammonia production, efficiency improvements in ammonia production, catalyst optimization, and the expected introduction of advanced motors and CHP plants to generate electricity. We estimate that natural gas-based ammonia production will grow from 20 percent to 35 percent of total production by 2030. High prices and low supplies of natural gas will limit further growth. China's government has pushed the use of advanced motors and CHPs in the past decade. By now, most newly built chemical plants have installed them.

The chemicals industry emits significant quantities of NO_x, which is a GHG and a major pollutant that causes acid rain. We expect China to have eliminated most NOx emissions from adipic acid production and (in part) from nitric acid production in our baseline scenario.[16]

16 Figures are for the full steel-making process from coking to casting and rolling.

Cement

China's cement industry is expanding, modernizing and upgrading quality. We estimate such efforts will help to cut emissions by around 200 million tons of CO_2e in 2030, saving 45 million tons of actual coal consumption.

Cement production in China will peak in 2020 at 1.7 billion tons, and gradually fall to 1.6 billion tons by 2030. In part, quality improvements will reduce the volume of cement (and, thus, clinker) needed in concrete production. We estimate that improvements to cement quality will help to cut GHG emissions by more than 120 million tons of CO_2e. Previously, Chinese standards allowed the use of "other substitutes" to replace clinker content without clearly regulating their type and specification. Moreover, clinker quality standards were lower in China than international benchmarks. To compensate for poor quality, the volume of cement in concrete was higher. New quality standards since 2008 have higher specifications for clinker and stricter definitions of clinker substitutes. The new standards specify the use of only granulated blast-furnace slag and fully granulated fly ash collected from the ventilation systems of coal-fired power plants. We expect such measures to reduce cement use in concrete making by 10 percent, cutting cement industry emissions proportionately. However, this will depend on large investments in milling capacity to produce high-quality fly ash and slag. Apart from GHG emissions reduction and energy savings, higher-quality cement contributes to sustainable development in China by improving the quality of the buildings and infrastructure as part of the massive construction effort in the coming decades.

Energy-saving technologies could reduce GHG emissions by a further 100 million tons of CO_2e. For example, advanced pre-calciner kilns could replace old wet-process kilns and vertical (shaft) kilns. The share of clinker produced by advanced kilns increased from 22 percent in 2003 to more than 50 percent in 2006, thanks to the widespread early retirement of old technology and sub-scale capacity. We expect pre-calciner kilns to produce about 70 percent of clinker by the end of 2010, and 95 percent by 2015. This wave of technology evolution offers a good opportunity for China's cement industry to adopt the latest global technologies. We therefore anticipate a wide adoption of various controlling technologies, including advanced process control (APC), which will push the energy efficiency of China's cement industry to the current global best level. A further energy-saving measure is to use low-temperature waste heat to generate electricity. This could provide up to 20 percent of the electricity needed for cement production. We expect a penetration rate for the technology of 40 percent by 2010, and 90 percent by 2020.

Coal mining

In our baseline scenario, we estimate total demand for coal in China at 4.4 billion tons in 2030. This is more than 40 percent lower than the 7.7 billion tons we forecast in our frozen technology scenario. The decrease is primarily due to the replacement of coal with cleaner energies in the power generation sector. In addition, energy efficiency improvements in end-user sectors (e.g., coal-fired power generation, industry and buildings) will reduce demand for coal and electricity (which lowers the demand for coal to generate power). Overall, we estimate a baseline carbon reduction of 0.4 Gt of CO_2e in the coal mining industry. Firstly, we assume efficiency improvements in coal mining will continue at 1998–2006 rates, i.e., 1.5–3 percent per year. In line with this, we assume energy efficiency per unit of output will improve by more than 40 percent by 2030.

In addition, our baseline carbon reduction figure takes into account cuts in coal-bed methane (CBM) emissions, which is critical to the sustainability of China's coal mining industry as it has important safety implications. Pure CBM contains more than 95 percent methane, an inflammable GHG that can cause explosions in underground coal mines. In China, some 95 percent of coal mines are underground, and over 90 percent register high levels of coalmine gas. Hence, without proper measures to drain CBM, the risk of underground explosions is high. In 2005, the death rate per million tons of coal produced in China was 70 times higher than in the US and 5–10 times higher than countries such as South Africa, Russia and India.[17] Coalmine gas is one of the main causes of fatal mining accidents. Significantly, methane recovery not only provides a source of energy, but also improves the safety of coal mines. Mature technologies can recover CBM by, first, using on-the-ground facilities to extract pure CBM from the coal layers before excavation. This relieves the methane pressure inside the coal layers. Once excavation begins, pipelines installed in underground mines drain the gas, thus lowering the methane concentration inside the mineshafts. China's Eleventh Five-year Plan mandates the recovery and reuse of some 40 percent of CBM by 2010. Regulations also state that all coal mines with high gas levels must start to extract CBM one or several years before excavation starts. However, a lack of technological know-how and the large capital investments required limit the full implementation of such technologies in smaller, local coal mines.

Waste management

We estimate a baseline carbon reduction in the waste management industry of 170 million tons of CO_2e. Growth in the waste industry's emissions is due largely to the increased use of solid waste as landfill and an increase in wastewater treatment as a direct consequence of urbanization, as well as a rise in organic waste as living standards improve.

Besides GHG emissions, the waste management industry has a direct impact on the environment. Municipal solid-waste (MSW) landfills, even when managed, may still cause problems due to the toxic or odorous elements of landfill gases, the occupation of land areas, and leachate pollution of underground water. The treatment of wastewater generates methane and sludge, which has high chemical oxygen demand (COD) and biochemical oxygen demand (BOD) levels and contains heavy metal ions. If used as land fill, the sludge can pollute the soil and water. To address these issues and GHG emissions, the industry uses municipal solid waste, landfill gases and the methane emitted by industrial wastewater processing to generate power. For example, by 2020, China will use 25 percent of its municipal solid waste and 34 percent of its landfill gases for power generation.

On the other hand, composting is not a major emissions-reduction lever. Composting breaks down biodegradable waste to produce methane and a residue. As the residue still contains biodegradable elements, disposal is achieved by returning it to the soil. However, China has

17 "The True Cost of Coal," Mao Yushi, Sheng Hong and Yang Fuqiang, 2008.

no well-functioning waste-sorting system to separate waste into different elements. Without this, harmful elements (e.g., heavy metal ions) may enter the compost material and remain in the residues, meaning they do not qualify for return-to-soil disposal. Composting also requires large areas of land and is less efficient in breaking down methane and waste.

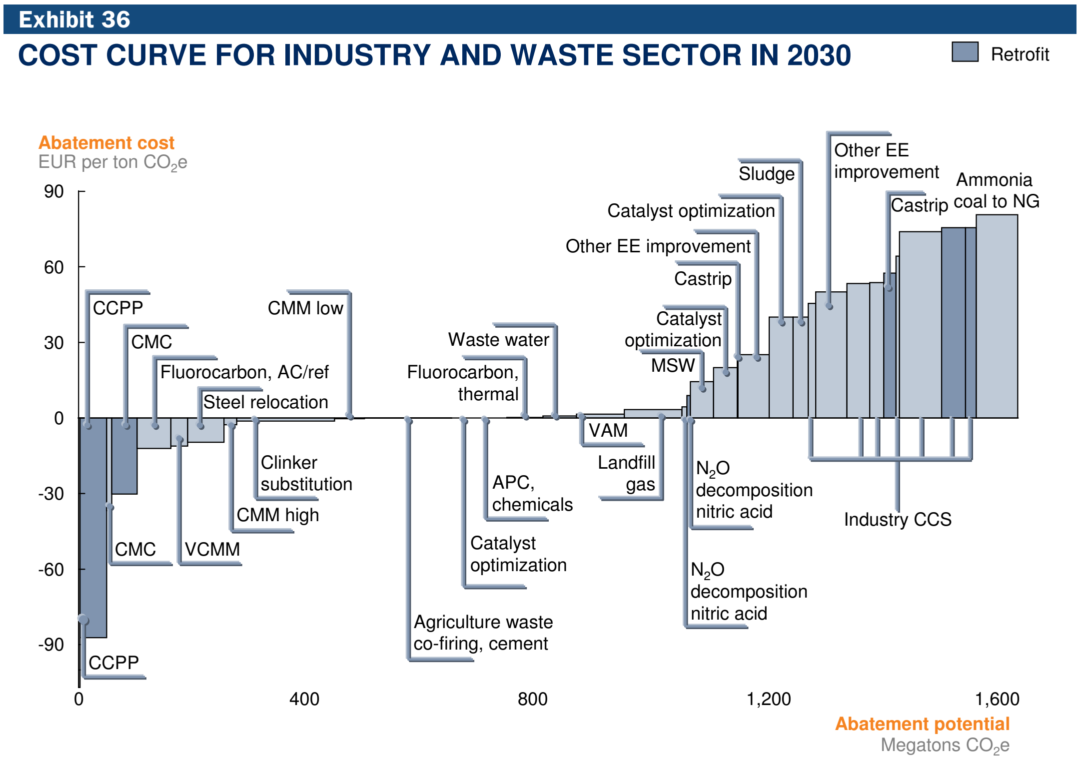
Overall, there are few opportunities to recycle MSW in China's waste management industry principally because some 60 percent of waste is kitchen residue. Waste collectors in China reuse or sell almost all of the recyclable household (and most of the industrial) waste. Hence, only non-reusable or non-recyclable waste ends up as landfill. This is a unique feature of waste processing in China compared with western countries.

ABATEMENT OPPORTUNITIES

We estimate the maximum technical GHG emissions abatement potential of the emissions-intensive industry sector at 1.6 Gt of CO_2e. The abatement cost is negative (i.e., a saving) or neutral for some 42 percent of the potential (Exhibit 36). The EII sector accounts for as much as 24 percent of China's total abatement potential. There is potential across all of the industries in the sector. The chemicals industry accounts for 445 million tons of CO_2e abatement, cement for 380 million tons, steel for 350 million tons, waste management for 215 million tons, and coal mining for 180 million tons (Exhibit 37).

Exhibit 36

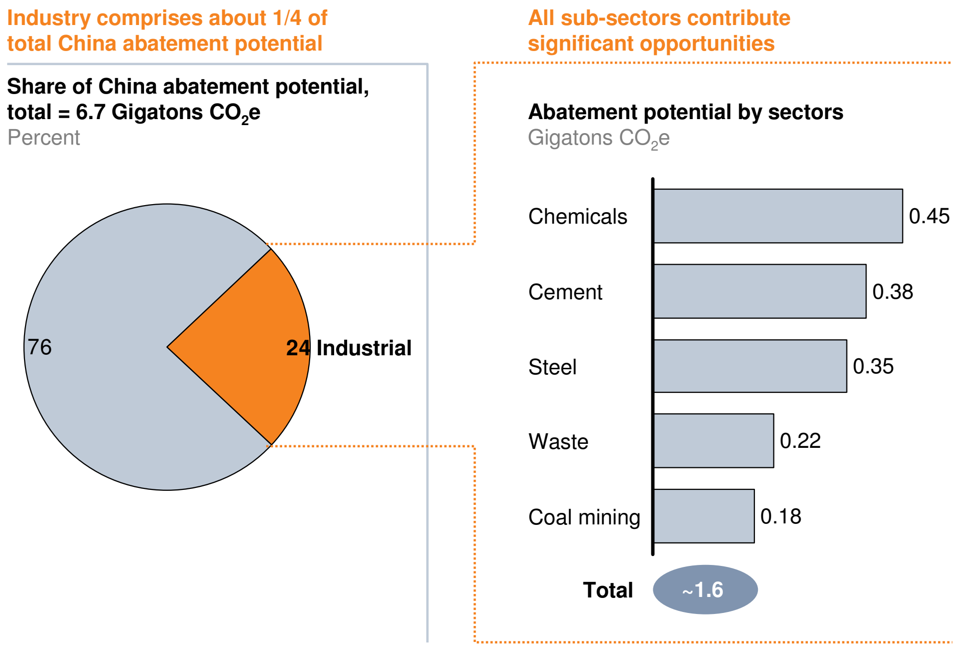
COST CURVE FOR INDUSTRY AND WASTE SECTOR IN 2030



Source: McKinsey analysis

Exhibit 37

ABATEMENT POTENTIAL BY INDUSTRY – 2030



Source: McKinsey analysis

Beyond our baseline scenario, which considers all the existing energy efficiency measures and plans, the largest GHG emissions abatement opportunity comes from waste and by-product recovery and reuse, accounting for more than 50 percent of the total. After this come energy efficiency improvements (25 percent of the total potential). Carbon capture and storage (CCS) and other innovative measures provide the remainder (Exhibit 38).

Recovering and reusing waste and by-products will be the key theme in the cement, waste management and coal mining industries. The abatement potential of waste recovery and reuse is 835 million tons of CO_2e. Waste and by-products recovery also tackles the waste pollution issue and stimulates the development of a "recycling economy" in various industries. The total abatement potential of energy efficiency improvements in the EII sector is 390 million tons of CO_2e. Improving energy efficiency will remain the focus in the chemicals and steel industries. Energy efficiency initiatives often help to reduce environmental pollution, too. Lastly, CCS and other measures can cut a further 340 million tons of CO_2e from the sector's GHG emissions.

Exhibit 38

3 CLUSTERS OF ABATEMENT OPPORTUNITIES IN THE EMISSIONS-INTENSIVE INDUSTRIES

	Potential Gigatons CO_2e	Industry focus	Key technologies	
By-product and waste recovering	0.84	• Coal mining • Waste management • Cement	• Coal bed methane utilization • Municipal waste management	• Clinker substitution • Fluorocarbon destruction
Energy efficiency	0.39	• Chemical • Steel	• Steel – CCPP – CMC – Direct casting	• Chemical – Process automation – Catalyst optimization
CCS and others	0.34	• All	• CCS • Relocating steel production to Australia for NG-based DRI	• Switching from coal-based ammonia production to NG-based
Total	~1.6			

Source: McKinsey analysis

We describe below the abatement potential of these three opportunities in the specific industries.

1. Waste and by-product recovery and reuse

Technologies to enhance waste and by-product recovery (abatement potential of 835 million tons of CO_2e) principally work by destroying or reusing non-CO_2 greenhouse gases (such as methane and fluorocarbons) and recycling industrial waste (such as slag from steel making and fly ash from power generation). These technologies apply to the cement, coal mining, municipal waste management, and chemicals industries (Exhibit 39).

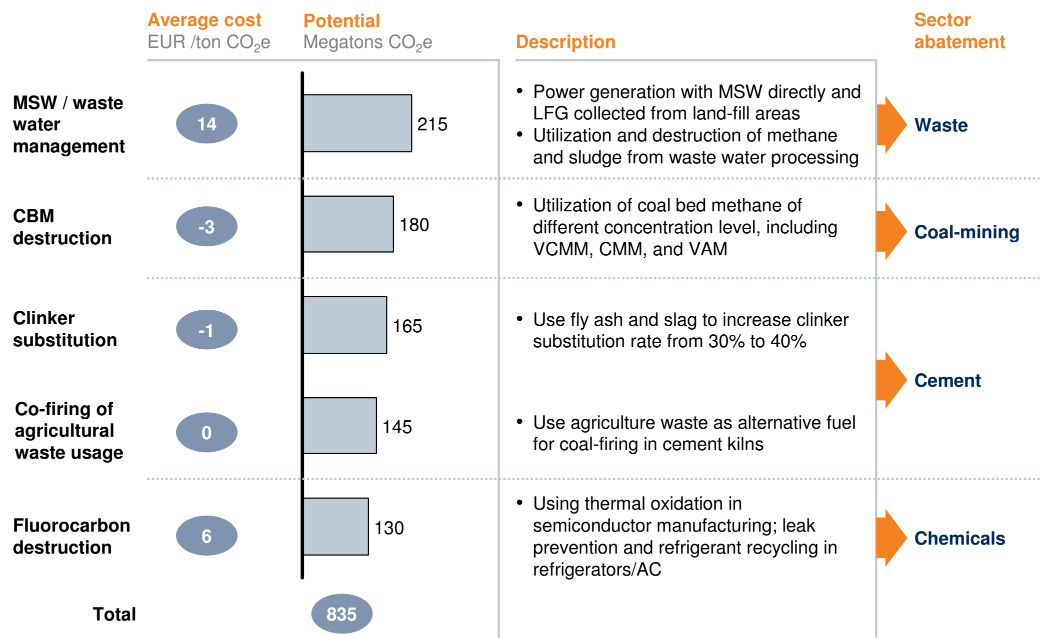
The significance of reusing industrial and municipal waste and by-products goes far beyond GHG emission abatement. Potentially reusable waste products have long been important sources of pollution or, at least, an environmental burden in China. For example, fly ash from coal-fired power plants and slag from steel plants account for a large volume of industrial waste. Disposing of them as land fill occupies a substantial and increasing area, with the potential risk of polluting and/or degrading the surrounding land. For years, the smoke from burning straw (an agricultural waste product) covered rural areas following the harvest. Explosions triggered by coalmine gas killed around 1,000 people in 2007.[18] With the rapid pace of urbanization, available landfill areas to deposit fast-growing municipal solid waste have become fewer. Those that remain are closer to the cities, thus threatening the quality of underground water and the air. Now that most cities in China have wastewater treatment facilities, they require a proper disposal method for the resulting toxic sludge. Therefore,

18 State Administration of Coal Mine Safety, 2007.

while most of the abatement levers detailed here have a positive cost, we consider them as priorities on the road toward sustainable development given their substantial positive impact on the environment and pollution levels.

Exhibit 39

ABATEMENT POTENTIAL AND COST – RECOVERY OF WASTE AND BY-PRODUCTS



Source: McKinsey analysis

Cement

- Clinker substitution

Clinker production is the cause of most emissions in the cement industry. According to the results of international industrial experiments and industry consensus, China could increase the clinker substitution rate from its current 30 percent to a maximum 40 percent by upgrading its milling and granulating capacity. Forecasts suggest that the supply of slag and fly ash will be sufficient for this by 2020. Increasing the clinker substitution rate in this way would reduce emissions by 165 million tons of CO_2e by 2030. The abatement cost of this measure is, in fact, negative at EUR –1 per ton.

The technology for clinker substitution above 30 percent is still untested for mass production and application. At 40 percent clinker substitution, cement's (and, hence, concrete's) characteristics change at a lower substitution rate, although its final performance is the same. During the early stages of application (i.e., less than 28 days), the cement's strength is weaker. After 28 days, its strength is the same as (or higher than) "regular" cement. Producers and end-users will need to work jointly to find ways to apply cement given these changes in its characteristics.

- Agricultural waste co-firing

  The cement industry could use agricultural waste as an alternative fuel for co-firing with coal in kilns. The abatement potential is 145 million tons of CO_2e. The cement industry could process a wide range of waste, including agricultural, industrial and many types of hazardous waste (e.g., waste engine oil, pesticides and old tires). Most industrial waste, however, is already recycled in China. While cement kilns could serve as a reliable solution to hazardous waste disposal, the quantity of hazardous waste available is very small (e.g., total waste engine oil is less than 5 million tons). It follows that the quantity of fossil fuels replaced is also small. Burning hazardous waste in cement kilns mainly serves to mitigate local pollution rather than abate GHG emissions. Based on current understanding, agricultural waste appears to be the only alternative fuel that the cement industry could process in significant quantities.

The uses of agricultural waste

The recovery and reuse of agricultural waste is relevant to several economic sectors (e.g., industry, power, and transportation) through the application of competing technologies. At maximum utilization, the abatement potential is 250 million tons of CO_2e. Using agricultural waste for co-firing in the cement industry provides 60 percent of the total potential. However, we need a comprehensive, cross-sector account of its potential utilization and its impact due to the scarce supplies of agricultural waste (see below) and the competing nature of the technologies in question (which allows for some substitution between them).

Apart from the benefits of fossil fuel replacement and subsequent GHG emissions abatement, the wide-scale use of agricultural waste in industry also provides a new waste disposal method. Today, disposal is mostly by means of burning in the open. This is one of the biggest causes of pollution in rural areas, particularly in the harvest season. The Chinese government aims to solve this issue.

Agricultural waste is mainly straw and husks from crops, along with some residues from sugarcane cultivation. By 2030, we anticipate an annual supply of some 200 million tons of agriculture waste for use as an alternative fuel (i.e., 100 million tons of SCE). Our figure is one-third lower than current estimates because demand will continue to grow for agricultural waste as animal feed and for returning to the soil, while the total supply will remain largely unchanged. The reserve supply of agricultural waste in China is around 600 million tons. We expect this to remain stable from now until 2030, as China's arable land will not expand. We therefore expect the total potential demand for agricultural waste from industries to outstrip the supply.

Currently, no single technology for reusing agricultural waste as an alternative fuel has found a mass application across the country. Three major technologies exist:

- *Co-firing in cement production* is the lowest-cost option, and the most flexible and efficient one to curb emissions. Burning agricultural waste with coal in cement kilns requires no major overhaul of the kilns, as they are already resistant to the chemicals released by incineration. Therefore, the abatement costs of co-firing are at a breakeven level.

- Ligno-cellulosic (LC) ethanol production ranks second in terms of abatement cost at around EUR 7 per ton of CO_2e. Investment and operating costs will remain high up until 2010, but we expect them to fall by 70 percent by 2020. The net abatement cost of LC-ethanol, however, is very sensitive to the price of the gasoline it replaces. A higher oil price than the USD 60 per barrel level we assume in our analysis could bring down the abatement cost significantly.

- Power generation has the highest abatement cost because generators require major overhauls before they can burn agricultural waste as a fuel. We estimate the required investment will be almost double that needed to build new coal-firing power capacity.

In cement production and power generation, we assume the incineration efficiency of agricultural waste is more than 80 percent of that of coal. However, we need further analysis to confirm its incineration efficiency in cement kilns. LC-ethanol is the least energy-efficient abatement technology, as the ethanol retains only 30 percent of the heat value of the waste.

The cement industry could easily switch back to burning coal without incurring any major sunk costs if other attractive opportunities emerged in the future. This would enable better use of agricultural waste elsewhere. This is a key advantage compared with its use for power generation and for LC ethanol production, both of which require large capital investments.

Currently, China only collects a small portion of its agricultural waste. The incremental costs of transporting agricultural waste compared to moving coal are not a major barrier, as the end-users are densely located in eastern and southern China, which also supplies most of the country's agricultural waste. The shortfall in supply is largely due to the ineffective collection system. Consequently, bio-waste power plants in China tend to have low utilization rates and high unit operating costs. It will probably need government intervention to coordinate agricultural waste collection effectively.

We have also identified three main ways to increase the supply of agricultural waste:

- *Ensure adequate labor for waste collection.* A system to mobilize labor to travel to rural areas to work on the land (with a guarantee they can return to their jobs in the cities afterward) would enable a supply of temporary labor to collect feedstock in the harvest season.

- *Improve mechanical straw collection.* Simple straw-collecting machinery attached to mechanized harvesters would accelerate straw collection during the harvest and reduce farmers' dependency on temporary labor.

- *Implement pre-processing technology.* Establishing small-scale, local pre-processing would make transporting and storing feedstock easier and lower its loss rate.

Coal mining

- CBM utilization

Coal-bed methane (CBM) is a term given to the gas trapped in coal seams. Coal excavation and extraction releases the gas into the surrounding environment. Methane has a greenhouse effect 21 times that of CO_2. Using CBM as an energy source reduces the greenhouse effect of methane to approximately the same of CO_2. CBM utilization eliminates the emissions from the energy sources it replaces (mainly coal and natural gas). It also reduces coal mine gas (an explosive mix of CBM and air), which is a major cause of coal mine incidents in China.

Coal-bed methane has four concentration levels found at different stages of mining. CBM concentration determines the technology for its use. CBM extracted from the ground before mining begins is 95 percent methane. CBM emitted from operational mines mixes with air to form coal mine gas. The methane concentration of coal mine gas may vary; for example, gas drained before coalface operations start normally has a higher concentration, while those drained at a later stage of operation will have lower concentration as more air flows into the mine. “High-concentration gas” contains over 30 percent methane, allowing its direct use or flaring. “Low-concentration gas” has between 5 percent and 30 percent methane; the air-methane mix makes it explosive and current regulations forbid its use and requires direct discharge into the air. Mines ventilate and discharge any gas left after drainage. This coal mine ventilation air usually contains around 0.5 percent methane.

Current mature technologies use CBM as a substitute for natural gas or, if it is high-concentration coal mine gas, to generate power. Our baseline scenario assumes around 40 percent penetration of these two technologies, in line with the Chinese government’s current plans. In our abatement scenario, we assume 100 percent penetration.

We also include in our abatement scenario two promising, emerging technologies: power generation using low-concentration gas and the oxidation of coal mine ventilation air. These two technologies would remove almost all CBM. Despite the current ban on burning low-concentration gas, internal combustion-based power generation can use it given several safety measures. The first wave of industrial pilot projects to use this new technology is underway in several of China’s large coal mines. The cost of power generation using low-concentration coal mine gas is negative at about EUR –1 per ton of CO_2e. Burning low-concentration gas to generate power is more expensive than high-concentration gas as it is less efficient and requires investments in anti-explosion safety measures.

In addition, new oxidation technology can mitigate methane emissions in coal mine ventilation air. Such systems can operate self-sustainably (i.e., with no auxiliary fuel) at a 0.2 percent concentration level. At a concentration level above 0.5 percent, the process can recover energy for heating and cooling, or even power generation. This technology is in use in several commercial trials in the UK, the US, and Australia. We estimate an abatement cost of around EUR 2 per ton of CO_2e.

Waste management

- Municipal solid-waste

In the waste management industry, abatement focuses on reducing the methane emitted from wastewater processing and municipal solid waste used as landfill. More than 60 percent (140 million tons of CO_2e) of the abatement potential comes from MSW management. In China, two main technologies use MSW to generate power: the collection and use of landfill gas (LFG), and the direct incineration of MSW. While the baseline assumes a penetration of about 30 percent, in the abatement scenario the penetration can climb up to 100 percent. Of the two, collecting and using LFG requires simpler, less capital-intensive and less costly technology. However, the LFG collection system demonstrates low efficiency and unstable performance. The current effective collection rate is under 50 percent. Under current best practice, it is still difficult to extract all of the available methane. By contrast, incinerating MSW destroys the emissions at source, making it a more efficient means of abatement (40 percent more potential than LFG for the same amount of waste). Direct power generation using MSW also reduces the volume of waste by 95 percent, cuts the need for landfill sites (saving valuable land around cities), and improves hygiene in urban areas. It is also a more effective method than LFG recovery to deal with leachate pollution, and odorous and toxic waste elements.

The abatement costs of these two measures are positive. The abatement cost of LFG utilization is EUR 3 per ton of CO_2e. Direct power generation using MSW costs more than EUR 10 per ton of CO_2e. Nevertheless, the direct incineration of MSW is preferable given the significant social benefits, particularly for urban areas.

Chemical and downstream industries

- Fluorocarbon destruction

Refrigerants, air-conditioning (AC) systems and semiconductor manufacturing all generate fluorocarbons. The fluorocarbons used today in refrigeration and AC systems have a global warming effect 1,300 to 3,300 times that of CO_2. While China controls emissions of certain fluorocarbons (e.g., ozone-diminishing gases), it has paid less attention to fluorocarbons' greenhouse effect. Repairing leaks, recovering and recycling refrigerants, disposing of refrigerants properly, and thermal oxidation (in the semiconductor industry) can all reduce fluorocarbon emissions.

Thermal oxidation, for example, requires only the installation of equipment in the semiconductor manufacturing line to oxidize the emissions from the processes. The fluorocarbon capture rate is above 90 percent at an abatement cost of EUR 1 per ton of CO_2e. However, although thermal oxidation is an efficient, low-cost technology, it offers little incentive to producers in China because its energy efficiency benefits are small.

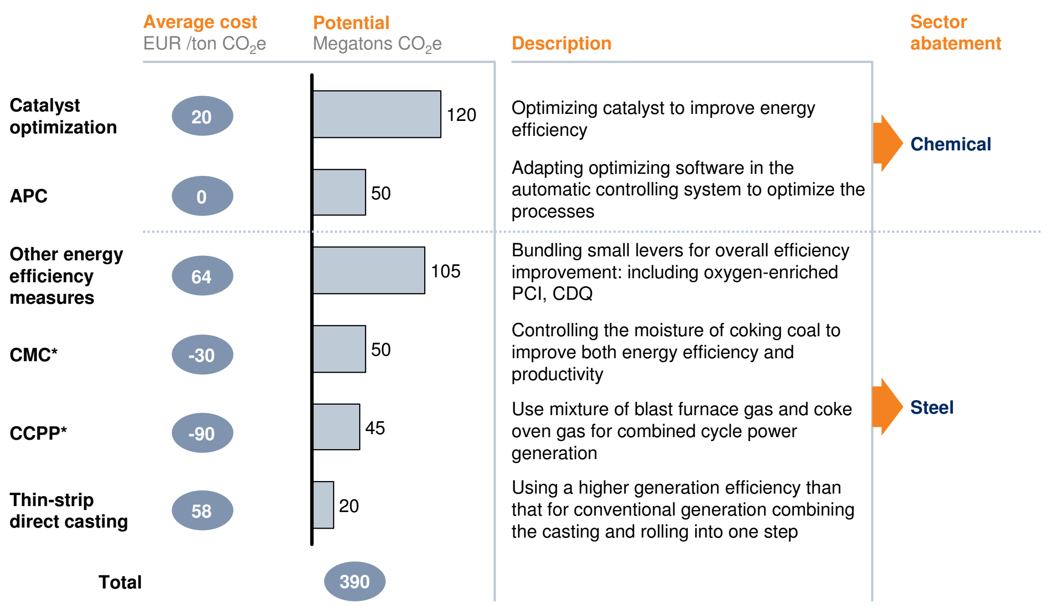
2. Improving energy efficiency

Technological applications to improve energy efficiency (beyond those included in our baseline scenario) apply mainly to the steel and chemical industries. Improvements in energy efficiency have a total maximum abatement potential of 390 million tons of CO_2e. The steel industry accounts for 220 million tons of the abatement potential and the chemical industry for 170 million tons. Energy efficiency measures generally have good economics thanks to the substantial cost benefits from energy savings (Exhibit 40).

In many cases, energy saving technologies also generate benefits to the environment. The technologies mostly fall into two categories: those that optimize the core process, and those that make better use of by-products, including heat and combustible gases. In the first case, advanced technologies (e.g., direct reduced iron and coal moisture control in the steel industry) often reduce the volume of pollutant by-products as well. In the latter case, using combustible gases instead of releasing them directly into the air is the major environmental benefit.

Exhibit 40

ABATEMENT POTENTIAL AND COST – ENERGY-EFFICIENCY IMPROVEMENT



* CMC: coal moisture control; CCPP: combined cycle power plant

Source: McKinsey analysis

Steel

We include many of the energy-efficiency options for the steel industry in our baseline scenario. Nevertheless, certain emerging technologies could lead to further improvements in energy efficiency and cuts in emissions. In our abatement scenario, therefore, we include combined cycle power plants (CCPPs), coal moisture control (CMC) and thin-strip direct casting.

We expect much of this new technology will require retrofitting to existing plants. Moreover, there are significant hurdles to the large-scale rollout of these technologies. China will build most of its new steel plants within the next ten years as steel demand and production peaks around 2020. As retrofitting is more expensive and is subject to technical constraints, swift action is necessary to seize the potential of these new technologies while mill construction is in progress.

- CCPP

  The use of combined cycle power plants has an abatement potential of 45 megatons of CO_2e at a negative cost of EUR –90 per ton. CCPPs use a mix of blast furnace gas and coke oven gas for power co-generation. CCPPs could improve the utilization rate of blast furnace gas by 5 percent and the power-generation efficiency of coal gases by 15 percent. By reducing the volumes of blast furnace gas released into the air and enabling better use of blast furnaces, CCPP also reduces emissions of SO_2, NO_x and particulates. However, its implementation is relatively limited in China because of the large capital investments and the need for adequate planning to secure sufficient supplies of coal gas for large mills. The major equipment suppliers today are international industrial leaders. As Chinese players catch up, the technology should become more affordable. The size of a steel mill is critical: it must produce sufficient blast furnace gas to support at least a 50 MW CCPP. We anticipate that 80 percent of plants will use this technology by 2030.

- Coal moisture control

  CMC is a relatively new technology that reuses waste heat from the burning of coke-oven gas to dry the coal used to produce coke. CMC has an abatement potential of 50 million tons of CO_2e at a negative cost of EUR –30 per ton. The moisture content of good coking coal is 8–9 percent. Reducing its moisture content to a constant 3–5 percent reduces fuel consumption in the coke ovens. The lack of reliable equipment and the sophisticated monitoring the system demands limit the prospects for CMC in China. Nevertheless, we expect technical improvements will increase the use of CMC by 2030. CMC also reduces the amount of ammonia emitted as a by-product of the coking process and thus decreases water pollution by steel mills.

- Thin-strip direct casting

  Thin-strip direct casting has an abatement potential of 20 megatons of CO_2e at a cost of EUR 58 per ton. This recently developed technology allows the direct casting of thin strips from liquid steel. The process saves about 80 percent of the energy used in conventional slab casting. Thin-strip direct casting is only applicable to strip casting and the quality of the steel produced is inferior to conventional casting and rolling. Thus, the technology needs further improvement before its large-scale implementation.

Chemicals

- Advanced process control

  The chemical industry comprises numerous different product lines and processes. Consequently, GHG emissions abatement is challenging, as the opportunities are small and, often, product-specific.

  Advanced process control (APC) is a means to increase energy efficiency across the industry. APC has an abatement potential of 50 million tons of CO_2e at zero cost. Most large chemical plants in China have installed automated systems to control and optimize various processing factors (e.g., temperature, pressure, fluid speed and materials flows).

However, future improvements could increase energy efficiency and further reduce process emissions. For example, APC can optimize the various processing factors and reduce energy consumption and raw material use by 2–3 percent, thus reducing emissions. The successful adoption of such technology requires a well-run automated platform as well as well-trained engineers and technicians to operate it. APC could also be applied to processes in other industries, such as cement, steel, and pulp and paper.

3. Carbon capture and storage and other methods

CCS

Carbon capture and storage (CCS) in the cement, steel and chemical industries has an abatement potential of 210 million tons of CO_2e at a cost of EUR 65 per ton (Exhibit 41). We expect 75 percent of CCS technology will require retrofitting as most new production will come on line before 2020, when we expect CCS to reach maturity.

Other methods: production relocation and raw material/fuel mix change

Other innovative methods include the relocation of steel production and the substitution of coal-based ammonia production by natural gas (NG)-based production. The abatement potential is 130 million tons of CO_2e.

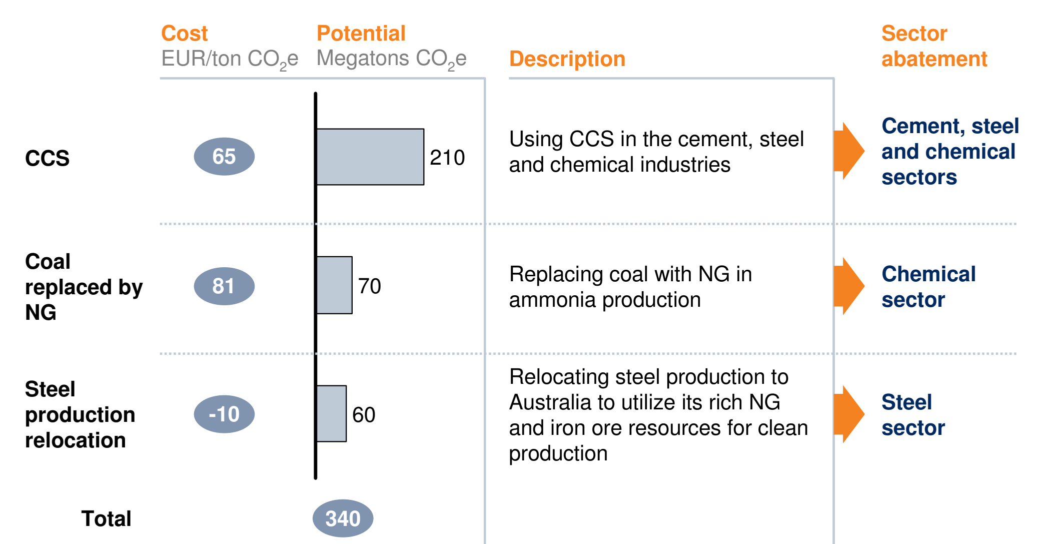
- Relocating steel production

  Shifting 25 million tons of steel production from China to Australia would yield an abatement potential of 60 million tons of CO_2e at a negative cost. Australia has rich reserves of iron ore and natural gas, enabling more efficient direct reduced iron (DRI) production using natural gas instead of coke as the reducing agent in steel making.

Exhibit 41

ABATEMENT POTENTIAL AND COST – CCS AND OTHERS

NON-EXHAUSTIVE



Source: McKinsey analysis

Relocating to Australia would be economically feasible. Australia has a lower domestic price for natural gas than the price of imported liquefied natural gas (LNG) used in China. Furthermore, the cost of shipping steel rather than iron ore from Australia to China would be 30 percent lower. Our estimates are subject to fluctuations in energy prices, but the overall cost difference between coke and natural gas is insignificant in the abatement cost calculation. Additionally, relocating production to Australia would help China secure access to iron ore and natural gas. In return, Australia might benefit from assigning the abatement credit (at least, in part) to itself. It would also increase local job opportunities and tax revenue in Australia. Using DRI would also generate significant environmental benefits as it lowers emissions of NOx and SOx by 25 percent compared to conventional integrated blast furnace/basic oxygen furnace (BF-BOF) steelmaking.

There are some caveats. First, it is not clear how to share the credit for carbon abatement between the two countries. Potentially, new global regulations could provide an incentive for both countries. Second, relocation would require close coordination between the two governments to guarantee long-term access to crucial resources and create the mutual trust needed for the massive initial investments. Third, relocation could mean a large influx of Chinese labor to Australia, which could raise issues for both countries.

- NG-based ammonia production

Compared to coal-based production, natural gas-based ammonia production would lower emissions by 3 tons of CO_2e per ton of ammonia produced. In our baseline scenario, we assume the high price of imported LNG limits the impact of NG-based production. In our abatement scenario, we expect NG-based production to make up 80 percent of total ammonia production (from 40 percent in our baseline scenario). The abatement potential is 70 million tons of CO_2e, although at a high cost of EUR 81 per ton.

We estimate ammonia production will rise from 52 million tons in 2005 to 76 million tons in 2030, driven mostly by moderate growth in fertilizer use. China already has a high fertilizer-utilization rate, which we expect to remain stable. Hence, we expect only moderate growth in ammonia production over the next 20 years. If 80 percent of ammonia production is NG-based in 2030, China will require 40 million cubic meters of natural gas, which is equivalent to 10 percent of total national natural-gas consumption in our baseline scenario.

The capital expenditure for building a NG-based ammonia plant is lower than that for a coal-based one. The cost difference is largely due to the difference in prices of natural gas and coal.

CHALLENGES TO IMPLEMENTATION

We see four main hurdles that could affect the above abatement opportunities in the emissions-intensive industry sector.

- *Lack of human resources.* A shortage of technical talent and management support would have a serious impact on the abatement opportunities. To increase the supply of technical talent requires more education and more experience. For example, some key subjects, such as systems engineering, are not part of current Chinese university curriculums. China also lacks engineers with expertise in advanced energy-efficiency technologies, as well as energy auditors and technicians to support advanced technologies. On the management side, Chinese companies have focused more on revenue growth than on driving out losses, mainly because the short-term return on capacity expansion is much higher than the return on energy efficiency improvements. Therefore, management has yet to learn how to maximize the effectiveness of energy-saving measures.

  Better training and regulation could resolve the issue. Apart from revising its educational curriculums, China needs to provide business training to improve managers' knowledge base and experience. Specific regulation on energy efficiency standards will push companies to focus on improvements, and better training would help the country develop a robust execution and monitoring system.

- *Cost of trial-and-error and transition.* Adopting new technology often involves shutting down production and affects performance, leading to economic losses. This could apply even in the case of mature technologies due to lack of experience. International technology transfer is crucial to minimize the cost and accelerate the adoption of new technologies in China. Subsidies or innovative technology-transfer arrangements should focus not only on one-time technology imports, but also on continuous user training, spare-parts supply and know-how transfer to ensure the smooth implementation and use of imported technology.

- *Lack of economic incentives.* This is the main barrier to waste recovery and reuse. Measures such as MSW incineration have significant social benefits, but there is no direct payback for operators. In such cases, the government could act as the central settlement instance for the cost of abatement, given that they would have to pay the social costs in any case.

- *Low return on investment.* Companies either face a higher opportunity cost of investment or think the total return on energy efficiency is too small to pursue. To tackle opportunity cost, cheap financing specifically channeled to energy-saving measures could help increase the attractiveness of abatement measures. Furthermore, the importance of energy-saving projects will become clearer to Chinese companies as market growth stabilizes and their profit focus evolves to embrace the benefits of eliminating system losses.

***

China has realized the serious problem of low efficiency in its industry sector. It is already taking action to catch up to global standards. The country has incorporated most of the required measures in its ambitious energy policies for the steel, cement, chemical and coal mining industries.

Beyond the scope of the current policies, there are new sustainability opportunities emerging in the areas of waste and by-products recovery and reuse and new efficiency improvement technologies. The majority of these offer largely favorable economics. The full utilization of coal-bed methane, municipal solid waste, agriculture waste, and fly ash would allow China to replace significant quantities of coal in industrial processes, reduce GHG emissions and lower local pollution levels. Such benefits are a major part of sustainable development efforts and hold the promise of a safer, cleaner, and healthier China.

The power generation sector: Producing cleaner power

The power generation sector is a very large emitter of greenhouse gases and the biggest direct user of coal in China. In 2005, the sector produced 2.0 Gt of CO_2e (i.e., 30 percent of China's total GHG emissions) and consumed 1 billion tons of coal (close to half of China's total coal consumption). In our baseline scenario, we estimate GHG emissions of 5.4 Gt of CO_2e in 2030 (i.e., 37 percent of total GHG emissions in that year). We also estimate coal consumption in the sector will increase to 2.5 billion tons of coal. This represents 57 percent of anticipated total coal consumption in 2030 (4.4 billion tons). China's rapidly growing demand for energy from its largely coal-based power plants will drive this substantial increase in coal consumption.

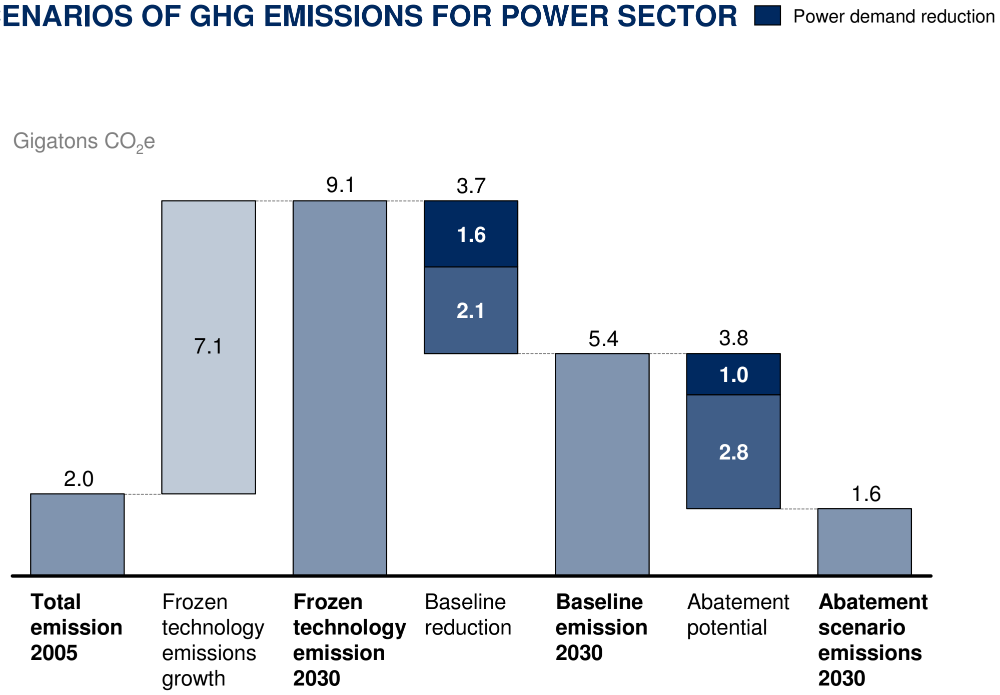
In addition to generating GHG emissions, the reliance on coal for power production exacerbates pollution. Burning coal is the single largest source of air pollutants in China, emitting more than 70 percent of all SO_x, NO_x, and total suspended particulate (TSP) matter. Moreover, coal consumption and coal mining affect water resources and soil through underground water leakage, wastewater discharged from coal-washing, land degradation caused by mining activities, and land occupied by heaps of fly ash and gangue. Research shows that factoring in such external costs adds another 150 percent to the cost of coal. The total amount of external costs are estimated to have reached EUR 170 billion in 2007.[19]

China has two main levers to reduce the power generation sector's GHG emissions and its dependence on coal to generate electricity. The country could develop cleaner energy sources (e.g., nuclear, solar, wind and small hydroelectric power plants) and it could use cleaner coal-based power technology (e.g., integrated gasification combined cycle, and carbon capture and storage). China is a rapidly developing country with a large and growing demand for energy. These two abatement levers could work in tandem to yield a substantial opportunity to reduce greenhouse gases and pollution. We estimate the total maximum GHG emissions abatement potential is 2.8 Gt of CO_2e by 2030. This is in addition to an abatement potential of 1 Gt of CO_2e stemming from declining demand for power in end-user sectors (e.g., buildings and industry) thanks to the implementation of other abatement measures as described in our report (Exhibit 42). Overall, we forecast a reduction of coal consumption by 1.2 billion tons (i.e., 27 percent of expected coal demand in our baseline scenario).

19 "The True Cost of Coal", Mao Yushi, Sheng Hong, Yang Fuqiang, 2008

Exhibit 42

SCENARIOS OF GHG EMISSIONS FOR POWER SECTOR



Source: McKinsey analysis

However, the average abatement cost in the power generation sector is among the highest of all those we analyzed, due to the capital–intensive nature of many of the abatement technologies. Moreover, time is a critical factor. Any delays in implementing the abatement technologies would reduce significantly China's opportunity to reduce its GHG emissions and its reliance on coal. This is because conventional coal-fired power plants have a lifetime of some 30–40 years before being retired. As China expands its power generating capacity, decisions taken today will therefore have a long-term effect on its abatement potential.

BASELINE SCENARIO

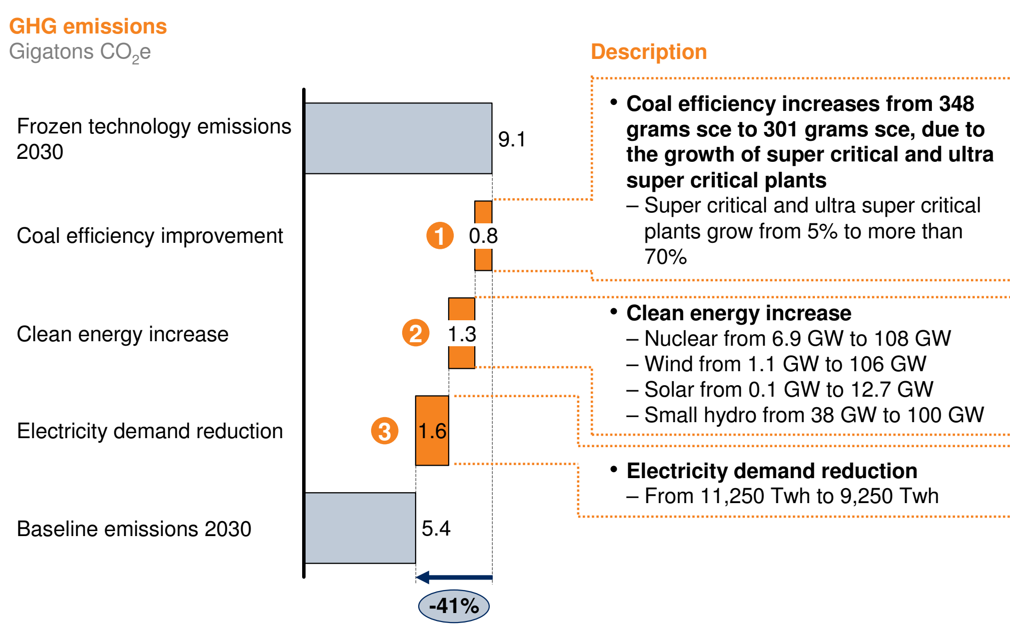
China has large reserves of coal, but few alternative natural energy sources, such as natural gas. Coal is therefore the main energy source for power generation in the country. In 2005, coal accounted for 81 percent of total electricity generation. The other energy sources in China comprise large-scale and small-scale hydroelectricity (16 percent), natural gas, and nuclear power. Renewable energies such as wind, solar and biomass provide less than 1 percent of the country's electricity.

In our baseline scenario, we forecast China's power demand to increase by 5.5 percent per year from 2005 to 2030. Total demand would therefore reach 9,250 TWh (1 TWh=1,000,000,000 KWh) in 2030 as industrialization and urbanization continue and living standards evolve. The buildings and appliances sector (residential and commercial properties) will be a key contributor to such growth. Its share of total demand for power will increase from around 20 percent in 2005 to almost 30 percent in 2030. In the emissions-intensive industry sector, the share of total power demand will fall from 25 percent in 2005 to approximately 15 percent in 2030. This reflects the development of higher value-adding, less energy-dependent, lighter industries.

China would need to quadruple its power generation capacity in 2005 in order to meet electricity demand in 2030. Despite this, the sector's GHG emissions would grow by only a factor of 2.5 thanks to cleaner energy sources and efficiency improvements in coal-fired power plants. Therefore, the baseline carbon reduction (i.e., compared to our frozen technology scenario, which assumes no changes in power generation technology) is about 3.7 Gt of CO_2e (Exhibit 43). Accordingly, coal consumption for power generation will be 40 percent lower.

Exhibit 43

GHG EMISSIONS REDUCTION IN THE BASELINE SCENARIO – 2030



Source: NDRC renewable development plan; NDRC nuclear development plan; McKinsey analysis

As mentioned above, the drivers of this reduction in GHG emissions in the baseline scenario are threefold. First, existing energy-efficiency improvements in end-user sectors (e.g., industry, residential and commercial buildings) will lead to a 17 percent fall in electricity demand. This would reduce GHG emissions in the power sector by 1.6 Gt of CO_2e and coal consumption by 770 million tons.

Second, the Chinese government is encouraging the rapid development of nuclear power and renewable energies. It passed the Renewable Energy Law in 2006 and published its mid- to long-term nuclear and renewable-energy development plan in 2007. According to the plan, China will increase its nuclear and renewable energy capacity by 2020 as follows:

- "Small hydro" plants to 75 GW
- Wind power plants to 30 GW (29 GW onshore and 1 GW offshore)
- Solar photovoltaics (Solar PV) to 1.5 GW
- Concentrating solar power (CSP) systems to 0.2 GW
- Nuclear plants to 60 GW.

The rapid development of such technologies should continue into the following decade. By 2030, the combined capacity of nuclear and renewable energy could reach 330 GW:

- Small hydro plants at 100 GW
- Wind power plants over 100 GW (mostly onshore)
- Solar power (PV and CSP) over 10 GW
- Nuclear plants over 100 GW.

In addition, from 2005 to 2030, large hydroelectric capacity will grow from 80 GW to around 350 GW, and natural gas capacity from 10 GW to over 140 GW. Such measures will reduce China's reliance on coal power for power generation from 81 percent of electricity production in 2005 to just 65 percent in 2030. And, coal-fired plants will make up 60 percent of its installed capacity in 2030, down from 73 percent in 2005. As a result, coal consumption will decrease by 720 million tons and GHG emissions would fall by 1.3 Gt of CO_2e in our baseline scenario.

Third, the Chinese government has mandated the closure of 14 GW of small and inefficient coal plants every year until 2010 to improve the overall efficiency of coal-fired power plants. China is also encouraging new coal-based plants to adopt new energy-efficient technology (e.g., super critical and ultra super critical plants). As a result, average coal consumption for each KWh of electricity generated will fall from 348 grams of standard coal in 2005 to 301 grams of standard coal in 2030. This will reduce coal consumption by 400 million tons and GHG emissions by 800 megatons of CO_2e in our baseline scenario.

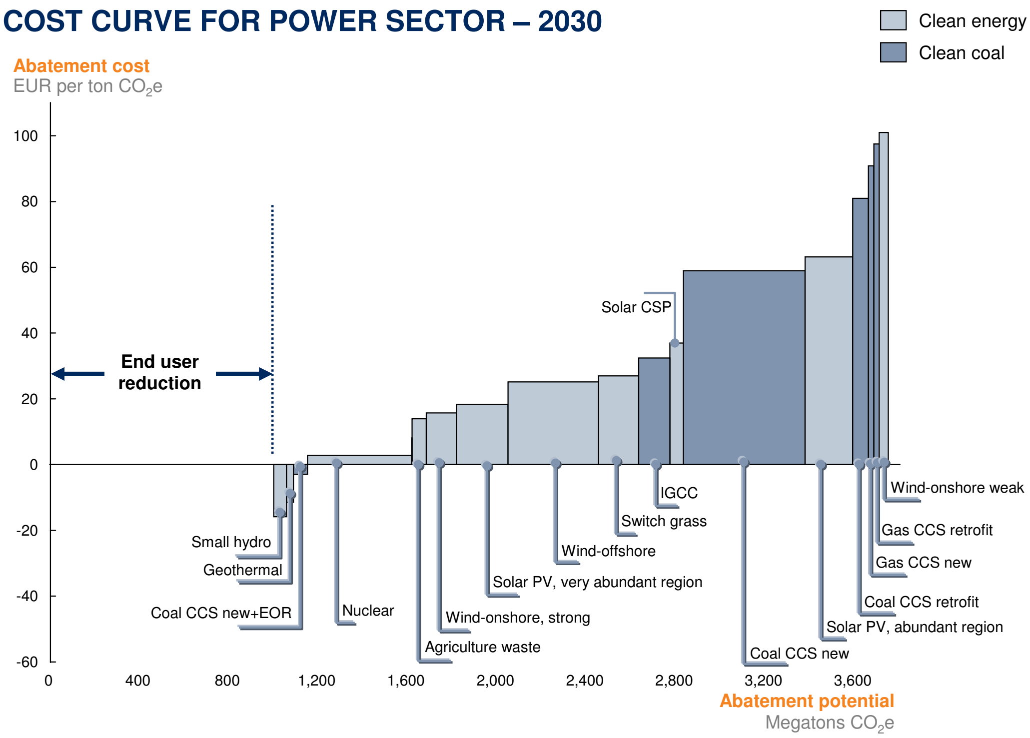
ABATEMENT OPPORTUNITIES

As mentioned above, we expect a reduction of 1 Gt of CO_2e and 450 million tons of coal from our baseline scenario owing to a 1,150 TWh decline in electricity demand, which will be driven by net gains in energy efficiency in end-use sectors such as industry and building. We therefore estimate total power demand of 8,100 TWh in our abatement scenario in 2030. In addition, the power generation sector has a GHG emissions abatement potential of 2.8 Gt of CO_2e and a potential to reduce coal consumption by close to 800 million tons a year from two main levers: cleaner energy and cleaner coal-based power-generation technology (Exhibit 44).

Developing cleaner energy has an abatement potential of 1.9 Gt of CO_2e at a relatively low average cost of EUR 22 per ton. Moreover, if China fully harnesses all the opportunities of cleaner energy sources, it can reduce the share of coal generated electricity to 34 percent of total power supply. China would no longer rely on coal as its primary energy source in the power generation sector (Exhibit 45). Cleaner coal-based power-generation technology has an abatement potential of some 0.9 Gt of CO_2e, but at a relatively high cost of EUR 55 per ton. Moreover, CCS technology would lower the overall efficiency of coal-fired power generation; hence, its application will lead to increased coal demand of about 120 million tons.

Exhibit 44

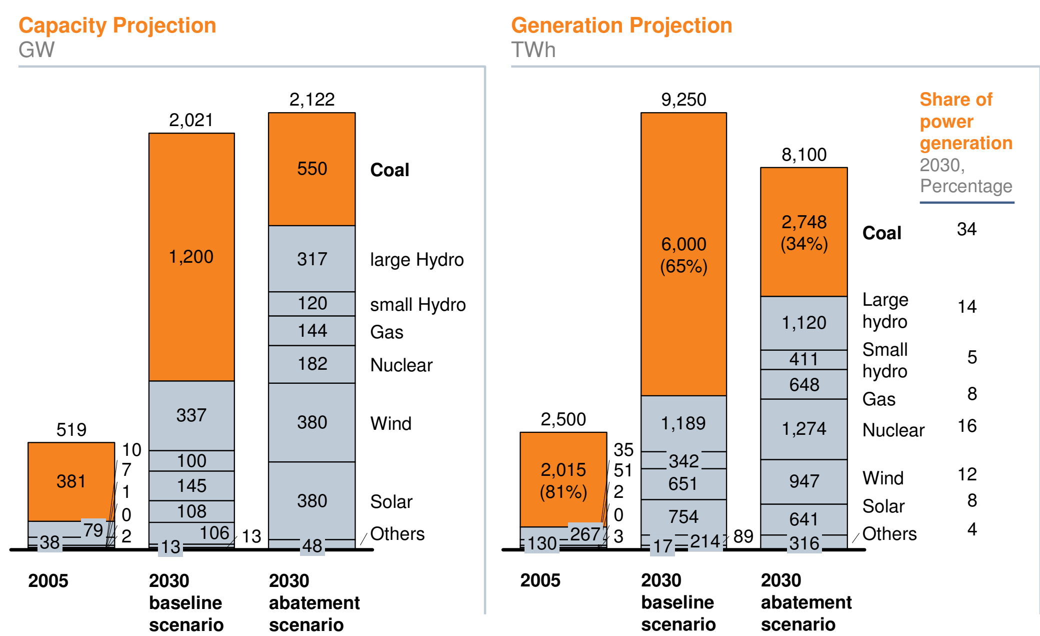
COST CURVE FOR POWER SECTOR – 2030



Source: McKinsey analysis

Exhibit 45

CHINA POWER MIX



* Including geothermal, CBM, MSW, LFG and biomass

Source: Expert interviews; literature research; McKinsey analysis

1. Cleaner energy

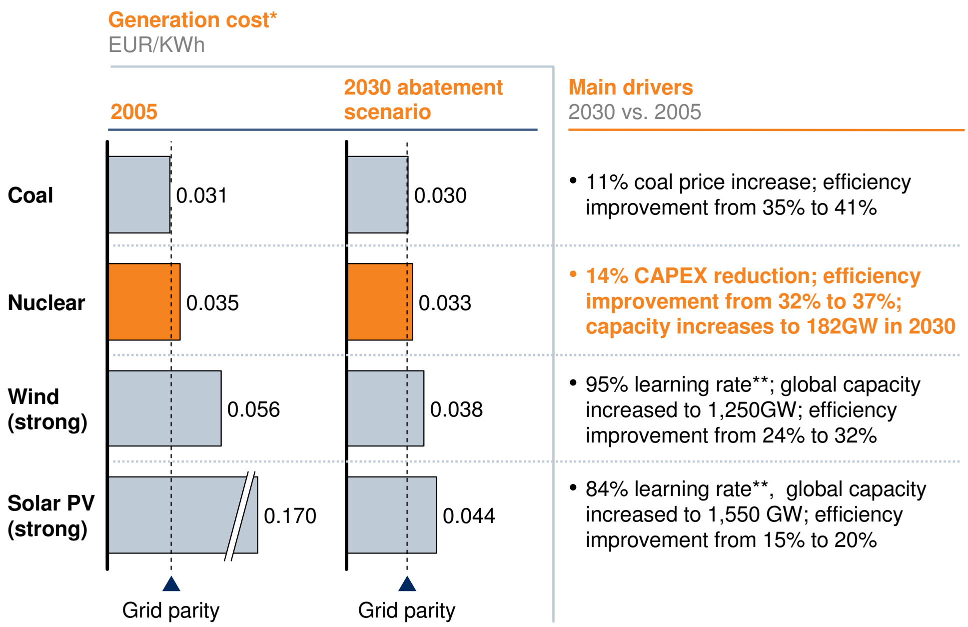
Nuclear power

In our abatement scenario, we assume an installed nuclear capacity of 182 GW by 2030, an increase of 74 GW on our baseline scenario. At this level, nuclear power has an abatement potential of 470 million tons of CO_2e at a relatively low cost of EUR 3 per ton. At approximately 7,000 annual operating hours, nuclear power plants can generate 1,280 TWh of electricity (about 16 percent of China's anticipated demand in 2030).

The Chinese government has advocated the use of nuclear energy as an alternative to coal power as a way to balance the country's power mix, secure its energy supplies and protect the environment. The investment cost for nuclear energy has steadily decreased over the last few years, not least because China already manufactures some 70 percent of the necessary equipment. We expect the cost to stabilize as the localization of equipment manufacturing grows. This, coupled with an expected efficiency increase of around 16 percent in the next 20 to 25 years, will make nuclear power cost competitive with coal-fired power generation (Exhibit 46).

Exhibit 46

ELECTRICITY GENERATION COST FOR DIFFERENT TECHNOLOGIES IN THE ABATEMENT SCENARIO – 2030



* Generation cost includes amortized capital at 4% risk free discount rate, OPEX and fuel expenses, and excludes tax, subsidy, etc.
** Learning rate is applied to global capacity built-up, as China is likely to be the world exporter for wind and solar equipment
Source: China solar association; Huangneng Group; Tsinghua Univ; SERC; McKinsey analysis

Second- and third-generation nuclear plants require abundant water for cooling purposes and will need to be located in coastal areas or along major rivers or lakes. Third-generation nuclear plants are much safer than previous generations. However, the nuclear industry has yet to resolve the major issues of nuclear waste (mostly radioactive) disposal. Over the next decade, as several new nuclear power plants come on stream, investment will be channeled into solving the problem of nuclear waste disposal.

China is also piloting fourth-generation nuclear technology, jointly developed by Tsinghua University and the State Nuclear Power Technology Corporation. If the technology proves viable, rollout could begin some time around 2012. The new plants should significantly reduce the amount of water needed, opening up the possibility to deploy nuclear power plants inland.

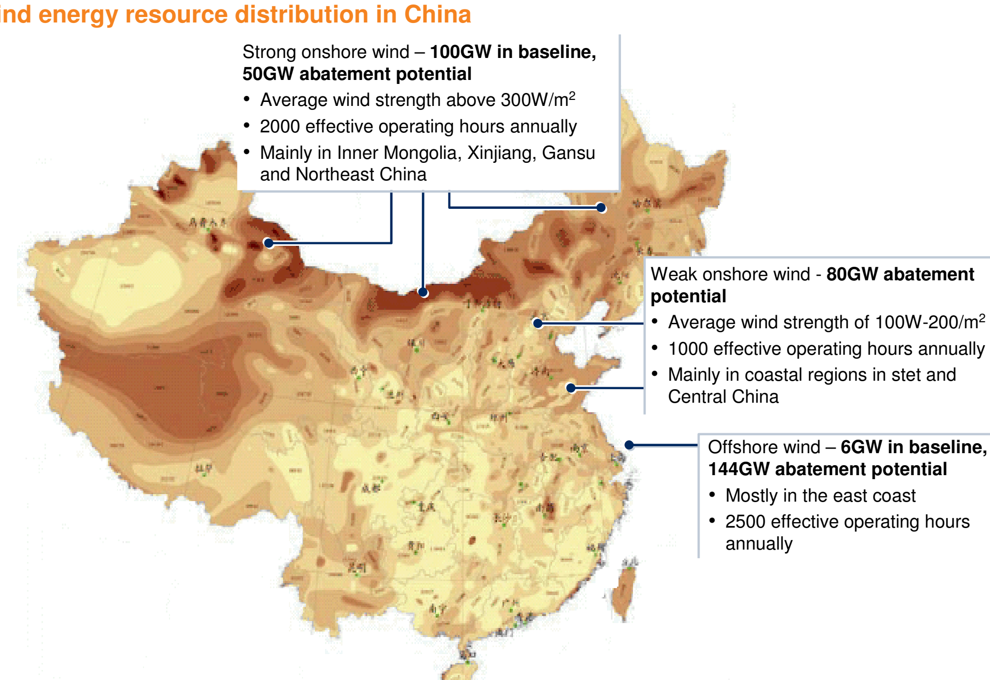
Wind

The cost of wind-based power generation depends on the strength and effective (sold) operating hours of the wind in the various locations. Strong onshore winds generate over 300 watts per square meter above a height of 50 meters. At 150 GW of installed capacity (50 GW more than in our baseline scenario), strong winds represent an abatement potential of 170 megatons of CO_2e at a cost of EUR 16 per ton. Weaker onshore winds generate in the range of 100–300 watts per square meter. The abatement potential is 40 megatons at a relatively high cost of over EUR 100 per ton at 80 GW of installed capacity. Offshore winds could provide an abatement potential of 400 megatons of CO_2e. Installed capacity could reach 150 GW, compared with 6 GW in our baseline scenario (Exhibit 47). Offshore wind-based power generation would cost a relatively high EUR 25 per ton of CO_2e, as setting up platforms and installing wind turbines requires higher upfront investments.

Exhibit 47

DISTRIBUTION OF WIND RESOURCES AND WIND POWER POTENTIAL – CHINA

Wind energy resource distribution in China



Source: McKinsey analysis

Strong onshore wind resources in areas like Inner Mongolia, Xinjiang, Gansu and Northeast China could yield total wind power of 300 GW. However, about half of the available wind resources are not economically viable under current technologies due to constraints (e.g., land availability, grid connectivity and grid stability). Weaker onshore wind resources are mainly found in areas like Shandong, Hebei, Jiangsu, Shanghai and Zhejiang provinces. Weak wind strength and short operating hours make wind-based power projects in these areas very expensive.

Locations on the east coast of China offer the highest potential for offshore wind-based power generation. Although relatively expensive, offshore wind power generation has many potential benefits. First, offshore wind plants are usually closer to the load centers of the electricity grid. Thus, they can significantly reduce demand for coal in such areas and release the pressure on rail transport. Second, by reducing the use of coal, offshore wind power can help cut coal-related pollution in cities and enhance the environment and public health in general.

Capital expenditure accounts for over two-thirds of the cost of wind-based power. We expect this to drop to slightly over a half by 2030 as wind turbines become more efficient and equipment costs decline steadily. The cost of onshore wind power could fall by 30 percent to around EUR 0.04 per KWh by 2030 as a function of the learning rate. Capital expenditure and maintenance costs are higher for offshore facilities as they are harder to construct and access. Hence, offshore wind power costs will be 35 percent higher than onshore costs.

Solar energy

Like wind-based power, the cost of solar power differs from area to area. The capacity of concentrating solar power (CSP) could reach 30 GW. However, its development is highly uncertain due to the high costs and issues of grid connectivity. Since CSP requires a high volume of sunlight radiation, it is typically located in the most remote places in China. Connecting CSP plants to the grid would prove both costly and difficult. In addition, CSP is a kind of steam turbine that relies on solar power (rather than fossil or nuclear fuels) as a heat source to make steam. Thus, water supplies become critical for CSP's continuous operation. However, supplying water to CSP plants is a major challenge, as water is normally scarce in the areas with the most sunlight, where there is little available surface or ground water.

By contrast, solar photovoltaic (PV) technology is much easier to deploy. It has a potential to reduce GHG emissions by 230 megatons of CO_2e at EUR 18 per ton in areas of very abundant sunlight.[20] In areas with abundant sunlight, the abatement potential is 220 megatons of CO_2e at EUR 63 per ton.[21] These areas are often densely populated; consequently, the cost of land on which to build solar power plants would be substantial. We assume an average cost of EUR 50 per square meter (Exhibit 48).[22]

20 Very abundant sunlight=annual solar radiation of 1,400 to 1,750 KWh per square meter; mainly occurs in East Inner Mongolia, North Jiangsu, Huangtu Plateau, East Qinghai, Gansu and West Sichuan.

21 Abundant sunlight=annual solar radiation of 1,050 to 1,400 KWh per square meter; regions include the southwest, northeast, and south and east coastal areas.

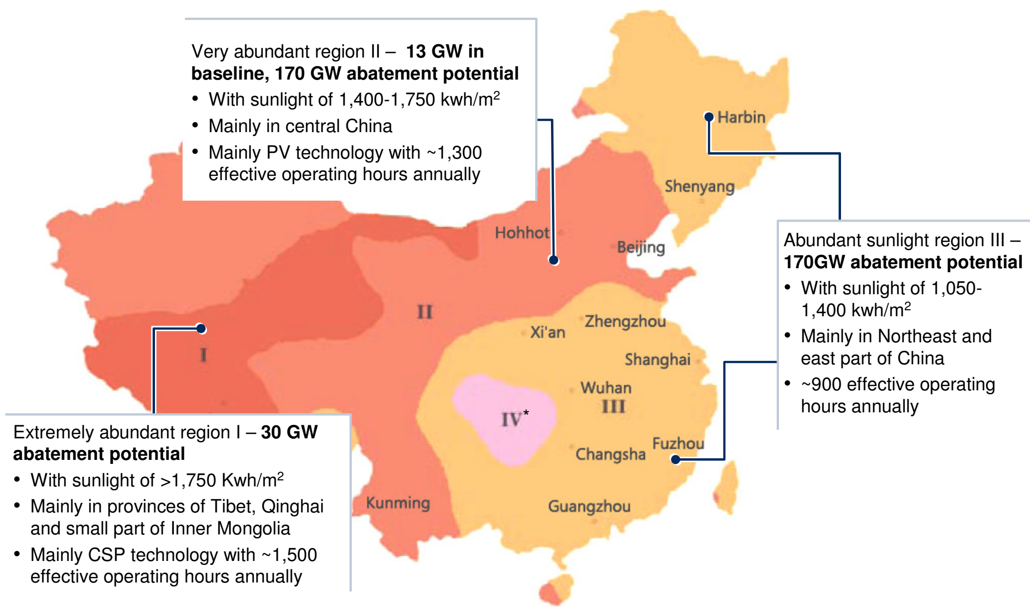
22 Mandated by the Ministry of Land and Resources in 2006 as the minimum transfer price for "mediocre land" in the areas suitable for solar power installations (see footnotes 1 and 2 above)

As the world's largest exporter of solar PV equipment, China has established a strong position in the solar industry. We expect its leadership to continue in the future. Based on projected world solar PV capacity and the historical learning rate of solar PV (around 84 percent), we expect capital expenditure for solar power installations in China to decrease almost 80 percent by 2030. As the technology improves, solar power generating costs will also fall to around EUR 0.045 per KWh in 2030 (i.e., 47 percent higher than coal, compared to over five times higher today). Although solar power would remain expensive in China in 2030, it would enjoy a competitive price in other parts of the world. For instance, a recent McKinsey report estimated that solar power would reach grid parity (i.e., the point at which photovoltaic electricity is equal to or cheaper than grid power) in southern Europe and California by 2020.

Exhibit 48

DISTRIBUTION OF SOLAR RESOURCES AND SOLAR POWER POTENTIAL – CHINA

Solar energy resource distribution in China



* IV is the region with sunlight <1,050 Kwh/m²

Source: China Solar PV Report 2007; Literature research; McKinsey analysis

Capturing the potential in remote areas

We do not include abundant wind and solar energy resources in remote locations such as Xinjiang and Tibet because they are too far away from China's load centers (distribution boards). To maintain grid stability with current technologies, we assume that the share of unstable power sources (including, mainly, wind and solar power) cannot exceed 20 percent of the total power generation in a given region.* Demand for power in these remote areas is very low, therefore most of the wind and solar power generated there (if utilized) must be transmitted to load centers in east or southeast China, presumably using ultra-high-voltage (UHV) lines (as advocated by State Grid, the largest transmission and distribution company in China). However, stable backup power plants (i.e., coal-fired plants) are necessary to prevent unstable wind power damaging the grids (including UHV lines). In addition, controversy surrounds the technological maturity, security and environmental effects of UHV lines. Lastly, building UHV lines is very expensive (about RMB 9 million per km based on an estimate of two UHV lines currently under construction). This makes the option economically unviable.

Two breakthroughs could significantly increase the abatement potential of wind and solar power. First, Xinjiang could use newly discovered coal deposits in the area to balance its wind and solar power resources, and allow more use of the latter. Second, new grid development could enable stable grids even when the share of renewable energy exceeds 20 percent. This would allow the development of wind and solar power in areas where there is no base load power plant (coal or nuclear).

* Some industry players and experts argue for a higher number, and propose different technological solutions. We take a more conservative view taking into account the complexity of a large developing country like China and the uncertainties surrounding renewable energy and grid development.

2. Cleaner coal-based power-generation technology

IGCC

Integrated gasification combined cycle (IGCC) is a technology that uses synthetic gas derived from coal. The exhaust gases are heat exchanged with water/steam to generate superheated steam that drives a steam turbine. The result is higher efficiency compared to supercritical and ultra supercritical coal plants, and lower emissions of sulfur dioxide, particulates and mercury. Currently, gasification efficiency (carbon conversion) is 70–83 percent at an operating temperature of 1,300°C to 1,600°C. The efficiency of IGCC is likely to improve further with future new technology breakthroughs in optimized humidification, hot gas cleanup, supercritical live steam in the bottoming steam cycle, staged gasification and chemical quenching. In our 2030 abatement scenario, taking into account site availability, construction cycle and supply constraints, we estimate that IGCC installed capacity will reach 100 GW (or about 7 percent of total power generation). The abatement potential is 140 megatons of CO_2e at a cost of EUR 32 per ton.

China currently has eight IGCC pilot projects in preparation or construction with a total capacity of 2.7 GW (although some of these projects do not focus on power generation). Most of the core IGCC technology is from foreign companies, but Chinese research institutes and manufacturers are stepping up their involvement. The localization of technology and manufacturing in China would help to reduce substantially the cost of IGCC.

There is still uncertainty about the maximum heat efficiency level of IGCC. Many researchers are optimistic and believe it can reach up to 58 percent.[23] However, some in the industry claim that IGCC efficiency will not exceed 50 percent, mainly because of the energy loss during gasification. In our report, we assume an efficiency level of 53 percent in 2030 (compared to a current level of 42 percent).

CCS

Carbon capture and storage (CCS) is a technology to capture carbon dioxide at its point of generation and store it, rather than release it into the atmosphere. CCS works with any fossil fuel. The economics of applying CCS improve when the emitted gases have a high carbon concentration, as is the case with coal-fired power plants. In contrast to many abatement options that reduce the use of fossil fuels, CCS actually increases fossil fuel consumption, especially in the capture phase. However, the CCS technology is particularly important from the perspective of GHG emissions abatement because it could help neutralize GHG emissions associated with China's most plentiful fuel source: coal.

We estimate that CCS will yield an abatement potential of 730 megatons of CO_2e at a cost of over EUR 60 per ton by 2030. Our calculations include both newly built and retrofitted coal-fired and gas-fired power plants. If fully implemented, more than 25 percent of China's coal-based power plants (new builds and retrofits) would be equipped with CCS technology by 2030. CCS retrofits have a lower abatement potential and are more expensive than new builds. Although they use the same basic technologies (e.g., oxy-fuel combustion and post-combustion) to enable carbon capture, retrofits incur additional costs due to space limitations and plant-tuning requirements. Thus, the abatement cost of a CCS retrofit is 40 percent higher than for a new build.

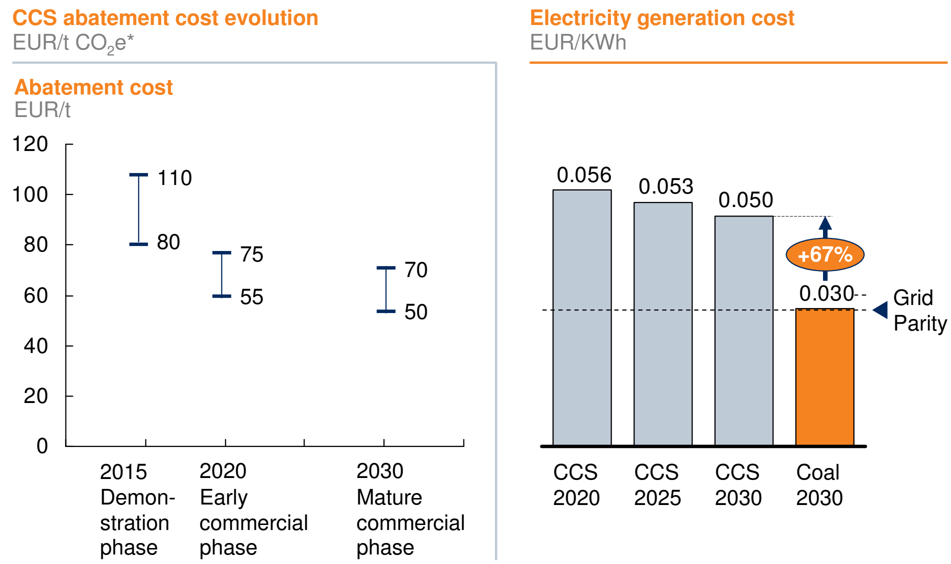
Combining CCS technology with other industrial applications, such as enhanced oil recovery (EOR), could significantly improve its return on investment. EOR injects CO_2 into oil wells to increase the amount of oil extracted from a field. In the US (Permian basin), two barrels of oil could be recovered per ton of CO_2 injected. CCS-EOR is economically attractive as the revenue from the recovered oil can offset the initial investment and the operating costs. We estimate a negative abatement cost of coal-based CCS-EOR (EUR –3 per ton). However, due to geographical constraints, the EOR market for CO_2 will be limited to around 60 megatons per year by 2030.

Currently, CCS is an expensive, early-stage technology that is unproven at a commercial scale. Based on interviews with a wide range of industry players and leading experts, we estimate the cost of building a CCS-equipped coal-fired power plant is about EUR 2,400 per KW. We expect this to fall to around EUR 2,000 per KW in 2030 (a figure based on Europe's learning rate of 88 percent). However, transport costs (most coal plants in China are located far from suitable storage locations) and high capital investments mean that CCS will remain expensive (Exhibit 49).

23 According to a research report produced for Siemens by the University of Essen, Germany.

Exhibit 49

ELECTRICITY GENERATION COST COMPARISON IN CCS ABATEMENT SCENARIO



* According to EU baseline scenario, adjusted with China transportation distance and operating hours of coal-based power plants

Source: McKinsey analysis

We do not expect the use of CCS in GHG emissions abatement until after 2020. This is partly due to probable delays in the progress of the first pilot plants. There are also difficulties in finding suitable locations and obtaining permits for carbon storage, as well as potential liability issues. Even after CCS becomes commercially available, concerns about its reliability and operational performance may delay deployment.

Although the overall cost of CCS is high and its implementation in China is uncertain, Chinese manufacturers still may find it an attractive investment opportunity. As developed countries face mounting pressure to fix emission targets, many will rely on CCS technology to meet their GHG reduction commitments. A recent McKinsey & Company study estimates a potential global market for CCS equipment worth over EUR 1 trillion in 2020–2030. Chinese manufacturers could position themselves to supply an emerging international market by acquiring expertise and manufacturing capacity at an early stage (possibly through low-cost EOR projects) and by securing a share of the sizable Chinese market.

Uncertainty about abatement potential and costs

We based our estimates of abatement potential and costs on currently available data. Nevertheless, uncertainty regarding the rates of technological penetration and cost evolution are critical factors that impact the calculation of the abatement potential and costs.

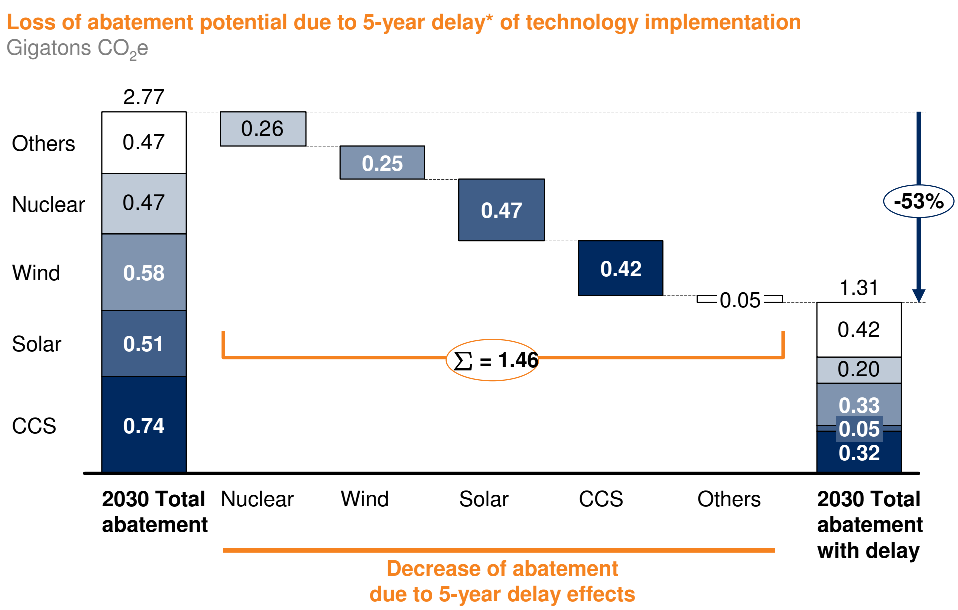
Technology advancement. Currently, we assume different learning rates for different technologies (e.g., 84 percent for solar energy, 95 percent for wind energy and 88 percent for new-build CCS). The learning rate helps evaluate the amount of cost reduction for every doubling of installed capacity. In our research, we based our assumed rates on historical technological development patterns and the views of industry experts on future patterns. In reality, many factors may delay technology penetration (e.g., insufficient R&D investment or problems initiating a technology breakthrough). Therefore, there may be wide variations in learning rates, which would affect, in particular, the amount of capital expenditure needed for solar, wind and CCS technologies.

Cost evolution. Several cost items influence the abatement costs of each technology, including fuel, labor and land. Fuel costs, in particular, have huge implications for cleaner energy sources. For instance, if the price of coal rises significantly, the cost of coal-based generation would rise and many cleaner energy alternatives might reach grid parity earlier. They may even become competitive without recourse to government subsidies. In addition, the costs of land and labor in China are likely to increase as the population grows, urbanization accelerates, and living standards improve. These factors would affect the costs of technology (and thus abatement) just as technological penetration and economies of scale reduce investment costs.

If China is to capture the full abatement potential in the power generation sector, it needs to implement most of the abatement measures starting in 2010 (with CCS right after 2020) and avoid the lock-in effect of building new coal-fired power plants. Missing the opportunity to replace coal with cleaner energy would mean 30–40 years of high carbon emissions that only expensive CCS technologies could remedy. A simple sensitivity analysis shows that postponing the implementation of the above technologies for just five years would cut the abatement potential by up to 1.5 Gt of CO_2e – over 50 percent of the total potential (Exhibit 50). In other words, China would need to build 80 percent more coal-based capacity by 2030, and carbon emissions would increase to 3.1 Gt of CO_2e – 55 percent more than in 2005. If the delay were 10 years, the abatement opportunity could shrink by as much as 80 percent.

Exhibit 50

IMPACT OF 5-YEAR DELAY OF IMPLEMENTATION – POWER SECTOR – 2030



* 5 year delay: nuclear, wind and solar start from 2016 instead of 2010, CCS from 2025 instead of 2020

Source: McKinsey analysis

IMPORTANCE OF GRID UPGRADES

The direct GHG emissions abatement potential of improvements to the power grid is less certain and the cost is very high. However, grid upgrades, particularly smart grids and ultra-high-voltage transmission, are essential enablers of abatement technologies not only with regard to power generation but also on the demand side (e.g., electric vehicles).

Smart grids include intelligent dispatching technologies (which prioritize clean energies), dynamic pricing meters, and technology to optimize the load balance by adjusting the output of appliances and machinery. Smart grid technology can enable better use of renewable energies and improve energy efficiency by means of several levers:

- *Demand-side management* gives consumers the incentives and the tools to shift some of their power demand from peak hours to off-peak hours.
- *Load matching* of available wind and solar power supplies available in off-peak periods with power-storage applications, notably EVs.
- *Distributed power generation (micro-grid)* enables households or communities to trade the power generated from small-scale wind, solar or geothermal devices to supplement the power from centralized power plants.

Although the definition of smart grid technologies is rather vague and many are still in their infancy, pilot sites exist in the United States. China would benefit from taking early action to scale up such technologies to maintain a rapid ramp-up of renewable energy and avoid the lock-in effect from near term expansion of coal-fired power plant capacity.

Ultra-high-voltage (UHV) transmission technology has a unique advantage in China, where load centers and the sources of (clean) energy are far apart. Despite the very high initial investments (about EUR 900,000 per kilometer of transmission distance), UHV is a key component in a power system where the share of renewable energy could exceed 20 percent.

CHALLENGES TO IMPLEMENTATION

Although the potential to reduce coal consumption and GHG emissions is substantial, there are significant challenges to widespread implementation, such as a lack of incentive schemes and barriers to technology transfer. Without proper incentive schemes, utility companies would be reluctant to invest in renewable energy, IGCC and CCS. The capital-intensive nature of the investments makes it difficult to recoup the initial investments. Grid companies would also be reluctant to extend networks to the more remote source locations of renewable energy and adopt advanced technologies to improve renewable energy use and electricity transmission efficiency. This, in turn, would make utilities even more reluctant to invest … and so on in a vicious cycle.

Combining the know-how of developed countries and China's advantage in mass production is essential to make the abatement technologies sustainable once any initial government incentives expire. Therefore, China needs an effective implementation strategy for the power sector, if it is to capture the full abatement potential.

- *Addressing safety concerns.* Several important technologies, e.g., nuclear and CCS, are subject to ongoing societal and political concerns of the safety of their expanded applications. These concerns have potential to present unforeseen challenges and slow down the approval of nuclear projects. Addressing these concerns, however, will require substantial investment, R&D and talent growth. For example, currently, nuclear waste is stored; in the future, regulations of more stringent waste disposal requirement will be established and nuclear power companies will have to develop and invest in nuclear disposal methods.

- *Addressing the economic feasibility issue.* Renewable energy and CCS technologies are expensive. In the near term, government subsidies are necessary for the renewable industry to build capacity and benefit from economies of scale. Along with that, the government needs to mandate power generation from renewable energy. It currently regulates that utilities with a total capacity over 5 GW must have 3 percent of total capacity in the form of non-hydro renewable energy by 2010 (and 8 percent by 2020). However, utilities might build capacity simply to fulfill the requirement, but not use it fully because the equipment is suboptimal and/or they lack grid connectivity. Launching IGCC and CCS technology will likely require more resources and foreign financial aid. Technology transfer is also important to bring down costs. CCS consumes more power and therefore more coal, reducing the efficiency of coal-fired power plants by up to 30 percent. Consequently, the operating costs of plants and the cost of electricity generation would rise. Utilities will need incentives to offset the additional costs of CCS to allow them to adopt the technology.

- *Addressing the substantial infrastructure needs.* To develop renewable energy, extending the grid to remoter areas is crucial, as there will be few available locations close to the grid by 2020. This may prove costly. Moreover, China needs integrated long-term grid design and advanced control systems to make the grid more efficient and smarter, in order to deal with the unstable nature and complex geographical deployment of renewable energy sources and ensure a high effective utilization rate. This requires substantial capital as well as talent.

***

China already has ambitious plans to expand its nuclear footprint. It has large areas of land suitable for the cost-efficient production of wind power. It also has the potential to tap into abundant supplies of solar energy. Although the upfront costs are significant, they are coming down gradually and the country has the ability to surmount its other implementation hurdles.

The future of China's power supply is in its hands. It could take a bold step on the path to sustainable, cleaner energy by adopting nuclear, solar and wind power, upgrading its power grid with smart grid and ultra-high-voltage technologies, and dedicating resources to develop IGCC and CCS. While the power sector is one of China's largest emitters of air pollutants and GHG, it also has tremendous potential to reduce carbon and pollution substantially – if China adopts the necessary technologies.

Agriculture and forestry: Expanding China's carbon sinks

For the purposes of this report, we have combined forestry and agriculture as one sector because of their common characteristics. Agriculture and forestry together contain most of China's land-based carbon sink system. Agriculture and forestry are critical to sustainable development as most of the GHG emissions abatement opportunities in the sector have significant environmental and ecological implications, while also making a modest contribution to total greenhouse gas abatement in China.

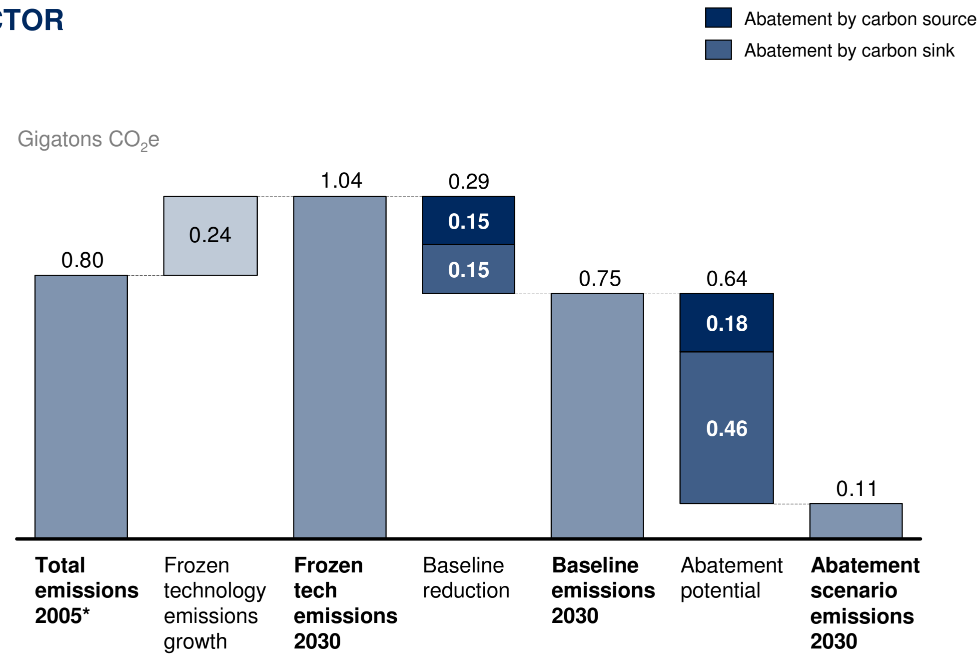
Our analysis shows that GHG emissions abatement opportunities in the agriculture and forestry sector would yield the highest benefits to China's ecosystems. This is because most of the abatement opportunities focus on expanding land-based carbon sinks through such measures as afforestation, grassland management and restoration, and conservative tillage. Improving the capacity of soil and plants to sequester carbon largely relies on increasing soil fertility and plant coverage. Such measures help to preserve the soil and water, thus reducing desertification and the occurrence of sand storms. Other abatement opportunities aim to control carbon emissions at source (e.g., livestock management and fertilizer management). Furthermore, the total abatement potential in the agriculture and forestry sector is 0.6 Gt of CO_2e in 2030. Although this is only 10 percent of the abatement potential of all the sectors we analyzed, this sector's emissions level in 2030 in the abatement scenario is 80-90 percent lower than that in 2005 (Exhibit 51).

Another important facet of the agriculture and forestry sector is climate change adaptation (i.e., actions to prepare for and respond to the potential impacts of climate change). Climate change has a substantial direct impact on agriculture and forestry – more than on any other sector we analyzed – especially in areas where ecosystems are already damaged or fragile. For instance, a drier and warmer climate (brought by increasing temperatures) exacerbates the problems of overgrazed grasslands. In such a case, ecological and environmental conservation actions serve a double purpose of adapting to climate change and reducing GHG emissions.

Nevertheless, most measures to expand carbon sinks in China have positive abatement costs and face significant implementation barriers. This is mainly because of the country's complex and some times intractable environmental conditions and the scattered presence of numerous stakeholders in rural areas.

Exhibit 51

SCENARIOS OF GHG EMISSIONS FOR AGRICULTURE-AND-FORESTRY SECTOR



* Assume carbon sink emission is zero in the scenario of frozen technology emissions

Source: McKinsey analysis

In our frozen technology scenario, we forecast emissions of 1.04 Gt of CO_2e in the agriculture and forestry sector in 2030. China has already implemented many sustainable development measures and halted most of the activities that destroy its carbon sinks (e.g., deforestation). Therefore, we assume zero growth in emissions due to further carbon sink losses. On the other hand, agricultural activities would drive up emissions. For example, carbon emissions from livestock will rise because the demand for animal products will increase as living standards improve in China. The use of fertilizers will also increase in order to improve arable land's productivity. However, the increase will be slight as cultivated arable land will remain approximately at its current level and China already has the world's highest rate of fertilizer use per unit of arable land. We expect emissions from China's anaerobic rice lands will remain almost unchanged.

In our baseline scenario, we have factored in the impact of the major policies of the Chinese government aimed at fostering sustainable agriculture and forestry. Historically, China exploited its forests and grasslands to an extent that was ecologically unsustainable. For example, original forest cover has been reduced to only 11 percent of the total land area, and 90 percent of China's grassland is degraded or at the risk of becoming so. The Chinese government recognized the risk and, in the 1980s, began a series of successful measures to reverse such trends. We have included these policies in our baseline scenario forecasts. We assume, for example, that forest cover will reach 20 percent of total land area after completion of the Natural Forest Protection Program, especially in the Yangzi River area and north China. In line with government targets, we estimate that 70 percent of families in the applicable rural areas will use methane produced "on the farm" from animal manure.

The government's project of calibrating fertilizer dosage according to soil characteristics/ type will save 5 percent of the fertilizer used nationally. Furthermore, a retreat from pastoral activity on overloaded pasturelands will save about half of China's degraded grasslands. All of these measures would reduce GHG emissions by 0.3 Gt of CO_2e.

As mentioned above, in our abatement scenario (which assumes the proactive application of GHG emissions abatement techniques), we estimate a total maximum abatement potential of 0.64 Gt of CO_2e in the sector. Because of the significant ecological benefits of carbon sink expansion beyond reducing GHG emissions, we assume the opportunity cost of land use for abatement levers such as afforestation and grassland restoration is zero in China.

Most of the abatement levers have positive (net) abatement costs, largely because we do not include their ecological benefits (e.g., reduced desertification and fewer sand storms) in our cost calculations. We take into account only the benefits that yield direct economic savings. In forestry, for example, no direct economic benefits are counted from afforestation. The abatement cost of afforestation in China is about EUR 22 per ton of CO_2e abated. In agriculture, the cost of grassland restoration is slightly higher than zero because higher grassland productivity cannot fully offset the costs (we only count the benefit accruing from the increased output of grass at its market price). Despite their positive abatement costs, these levers are likely to remain priorities if only for the sake of sustainable development. However, applying them will be a significant challenge.

In the agriculture and forestry sector, the uncertainty associated with the estimates of abatement potential and cost is particularly high. Such uncertainty does not originate from future technology evolution, as in other sectors, but from the lack of standardization of many technologies and the complex natural conditions of China. For example, the cost estimate of grassland management and restoration is based primarily on projects that have been implemented so far. However, such projects have covered less than 50 percent of all overloaded grasslands. For the remaining grasslands, especially areas that are drier, more remote, and economically under developed, the effectiveness and cost of implementing grassland restoration are still uncertain. Therefore, the current cost estimate of abatement options is not necessarily applicable to future projects. As the abatement option penetrates into areas that are more remote, and less endowed with natural resources, implementation could be significantly harder and the cost higher.

Nevertheless, implementing the abatement options will still be a large challenge even with favorable natural conditions and a good understanding of cost. To develop and enforce an effective incentive system, concerted efforts from the central and local governments will be needed, while hundreds of millions farmers across China must be actively involved.

BASELINE SCENARIO

In our baseline scenario, we estimate that the known and existing measures to restore land-based ecosystems and improve the rural environment will reduce GHG emissions (compared to our frozen technology scenario) by some 290 megatons of CO_2e. Of this, 70 percent will stem from agriculture thanks to government policies aimed at fostering sustainable agricultural practices (Exhibit 52).

Exhibit 52

GHG EMISSIONS REDUCTION IN THE BASELINE SCENARIO – 2030

Abatement options	Potential Gigatons CO_2e	Key government initiatives
Methane utilization in rural area	0.12	Construction of family-based methane-generating pits, penetration 30% by 2010, 70% by 2020
Forestry coverage rate increase	0.08	Yangzi River and North China ecological protection forest program
Grassland management and restoration	0.04	Ministry of Agriculture's program to stop pasturing in degraded grassland areas and subsidies for enclosed breeding
Nutrient management	0.03	Program to calibrate fertilizer dosage according to soil characteristics/type
Cropland management and restoration	0.03	Promotion of conservative tillage technology
Total abatement	0.29	

Source: McKinsey analysis

With regard to forestry, China has been restoring tree cover for over 20 years now. The country is approaching its "ecological protection" target of 20 percent forest cover to prevent the loss of soil and water, and reduce sandstorms. Currently, forest cover stands at over 18 percent and will likely reach its target by 2010.

In agriculture, the control of sources of carbon emissions and the expansion of carbon sinks to capture emissions both play an important role in our baseline scenario. One measure to manage the sources of carbon emissions is the use of methane generated from animal manure as an energy source. We estimate it has a GHG emissions abatement potential of 115 megatons of CO_2e. This is also an important measure to improve living conditions in rural areas. It gives rural families an alternative, clean source of energy to replace coal or wood, at a time when China has to import most of its natural gas and lacks gas-distribution pipelines in rural areas. The Chinese government has actively promoted the use of animal manure-based methane in rural areas since 2005. By the end of 2006, an estimated 23 million rural families (15 percent of the applicable population) had started using methane from home-based methane-generating pits as their main energy source for heating water and cooking. The Ministry of Agriculture plans to reach 30 percent of the applicable population (40 million rural families) by 2010, and 70 percent by 2020. Our estimate of the GHG emissions abatement potential only takes into account the impact of substituting fossil fuels. We do not consider the effect of methane destruction because the majority of animal manure discharge occurs on open land and does not generate methane, which requires anaerobic conditions to ferment the organic matter (e.g., a methane pit).

Nutrient (fertilizer) management is the second biggest lever of carbon source control. We estimate it has a GHG emissions abatement potential of 30 megatons of CO_2e. Agriculture in China needs to preserve soil fertility by reducing fertilizer utilization in general and, at the same time, increase the crop output potential to maintain (at least, in part) the nation's food supply. Hence, nutrient management could play a major role in improving the sustainability of agriculture. Starting in 2005, the Ministry of Agriculture has promoted technology aimed at calibrating fertilizer dosage according to soil characteristics/type. This should improve soil efficiency by 5 percent without having a negative impact on crop output. We assume nutrient management techniques and technologies will achieve 100 percent penetration by 2007.

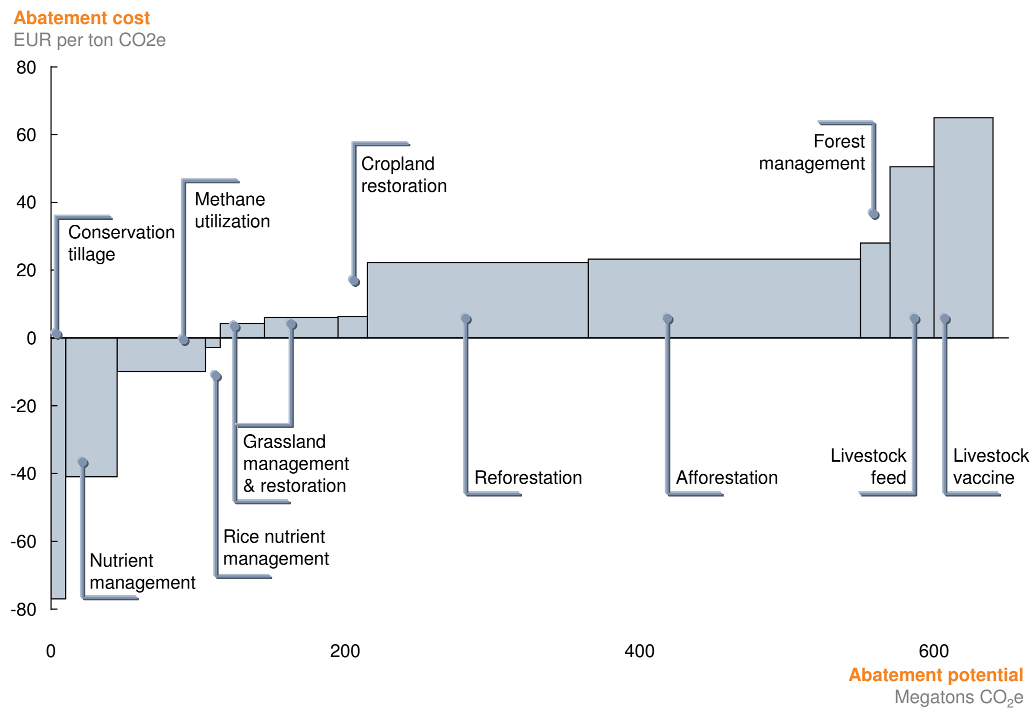
Turning to measures that expand carbon sinks, the most important opportunity in agriculture is the restoration and preservation of grasslands. China's grasslands face a serious threat from degradation and desertification. In 2000, the government launched a number of projects to restore grassland vegetation, by establishing forage-seed bases and fencing off grasslands. It also restricted grazing to special zones to enable the rehabilitation of pastures. By 2008, pastoral activity had retreated from 30 percent of the degraded grassland areas. We anticipate a further retreat by 2030, leaving 50 percent of the currently overloaded grasslands ungrazed. In addition, the widespread adoption of cropland improvement techniques (e.g., shallow flooding of rice lands) helps preserve arable land and boost its fertility.

ABATEMENT OPPORTUNITIES

As mentioned above, we estimate a total maximum GHG emissions abatement potential in the agriculture and forestry sector of 0.64 Gt of CO_2e by 2030 (Exhibit 53). Of this, increasing China's forest cover will yield 0.35 Gt of CO_2e. Agriculture will contribute 0.29 Gt of CO_2e through a number of smaller, more fragmented abatement opportunities (Exhibit 54).

Exhibit 53

COST CURVE FOR AGRICULTURE-AND-FORESTRY SECTOR – 2030



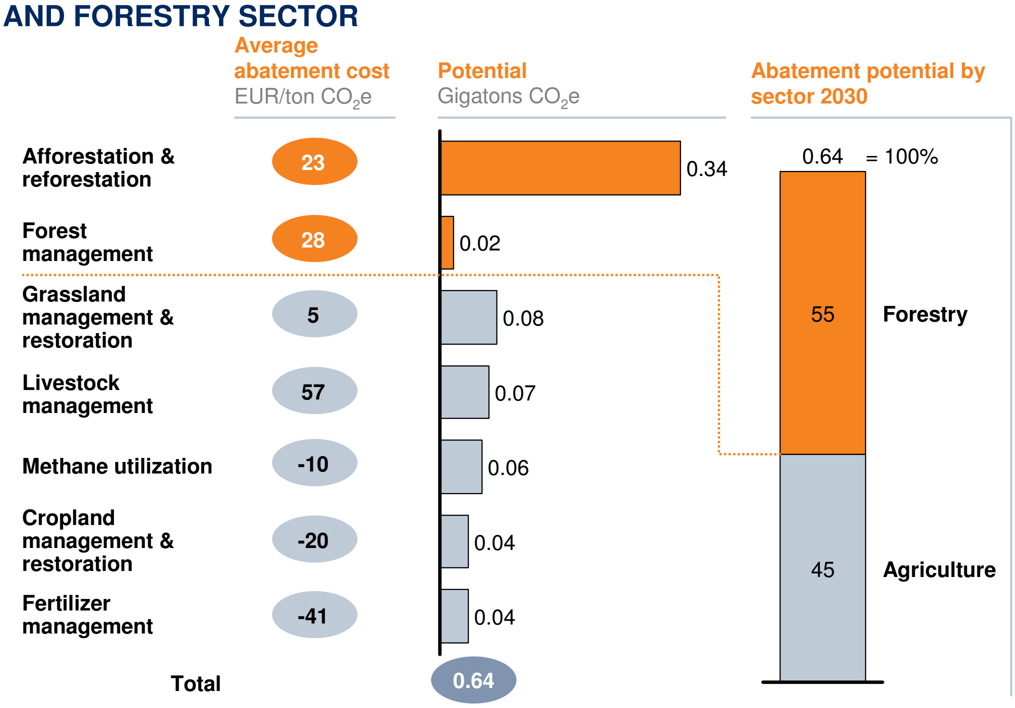
Forestry

Increasing the forest cover

China could increase GHG emissions abatement by maintaining its recent momentum of afforestation and reforestation, and increasing its forest cover from 20 percent to 25 percent. Increasing forest cover has an abatement potential of 335 million tons of CO_2e. However, the cost of afforestation and reforestation in China is 30 percent higher than the global benchmark because more resources are required in China to improve the degraded soil, nurture young trees and maintain grown forests. Nevertheless, the abatement potential alone does not represent the full ecological impact. China started massive afforestation decades ago, and is still in the stage of accumulating experience and searching for best practices. Moreover, some forests were planted specifically for commercial logging. The real effect of ecological improvement and the associated cost will take time to unfold. In addition, some other factors not covered in this report, such as water resource availability and biological diversity preservation, will also have an impact on the achievement of forestry expansion targets and eco-system improvement.

Exhibit 54

7 CLUSTERS OF ABATEMENT OPPORTUNITIES IN THE AGRICULTURE AND FORESTRY SECTOR



Source: McKinsey analysis

Agriculture

Agricultural opportunities contribute about 45 percent of the total GHG emissions abatement potential through the combined use of 10 technologies. We group them into two clusters of carbon sink expansion technologies (grassland management and restoration and cropland management and restoration) and three clusters of carbon source control technologies (live stock management, methane utilization and fertilizer management).

Grassland management and restoration

With an abatement potential of 80 megatons of CO_2e and a substantial ecological impact, grassland management and restoration is the most important abatement opportunity in agriculture. China has more than 400 million hectares of grasslands, of which 60 percent are pasture lands. In turn, some 90 percent of China's pasture lands face issues of degradation. The overload rate of original grassland is 33 percent on average, and over 70 percent of all pasture lands in China suffer from overload. In our abatement scenario, we assume that 100 percent of China's overloaded pasture lands are left ungrazed (compared with 50 percent in our baseline scenario). Effective grassland management and restoration requires a shift from pastoral to enclosed animal stockbreeding, leaving grass to grow undisturbed. This will require large investments in enclosed stockbreeding capacity. For slightly degraded grasslands, fencing off the land to keep out grazing animals is sufficient to allow natural recovery. Seriously degraded grasslands will need additional investment to re-plant and maintain grass. The investments required to move to enclosed stockbreeding include expenditure on animal housing, fencing, and grass planting. The ongoing expenses include expenditure on the purchase and transportation of concentrated feed and grass. Given the lack of detailed tracking data, we estimate the total cost of grassland restoration based on a comparison of farmers' willingness to accept compensation (for retiring from pasture lands) and the total project budget.

Data from the Ministry of Agriculture shows that the grass output of grasslands covered by ecological projects increased by 20–60 percent compared with areas not covered by such projects. The benefit from increased grass output alone, calculated using the market price of grass, can largely offset the costs of restoration. We estimate a net abatement cost of EUR 4–6 per ton of CO_2e.

In addition, grassland restoration can help to control desertification. For example, the area classified as desert is 10–20 percent lower in the grasslands covered by ecological projects in China. Without restoration measures, overgrazing could have depleted these grasslands, leading to far greater losses than those attributable simply to the reduction in grass output.

However, the wide differences in China's natural environment, in particular the varying supply of water resources, significantly affect the actual costs and potential of grassland restoration. In drier areas, with less than 200 milliliters of annual precipitation, irrigation is a serious challenge to successful grassland recovery. Therefore, there is a risk of overestimating the real upper limit of GHG emissions abatement from such measures.

Cropland management

Most cropland-management measures have negative abatement costs thanks to the savings farmers can realize in fertilizer use or tillage activities. The most important technique is conservation tillage, which minimizes or even eliminates tillage by increasing the return-to-soil ratio of the straw from the previous season's crop. Reducing soil disturbance and increasing the organic coverage of soil, enhances the soil's carbon-capture capability and helps to maintain its fertility. However, the impact of conservative tillage on crop output is uncertain, not least due to a lack data for its mass application. We therefore do not account for any benefits from improved crop production in our estimates. In our baseline scenario, we assume China exploits most of the abatement potential from conservative tillage by 2030.

Another important abatement measure is the restoration of degraded croplands. China could recover croplands damaged by soil erosion and from activities such as mining, and increase the organic carbon content of soil through sludge flooding, soil stabilization, and vegetation recovery. However, compared with grassland, the amount of such land that is available is relatively small, as is its abatement potential.

Livestock emissions control

With an abatement potential of just under 0.1 Gt of CO_2e, the cost of controlling livestock emissions is very high (EUR 50 per ton of CO_2e). This is because GHG emissions abatement is the only benefit from this measure. Controlling livestock emissions involves the use of specific animal-feed ingredients and methane-control vaccines to control the methane emissions of ruminant animals. Compared with other technologies, these measures are standardized and very easy to apply once mature. However, they are still largely unknown in China, partly because they have a very limited impact on sustainable agriculture (apart from controlling GHG emissions). The only potential barrier to their application is the very scattered distribution of animal farms in China. We assume a vaccine penetration rate of about 75 percent of all livestock.

Fertilizer efficiency improvement

Applying the latest technology to improve the efficiency of fertilizers can cut the use of such products by up to 20 percent. Improving fertilizer efficiency has an abatement potential of 40 megatons of CO_2e at a negative cost, thanks to the savings from reducing the amount of fertilizer farmers need to use. However, we have not tried to estimate the investments required to train farmers in applying the technology.

Methane use increase

As mentioned above, China plans to achieve a 70 percent penetration rate for methane use in 2020. Extending the technology to 100 percent of all rural households that can apply it would yield a further abatement potential of 60 megatons of CO_2e. This would be at a negative cost, driven by fossil fuel savings. It will also bring other benefits, which we have not considered in our cost curve (e.g., improvements to the rural environment and hygiene conditions, or improved sources of “green” fertilizer from the organic residues of fermentation).

IMPLEMENTATION BARRIERS

Due to its importance in the agriculture and forestry sector, we focus here on the institutional hurdles to capturing the full GHG emissions abatement potential from expanding carbon sinks.

- *Fluctuating market prices.* The government fixes its feedstock subsidy for a period of one or two years. Hence, farmers that practice enclosed stockbreeding remain sensitive to changes in feedstock prices. If feedstock prices rise too high, farmers may suffer heavy losses and return to grazing their livestock on pasture lands. To avoid this, China would need a flexible subsidy system that covers the full cost of transitioning farmers from pastoral to enclosed stockbreeding regardless of market price changes.

- *The "free rider" problem.* Some farmers may see an opportunity to save the cost of enclosed breeding by returning their animals to grazing while other farmers practice enclosed stockbreeding. As it is difficult to monitor the grasslands, many farmers might resume grazing activities that further degrade grasslands, leading to a net loss of grasslands overall. Consolidation of the animal stockbreeding industry would help to address this issue by making monitoring easier.

- *Lack of technical know-how.* The remote and scattered grasslands and croplands of China pose a double challenge to applying technological solutions in the agriculture sector. First, applying new technologies in such areas will require significant resources. Second, and more important, the diverse and difficult natural conditions in China will likely require some customization of the technologies. For example, irrigation in areas where there is a lack of water resources is a serious complication for grassland restoration and forestation. Developing practical solutions may only be possible after conducting pilot programs and on a case-by-case basis. Therefore, it is crucial to set up proactive programs to develop solutions that are tailored to specific local natural and economic conditions. A sophisticated technical support system would help to ensure the promotion and rapid adoption of useful technologies throughout China.

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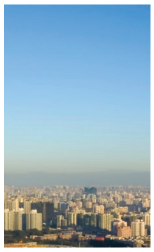
GHG emissions abatement measures in the agriculture and forestry sector are critical to ecological protection and recovery. They also work in tandem with climate-change adaptation efforts. Overall, improving the forest cover in China and forest management would yield an abatement potential of 0.35 Gt of CO_2e, while various agricultural technologies would contribute around 0.29 Gt of CO_2e abated. However, many of the abatement measures we describe above face significant implementation barriers, in particular because many of the technologies are not standardized and the diverse and often difficult natural conditions in China make it complicated to apply them. Hence, the actual maximum abatement potential may be lower than our estimates.

China is striving to improve its historically overexploited natural environment. Moreover, the benefits of these measures go far beyond GHG abatement alone. Despite the relatively low GHG emissions abatement potential and high costs, therefore, we expect abatement measures in agriculture and forestry will remain high up on China's sustainable development agenda.



Areas of further research

We hope that this report will help policy makers, business leaders, academics and others to define and prioritize economically sensible approaches to address China's rising challenge in securing sustainable development.

Based on our findings, and the understanding we have developed over the course of the study, we suggest some areas for further research that could yield additional insights:

- Analyzing the economy-wide effects relating to sustainability improvement, such as shifts in employment, the impact on GDP and the productivity of capital investments, and the impact on existing or new businesses, including changes in the global competitiveness of Chinese companies
- Calibrating specific policy choices, such as energy price reform, on the basis of a full set of factors (e.g., cost, carbon abatement, energy security, local pollution, employment, global competitiveness in specific industries, and impact on the lower-income population)
- Identifying a list of key technologies that require international support to promote their availability, funding and diffusion
- Developing mechanisms to secure funding from domestic and international sources to cover the incremental cost of abatement technologies, especially upfront investments
- Analyzing the value chain of key technologies to identify and understand the value extraction opportunities, and define a regulatory framework to accelerate the development of a healthy industry around a particular technology
- Investigating consumer choices and infrastructure needs to ensure the rapid diffusion of key technologies
- Researching the need for adaptation to potential climate change and the resulting impact and cost

Glossary

Abatement. The purposeful reduction of the quantity (volume) or the growth rate of greenhouse gas emissions.

Abatement cost. The engineering and resource costs required to capture a specified abatement option. These costs include all capital, operations and maintenance costs, but exclude all social, welfare, and regulatory costs associated with realizing an opportunity. A "per-ton" cost is the net discounted cost (including benefits) divided by the total emissions reduction. We have calculated the abatement cost over the lifetime of a measure.

Afforestation. The natural or human-induced spread of forest to previously unforested land, such as fields and pastures. The replanting of forest land after the removal of trees is usually called "reforestation".

APC. Advanced process control.

Building envelope. The outer shell of a building (e.g., insulation, windows, sealing, and "thermal bridges") that controls the exchange of heat between the indoor and outdoor environment.

Carbon sink. A reservoir of carbon that absorbs CO_2 thus delaying its release into the atmosphere. Land-based organic matter – mainly forests, but also agricultural land and crops – constitutes the main carbon sink. (We do not discuss other potential carbon sinks, such as oceans and other bodies of water in this report.)

Carbon stock. The quantity of stored carbon in a "pool". Land-based carbon stocks include forest stocks (living and standing dead vegetation, wood debris and litter, and organic material in the soil) and harvested stocks (wood for fuel and wood products, such as lumber and paper).

CCPP. Combined cycle power production. CCPP is a gas turbine generation system that uses waste heat to produce steam to generate additional electricity via a steam turbine.

CCS. Carbon capture and storage. A process that captures CO_2 released from the combustion of fossil fuels, prepared for transportation, moved and delivered to a storage site, and permanently stored to prevent its release into the atmosphere.

CDQ. Coke dry quenching. The use of an inert gas instead of water to cool hot coke. It improves both the energy utilization rate from hot coke as well as the quality of the coke.

CHP. Combined heat and power, also known as “co-generation”. The use of a heat engine or a power station to generate electricity and steam from a single fuel at a facility near the consumer.

CMC. Coal moisture control. CMC uses the waste heat from a coke oven gas to dry the coal used for coke making, which reduces the coking process’ fuel consumption.

CMM. Coal mine methane. The methane component of gases drained from coal mines. CMM is “high density” if the methane component is higher than 30 percent. “Low density” CMM is between 5 percent and 30 percent (which is still in the explosive range).

CO_2e. Carbon-dioxide equivalent. A standardized measure of greenhouse gas emissions developed to account accurately for the differing global warming potentials of the various gases. Emissions are measured in metric tons of CO_2e per year, usually in millions of tons (megatons) or billions of tons (gigatons).

Conservation tillage. The preparation of agricultural land by plowing, ripping, or turning while leave a minimum of 30 percent of crop residue on the soil surface. This reduces soil erosion and compaction. Farmers realize significant savings in fuel by reducing the number of times they have to travel over a field.

Cropland management and restoration. Techniques to improve the coverage and productivity of croplands. Restoration involves manual replanting to resume agricultural activities on abandoned land.

CSP. Concentrating solar power. CSP systems use lenses or mirrors and tracking systems to concentrate a large area of sunlight into a small beam. A conventional power plant uses the concentrated light as a heat source to generate electricity.

Economic retrofit package. Tailored retrofit packages that provide cost-effective solutions for a specific climatic region.

EOR. Enhanced oil recovery. A technology that injects CO_2 into oil wells to increase the amount of oil extracted from a field.

EV. Electric vehicle. A vehicle with one or more electric motors for propulsion. The term includes plug-in hybrid vehicles (PHEV) and pure electric vehicles (PEV).

Fertilizer management. Techniques allowing for the more efficient use of fertilizers.

Fluorocarbon thermal oxidation. The destruction of fluorocarbons by means of thermal oxidation.

Geothermal. Technologies that harness geothermal (i.e., heat coming from within the Earth) energy to generate electricity.

GHG. Greenhouse gases. The major ones are:

- CO_2 – Carbon dioxide
- CH_4 – Methane
- N_2O – Nitrous oxide
- CFCs – Chlorofluorocarbons
- HFCs – Hydrofluorocarbons
- PFCs – Perfluorocarbons
- SF_6 – Sulfur hexafluoride

Gigaton. 1 billion metric tons.

Grassland management and restoration. Improving the coverage and productivity of grasslands by stopping their use as pasture and introducing enclosed breeding. This requires grassland fencing and the construction of enclosed-breeding facilities. Restoring degraded grassland requires the manual replanting of grass.

HVAC. Heating, ventilation, and air conditioning. Climate control systems for commercial and residential buildings.

IGCC. Integrated gasification combined cycle. A technology that turns coal into gas, and then removes the impurities from the coal gas before it is combusted. In a combined cycle, the combusted gas drives a gas turbine, while the exhaust gases are heat exchanged with water and/or steam to generate superheated steam to drive a steam turbine.

LC-ethanol. Second-generation bio-ethanol produced from lignocellulose, a fibrous material found in nearly all plants.

LFG. Land-fill gas. Gas emitted from land fills of solid waste, containing mainly methane. LFG can be collected through drilled-in or pre-installed pipelines.

Lighting control. Sensors that enable lights to be turned on and off automatically.

Livestock management. Techniques to reduce the GHG emissions from livestock using vaccines and feed supplements.

Megaton. 1 million metric tons.

NG-based DRI. Natural gas-based direct reduced iron. The reduction of iron ore pellets below melting point using natural gas as the reducing agent. Midrex is the major NG-based DRI technology.

Passive design. A building approach that exploits natural solar heating, light, ventilation, and shade, as well as the smart integration of building components and design. Its successful application requires the close cooperation of engineers and architects.

PCI. Pulverized Coal Injection. The replacement by pulverized coal of some of the coke in a blast furnace.

PEV. Pure electric vehicle. A vehicle run solely on battery power without the aid of an internal combustion mechanism.

PHEV. Plug-in hybrid electric vehicle. A vehicle with a rechargeable electric motor and a backup internal combustion engine (ICE) for power. PHEVs reduce the contribution of the traditional ICE.

Small hydro. Small-scale hydroelectric power generation (i.e., less than 50 MW) serving a small community or industrial plant.

Solar PV. Solar photovoltaics. A technology to generate solar power by using solar cells packaged in photovoltaic modules (often electrically connected in multiples as solar photovoltaic arrays) to convert the energy from sunlight into electricity.

Subcritical/supercritical/ultra supercritical coal-fired plant. A subcritical coal-fired power plant has a main steam temperature of approx. 560°C at a pressure of approx. 240 ata. A supercritical coal-fired plant has a main steam temperature of approx. 535°C at approx. 170 ata. An ultra supercritical coal-fired power plant has a main steam temperature of approx. 600 °C at approx. 300 ata.

(Note: ata = atmosphere absolute; 1 ata is the average atmospheric pressure at sea level).

Thin-strip direct casting. A process that combines direct casting and hot rolling to produce a thin strip from liquid steel in a single step.

TRT. Top pressure recovery turbine. A power generation system that uses the physical energy of the furnace-top gas pressure of a high-pressure blast furnace to drive a gas turbine.

VAM. Ventilation air methane. Methane in the ventilation air pumped out of coal mines; normally, the methane density is around 0.5 percent.

VCMM. Virgin coal mine methane. Methane extracted directly from coal mines by surface equipment.

Ventilation air. Air pumped through coal mines to ventilate the remainder of the gas after drainage.

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