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China's sustainable energy future: Scenarios of energy and carbon emissions (Summary)

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Abstract:

China has ambitious goals for economic development, and must find ways to power the achievement of those goals that are both environmentally and socially sustainable. Integration into the global economy presents opportunities for technological improvement and access to energy resources. China also has options for innovative policies and measures that could significantly alter the way energy is acquired and used. These opportunities and options, along with long-term social, demographic, and economic trends, will shape China's future energy system, and consequently its contribution to emissions of greenhouse gases, particularly carbon dioxide (CO₂). In this study, entitled China's Sustainable Energy Future: Scenarios of Energy and Carbon Emissions, the Energy Research Institute (ERI), an independent analytic organization under China's National Development and Reform Commission (NDRC), sought to explore in detail how China could achieve the goals of the Tenth Five-Year Plan and its longer term aims through a sustainable development strategy. China's ability to forge a sustainable energy path has global consequences. China's annual emissions of greenhouse gases comprise nearly half of those from developing countries, and 12 percent of global emissions. Most of China's greenhouse gas emissions are in the form of CO₂, 87 percent of which came from energy use in 2000. In that year, China's carbon emissions from energy use and cement production were 760 million metric tons (Mt-C), second only to the 1,500 Mt-C emitted by the US (CDIAC, 2003). As China's energy consumption continues to increase, greenhouse gas emissions are expected to inevitably



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increase into the future. However, the rate at which energy consumption and emissions will increase can vary significantly depending on whether sustainable development is recognized as an important policy goal. If the Chinese Government chooses to adopt measures to enhance energy efficiency and improve the overall structure of energy supply, it is possible that future economic growth may be supported by a relatively lower increase in energy consumption. Over the past 20 years, energy intensity in China has been reduced partly through technological and structural changes; current annual emissions may be as much as 600 Mt-C lower than they would have been without intensity improvements. China must take into account its unique circumstances in considering how to achieve a sustainable development path. This study considers the feasibility of such an achievement, while remaining open to exploring avenues of sustainable development that may be very different from existing models. Three scenarios were prepared to assist the Chinese Government to explore the issues, options and uncertainties that it confronts in shaping a sustainable development path compatible with China's unique circumstances. The Promoting Sustainability scenario offers a systematic and complete interpretation of the social and economic goals proposed in the Tenth Five-Year Plan. The possibility that environmental sustainability would receive low priority is covered in the Ordinary Effort scenario. Aggressive pursuit of sustainable development measures along with rapid economic expansion is featured in the Green Growth scenario. The scenarios differ in the degree to which a common set of energy supply and efficiency policies are implemented. In consultation with technology and policy experts domestically and abroad, ERI developed strategic scenarios and quantified them using an energy accounting model. The scenarios consider, in unprecedented detail, changes in energy demand structure and technology, as well as energy supply, from 1998 to 2020. The scenarios in this study are an important step in estimating realistic targets for energy efficiency and energy supply development that are in line with a sustainable development strategy. The scenarios also help analyze and explore ways in which China might slow growth in greenhouse gas emissions. The key results have important policy implications: Depending on how demand for energy services is met, China could quadruple its gross domestic product between 1998 and 2020 with energy use rising by 70 percent to 130 percent (Figure 1). Continual progress in improving the efficiency and structure of industry is crucial to maintaining economic growth with minimal growth in energy use. In some industries, output may grow with no rise in energy use at all. Swelling ranks of motor vehicles will deepen China's dependence on imported oil up to 320 Mt per year by 2020 an amount that global markets can easily supply. To moderate growth in transportation energy use, the strong promotion of convenient public transport will be needed in addition to tighter fuel efficiency standards and advanced vehicles. Fuel switching, efficient appliances, better heating and cooling systems, and improved building envelope technologies will be needed in the fast-growing buildings sector. By 2020, China will still be dependent on coal for 54 percent to 65 percent of its primary energy, even with rapid growth of other fuels and substantial progress in raising the efficiency of coal use. Natural gas supplies, including imported pipeline gas and LNG, will have to expand tremendously to meet demand from households, commercial buildings, and electric utilities; obtaining sufficient supply is a crucial uncertainty. Sustainable growth in electricity generation will require strong policy support for a range of technologies, including advanced coal-fired generation, natural gas, hydropower, non-hydro renewables, and nuclear. If sustainable policies for energy development are not pursued, energy-related carbon emissions could more than double between 1998 and 2020, but if such policies are aggressively pursued carbon emissions could increase by only 50 percent. Although China's energy sector faces many future challenges, it is technically feasible for China to progress towards meeting its development goals while limiting the growth of energy use. However, each of the three scenarios in this report will require significant, long-term policy efforts to achieve the energy and emission trajectories described in the following pages.

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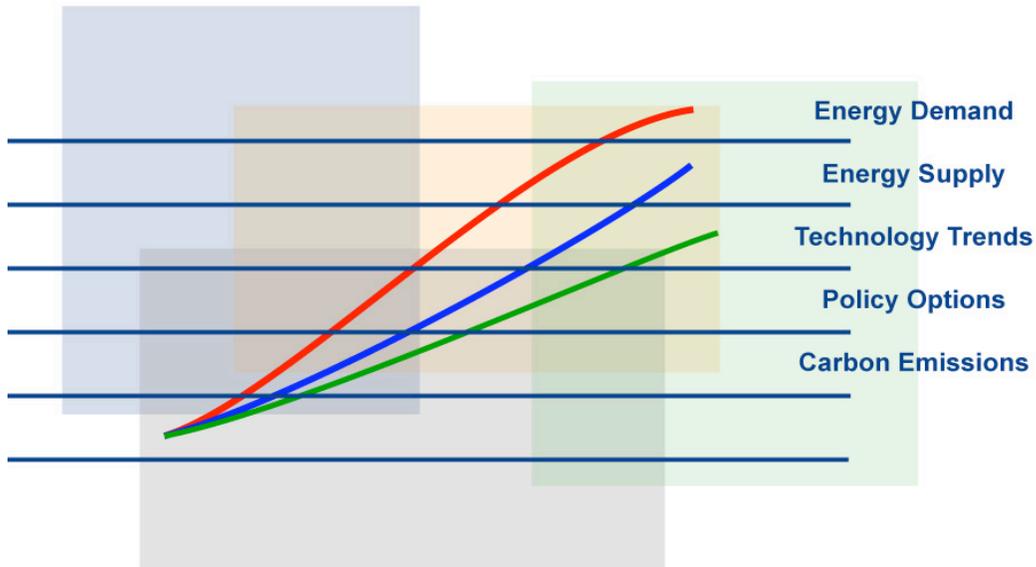
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SUMMARY

CHINA'S SUSTAINABLE ENERGY FUTURE

Scenarios of Energy and Carbon Emissions



Energy Research Institute
of the National Development and Reform Commission,
People's Republic of China



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EXECUTIVE SUMMARY: CHINA'S ENERGY CHALLENGE

China has ambitious goals for economic development, and must find ways to power the achievement of those goals that are both environmentally and socially sustainable. Integration into the global economy presents opportunities for technological improvement and access to energy resources. China also has options for innovative policies and measures that could significantly alter the way energy is acquired and used. These opportunities and options, along with long-term social, demographic, and economic trends, will shape China's future energy system, and consequently its contribution to emissions of greenhouse gases, particularly carbon dioxide (CO₂). In this study, entitled *China's Sustainable Energy Future: Scenarios of Energy and Carbon Emissions*, the Energy Research Institute (ERI), an independent analytic organization under China's National Development and Reform Commission (NDRC), sought to explore in detail how China could achieve the goals of the Tenth Five-Year Plan and its longer-term aims through a sustainable development strategy.

China's ability to forge a sustainable energy path has global consequences. China's annual emissions of greenhouse gases comprise nearly half of those from developing countries, and 12% of global emissions. Most of China's greenhouse gas emissions are in the form of CO₂, 87% of which came from energy use in 2000. In that year, China's carbon emissions from energy use and cement production were 760 million metric tons (Mt-C), second only to the 1,500 Mt-C emitted by the US (CDIAC, 2003).

As China's energy consumption continues to increase, greenhouse gas emissions are expected to inevitably increase into the future. However, the rate at which energy consumption and emissions will increase can vary significantly depending on whether sustainable development is recognized as an important policy goal. If the Chinese Government

chooses to adopt measures to enhance energy efficiency and improve the overall structure of energy supply, it is possible that future economic growth may be supported by a relatively lower increase in energy consumption.

Over the past 20 years, energy intensity in China has been reduced partly through technological and structural changes; current annual emissions may be as much as 600 Mt-C lower than they would have been without intensity improvements. China must take into account its unique circumstances in considering how to achieve a sustainable development path. This study considers the feasibility of such an achievement, while remaining open to exploring avenues of sustainable development that may be very different from existing models.

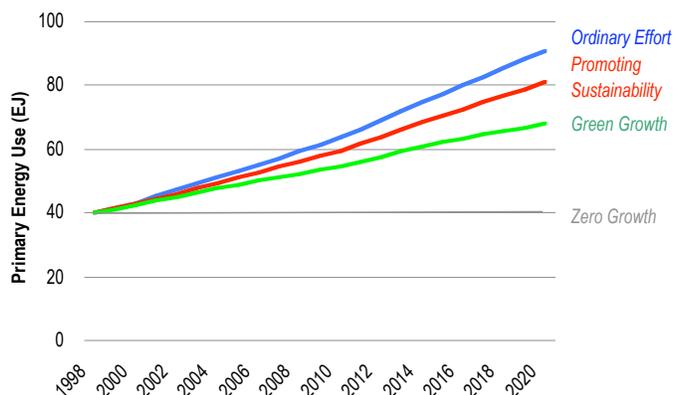
Three scenarios were prepared to assist the Chinese Government to explore the issues, options and uncertainties that it confronts in shaping a sustainable development path compatible with China's unique circumstances. The *Promoting Sustainability* scenario offers a systematic and complete interpretation of the social and economic goals proposed in the Tenth Five-Year Plan. The possibility that environmental sustainability would receive low priority is covered in the *Ordinary Effort* scenario. Aggressive pursuit of sustainable development measures along with rapid economic expansion is featured in the *Green Growth* scenario. The scenarios differ in the degree to which a common set of energy supply and efficiency policies are implemented.

In consultation with technology and policy experts domestically and abroad, ERI developed strategic scenarios and quantified them using an energy accounting model. The scenarios consider, in unprecedented detail, changes in energy demand structure and technology, as well as energy supply,

from 1998 to 2020.

The scenarios in this study are an important step in estimating realistic targets for energy efficiency and energy supply development that are in line with a sustainable development strategy. The scenarios also help analyze and explore ways in which China might slow growth in greenhouse gas emissions. The key results have important policy implications:

- Depending on how demand for energy services is met, China could quadruple its gross domestic product between 1998 and 2020 with energy use rising by 70% to 130% (Figure 1).
- Continual progress in improving the efficiency and structure of industry is crucial to maintaining economic growth with minimal growth in energy use. In some industries, output may grow with no rise in energy use at all.
- Swelling ranks of motor vehicles will deepen China's dependence on imported oil—up to 320 Mt per year by 2020—an amount that global markets can easily supply.
- To moderate growth in transportation energy use, the strong promotion of convenient public transport will be needed in addition to tighter fuel efficiency standards and advanced vehicles.
- Fuel switching, efficient appliances, better heating and cooling systems, and improved building envelope technologies will be needed in



the fast-growing buildings sector.

- By 2020, China will still be dependent on coal for 54% to 65% of its primary energy, even with rapid growth of other fuels and substantial progress in raising the efficiency of coal use.
- Natural gas supplies, including imported pipeline gas and LNG, will have to expand tremendously to meet demand from households, commercial buildings, and electric utilities; obtaining sufficient supply is a crucial uncertainty.
- Sustainable growth in electricity generation will require strong policy support for a range of technologies, including advanced coal-fired generation, natural gas, hydropower, non-hydro renewables, and nuclear.
- If sustainable policies for energy development are not pursued, energy-related carbon emissions could more than double between 1998 and 2020, but if such policies are aggressively pursued carbon emissions could increase by only 50%.

Although China's energy sector faces many future challenges, it is technically feasible for China to progress towards meeting its development goals while limiting the growth of energy use. However, each of the three scenarios in this report will require significant, long-term policy efforts to achieve the energy and emission trajectories described in the following pages.

Figure 1. In the Ordinary Effort scenario, primary energy use grows at an average of 3.2% per year, while in the Promoting Sustainability scenario growth is 3.8%, and 2.4% in the Green Growth scenario.

A BROAD-BASED APPROACH

Scenario analysis is used worldwide in support of energy and environmental planning. While scenarios are not forecasts, they offer a valuable method for thinking systematically about processes of change. The process of creating energy scenarios leads to a more robust understanding of energy dynamics and opportunities for change, and can greatly assist in the decision making of governments, businesses, and other organizations. Useful scenarios concentrate on specific issues faced by decision makers. Acceptance is enhanced by including a wide variety of stakeholders in the development of scenarios. This study used both *scenario analysis* for the creation of the baseline and policy scenarios, and detailed *end-use analysis* to quantify forecasts based on each scenario.

While many studies have been conducted on future energy use and pollutant emissions in China, this effort was undertaken for several reasons, including:

- New developments in technology, markets, and economic structure necessitate periodic updating of analyses.
- Many previous studies have had an academic focus, while this effort provided direct support for national energy efficiency planning.
- Understanding of barriers to deployment of new technologies has advanced and needs to be incorporated into forecasting analysis.
- Past studies have considered end-use sectors in insufficient detail to capture important dynamics unique to particular activities and technologies.

During the first stage of this project (April 1999 to March 2000), the project team focused on developing the energy efficiency component of the Tenth Five-Year Plan (2001-2005), providing direct support to the Department of Infrastructure of the former State

Development Planning Commission (SDPC). Through on-site surveys, workshops, and consultations with sectoral experts (see list of acknowledgements at the end of this summary) the team analyzed the status quo of energy efficiency in all energy-consuming sectors across all provinces and municipalities, with special attention to energy-intensive industries. The team also assessed the impact of past development plans, investments, and energy efficiency policies on sectoral and technological development, considered barriers to reaching past goals, and assessed the potential for improvements in energy efficiency. At the end of 1999, the project team submitted a background report to SDPC's Department of Infrastructure, and participated in drafting the energy conservation plan for the Tenth Five-Year Plan.

In the second stage (April 2000 to December 2000), the team embarked on the process of developing and quantifying scenarios, guided by the conceptual procedure in Figure 2. Key research team members and experts from China trained in scenario-building and modeling methods for the buildings sector and industrial sectors at Lawrence Berkeley National Laboratory (LBNL), and for the transportation sector at Oak Ridge National Laboratory (ORNL). The team and its collaborators selected the Long-range Energy Alternatives Planning System (LEAP) software, developed for scenario analysis by the Stockholm Environment Institute-Boston (SEI-Boston). LEAP is an accounting program that allows users to track how energy is consumed, converted and produced under a range of assumptions, at a high level of detail in supply and end-use sectors. The basic framework of the energy model was established based on the anticipated needs of the scenario analysis, a base year selected (1998), and initial data sets developed.

In the third project stage (January 2001 to December 2001), the team focused on determining the macroeconomic design elements for three main

scenarios and the resulting impacts on energy use and energy-related carbon emissions. A seminar was held with the Shell Foundation to analyze the scenarios and how they may influence actual energy demand scenarios for China. Modeling experts from LBNL, ORNL, the National Renewable Energy Laboratory, and SEI-Boston participated in a seminar in Beijing to help establish detailed models for all major sectors. Key members of the team visited the Shell Centre in the UK and worked with the model to determine the framework and key drivers of the scenarios, thus completing the first round of scenario analysis.

The fourth stage of the project (January 2002 to May 2003) focused on refining and testing the model and its inputs, developing and analyzing scenario results, and writing the final report. The team reviewed the connections between economic growth and energy consumption in China, drafted a summary report on the scenarios and results for each sector individually, and then unified the sectoral models to resolve

inconsistencies among the sectoral inputs and results. The team prepared a draft final report, presented the research results and implications to relevant state authorities, and then further revised the report based on comments provided by experts and stakeholders.

The research team has completed a systematic scenario-based assessment of China's energy options, based on four years of preparation, engagement, analysis, and revision, and has drawn a series of valuable conclusions. The analysis describes future options for sustainable energy development in China, how to raise end-use efficiency of the energy system and improve the structure of energy supply, and how to expedite the development of clean energy technologies while achieving the social and economic goals driving China's development. The findings and recommendations comprise a scientific foundation for the Government's formulation of policies for sustainable development, and will no doubt serve as an important guide in the development and utilization of energy in China.

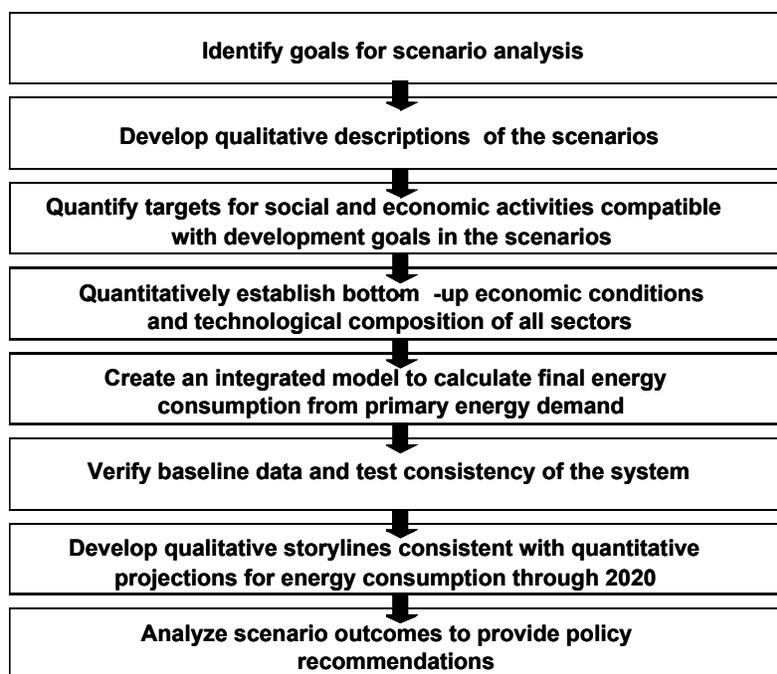


Figure 2. The framework for development and quantification of scenarios was a multi-staged approach designed to elicit input from a broad range of stakeholders and experts to address policy questions directly confronting national decision makers.

THREE SCENARIOS

Three scenarios were created to examine possible ways in which key input variables could influence China's future energy consumption and carbon emissions. The major differences in the three scenarios are the extent to which sustainable development policies are implemented, and the extent to which government-estimated economic growth targets are achieved. Major assumptions made in the three scenarios are summarized in Table 1. In order to maintain consistency with their respective storylines, key driver variables, like population and urbanization rates, differ among the scenarios. Growth in GDP is assumed to be the same in all scenarios, in order to show different pathways to reaching the same level of GDP per capita. While the same basic set of energy demand and supply policies were considered in the three scenarios, they differed significantly in the assumed timing, success and degree of implementation (Table 2). In all scenarios, China is assumed to have unrestricted access to international oil and gas markets.

Scenario 1: Ordinary Effort

This scenario depicts a situation in which sustainable development and environmental policies receive much less emphasis than economic policies. *Ordinary Effort* represents a trajectory for China that could result if the Government fails to assign a high priority to reducing growth in energy use. It assumes that China's current high economic growth trajectory will continue at the rates projected in government plans, and that no significant new environmental or energy efficiency policies will be adopted.

Population growth is at the high end of current forecasts, reaching 1.485 billion in 2020. Urban and rural housing grows rapidly, and urbanization rises, but less so than in the other scenarios. Although penetration of household appliances rises quickly, the rate of energy efficiency improvements is slow, leading to rapid growth in residential energy use.

In the transportation sector, *Ordinary Effort* assumes only minimal upgrading and replacement of rural motor vehicles and a large increase in the total number of motorcycles and automobiles. Small and medium cities continue to lack effective planning mechanisms for public transport, causing heavy reliance on private vehicles, and a resultant increase in traffic congestion. These trends are accompanied by slow improvement in fuel economy. The Government plays a minimal role in directing manufacturers to produce or consumers to choose efficient technologies and make environmentally conscious decisions. Vehicle stocks are the same as in other scenarios, but vehicles are used more in this scenario than in the others.

Industrial reorganization is relatively unsuccessful in changing energy intensity. China experiences difficulty adapting to global economic changes, damaging competitiveness in international markets. Domestically, the closure, merger and reorganization of small enterprises is not implemented successfully, leading to major economic inefficiencies. Progress in energy-sector reform lags behind other sectors, and monopolies continue to exist in some areas.

In the electric power sector, desulfurization devices are gradually applied to coal-fired power plants. However, by 2020, power plants without desulfurization still comprise a large proportion of capacity. The development of hydropower, nuclear power, IGCC and wind power is relatively steady, but no direct policy emphasis is placed on renewable technology development.

Energy efficiency policy is minimal in this scenario. The Energy Conservation Law is implemented, but policy measures fall short of creating effective market incentives. Technological development is hindered and the operating efficiency of equipment does not reach advanced international levels.

Table 1. Assumptions in the three scenarios establish different paths by which China might meet the same economic development goals by 2020.

	Scenario 1: <i>Ordinary Effort</i>	Scenario 2: <i>Promoting Sustainability</i>	Scenario 3: <i>Green Growth</i>
Population in 2020	<ul style="list-style-type: none"> 1.485 billion 	<ul style="list-style-type: none"> 1.47 billion 	<ul style="list-style-type: none"> 1.445 billion
Urbanization Rate in 2020	<ul style="list-style-type: none"> 52.86% 	<ul style="list-style-type: none"> 55.78% 	<ul style="list-style-type: none"> 58.29%
Gross Domestic Product	<ul style="list-style-type: none"> Before 2010, GDP grows at 7.3% per year, and after 2010 at 6.7% per year. 	<ul style="list-style-type: none"> Same as <i>Ordinary Effort</i>. 	<ul style="list-style-type: none"> Same as <i>Ordinary Effort</i>.
Integration into Global Economy	<ul style="list-style-type: none"> Difficult 	<ul style="list-style-type: none"> Low impact on China's economy 	<ul style="list-style-type: none"> Positive impact on China's economy
Industrial Sectors	<ul style="list-style-type: none"> Low economic efficiency and international competitiveness 	<ul style="list-style-type: none"> Somewhat improved economic efficiency and international competitiveness 	<ul style="list-style-type: none"> High economic efficiency and international competitiveness
Transportation	<ul style="list-style-type: none"> Public transportation development is poor. Use of private vehicles grows quickly. Fuel efficiency of vehicles rises slowly. 	<ul style="list-style-type: none"> Public transportation development is strong. Motorcycle use rises. International vehicle emissions standards are adopted. 	<ul style="list-style-type: none"> Public transport is developed extensively; private vehicle use grows more slowly than in other scenarios. International vehicle emissions standards are adopted, as in <i>Promoting Sustainability</i>. Advanced clean-fuel technologies are used for public transport and automobiles.
Power Generation	<ul style="list-style-type: none"> Increased use of sulfur control technology on power plants Coal-fired power plants generate most electricity Gradual development of hydropower, nuclear power, IGCC and wind power 	<ul style="list-style-type: none"> Very high growth rate in sulfur-control technology on coal-fired power plants, reaching all plants by 2020. Clean-coal power generation technologies are introduced beginning in 2010. Development of hydropower, nuclear power, IGCC and wind power is faster than in <i>Ordinary Effort</i>. 	<ul style="list-style-type: none"> Introduction of sulfur-control technology is same as in <i>Promoting Sustainability</i>. Clean technologies introduced sooner than in other scenarios, including supercritical generation and IGCC. Hydropower, nuclear, IGCC, and wind power increases more rapidly than other scenarios.
Energy Sector Reform	<ul style="list-style-type: none"> Reform progress lags behind other sectors and monopoly continues to exist in some areas. 	<ul style="list-style-type: none"> Energy enterprises will be restructured and monopoly is broken. 	<ul style="list-style-type: none"> Reform proceeds rapidly and international competitiveness of China's energy enterprises is improved.

Table 1. Assumptions in the three scenarios establish different paths by which China might meet the same economic development goals by 2020.

	Scenario 1: Ordinary Effort	Scenario 2: Promoting Sustainability	Scenario 3: Green Growth
Energy Conservation Policies	<ul style="list-style-type: none"> Implementing measures to the Energy Conservation Law are adopted but many measures are not successfully achieved. 	<ul style="list-style-type: none"> Implementing measures to the Energy Conservation Law are successfully adopted and improved upon. 	<ul style="list-style-type: none"> Complete implementation of financial incentives and an energy pricing system to promote energy conservation. Implementing measures to the Energy Conservation Law are successfully adopted and improved upon.
Energy Efficiency Level	<ul style="list-style-type: none"> Technological development is hindered and the operating efficiency of equipment does not reach advanced international levels. 	<ul style="list-style-type: none"> Energy efficiency of technology in all sectors and industries on track to reach current advanced international levels by 2030. 	<ul style="list-style-type: none"> Same as <i>Promoting Sustainability</i>.
Energy Resources	<ul style="list-style-type: none"> Access to international oil resources over next 20 to 30 years is unrestricted. Difference between domestic oil supply and demand is met through oil imports. Consumers find natural gas prices too high, limiting exploration, development and network construction. Imports of LNG and pipeline gas are restricted. Domestic output of natural gas reaches 80 bcm and imported gas 40 bcm in 2020. 	<ul style="list-style-type: none"> As in other scenarios, access to international oil resources over next 20 to 30 years is unrestricted. As in other scenarios, difference between domestic oil supply and demand is met through oil imports. Domestic development and infrastructure construction of natural gas is successful and creates a strong market for natural gas. Domestic output of natural gas reaches 120 bcm and imported gas 50 bcm in 2020. 	<ul style="list-style-type: none"> As in other scenarios, access to international oil resources over next 20 to 30 years is unrestricted. As in other scenarios, difference between domestic oil supply and demand is met through oil imports. Natural gas pricing system is improved and demand for gas grows quickly. Gas imports rise. Domestic output of natural gas reaches 120 bcm and imported gas 80 bcm in 2020.
Energy Security	<ul style="list-style-type: none"> China primarily relies on domestic energy resources. 	<ul style="list-style-type: none"> China establishes a diversified energy import system to utilize high quality foreign energy resources. 	<ul style="list-style-type: none"> China establishes a diversified energy import system to utilize high quality foreign energy resources.
Environmental Protection Policies	<ul style="list-style-type: none"> Existing environmental standards persist. Air pollution controls in Acid Rain Control Regions and key cities are implemented by 2005, with SO₂ emission standards achieved by 2010. 	<ul style="list-style-type: none"> Existing environmental standards persist Air pollution controls in Acid Rain Control Regions and key cities are implemented by 2005; SO₂ emission standards are met by 2010; all standards are met by 2020. PM₁₀ and PM_{2.5} are key focus of control policies. Air quality of big cities is improved by increasing supply of gas fuels. 	<ul style="list-style-type: none"> Emissions standards in large cities are tightened. Stricter NO_x emission standards are enforced. Coal substitution proceeds in large and some medium cities. More stringent legal system is put in place to enforce environmental regulations. Stricter SO₂ emission standards for power plants encourage adoption of desulfurization technology.
Public Awareness of Energy and Environmental Issues	<ul style="list-style-type: none"> Moderate 	<ul style="list-style-type: none"> Moderate 	<ul style="list-style-type: none"> Good

Table 2. The same set of energy policies were considered in the three scenarios, but timing and degree of implementation differed.

Transportation Sector Policies

1. Fuel tax for vehicles
 2. Development of public transportation and institution of Intelligent Transportation Systems (ITS) in big and medium cities
 3. Clean fuel program for automobiles
 4. Incentive program for international automobile manufacturers to introduce energy-efficient and environmentally friendly vehicles to Chinese market
 5. Fuel efficiency standards for vehicles
-

Buildings Sector Policies

1. Energy efficiency standards and reform of heat pricing
 2. Minimum efficiency standards for household electrical appliances
 3. Use of energy-efficient wall insulation expanded
-

Industry Sector Policies

1. Demonstration and further dissemination of voluntary agreements for energy conservation
 2. Modification of industrial design standards to promote energy conservation
 3. Energy consumption benchmarking system for industrial processes
 4. Regulatory system established to assist in enforcement of the Energy Conservation Law and implementation of pilot projects
-

Energy Supply Sector Policies

1. Further promotion of electric power system reform
 2. Elimination of coal generating units under 100 MW capacity by the State Power Corporation
 3. Installation of desulfurization devices in all new coal-fired power plants
 4. Increased efforts to develop low- and zero-carbon power generation technologies, including hydropower
 5. Support for increased imports of advanced renewable energy technologies, including solar photovoltaics and fuel cells
-

Current environmental policies persist. Air pollution controls in Acid Rain Control Regions and key cities are implemented by 2005, and emissions standards for sulfur dioxide (SO₂) met by 2010. Public awareness of energy conservation and environmental protection is moderate.

Domestic oil supply shortages are met through imports. Consumers find natural gas prices too high, limiting exploration and development and restricting imports of LNG and pipeline gas. In 2020, domestic output of natural gas is 80 billion cubic meters (bcm) and imports reach 40 bcm.¹ In this scenario, China relies on domestic energy resources whenever possible to protect energy security and reduce dependence on foreign resources.

Scenario 2: Promoting Sustainability

Promoting Sustainability illustrates the implementation of government targets as promulgated in the 10th Five-Year Plan and related policy documents. It represents China's energy growth trajectory through 2020 if current government targets are met. Compared to *Ordinary Effort*, policies to promote sustainable development are implemented earlier and more vigorously.

Promoting Sustainability portrays a future in which current government policies and programs are carried out as expected. Population growth trends reflect effective implementation of State policies. Development of small cities is emphasized, with consideration given to sustainable urban development practices. The consumption of housing and automobiles increases significantly. Household energy used in large cities is mainly electricity and gas, while households in small cities use mainly electricity, coal and LPG. Demand for household appliances spurs a large increase in sales. Natural gas is used in large amounts in eastern China.

Throughout China, the scale and structure of enterprises are successfully reformed to increase economic efficiency. Energy firms are restructured and monopolies broken. The technical efficiency of industrial processes continues to improve at rates similar to those in recent years.

Public transport and motorcycles are a key development focus. Between 2005 and 2010, Euro-II vehicle emissions standards are implemented in all big cities and some smaller coastal cities. These standards are also implemented in medium-sized and small cities between 2010 and 2020. From 2005 to 2010, LPG use in urban public transportation and taxis rises.

In the electric power sector, all newly built coal-fired power stations are equipped with desulfurization equipment by 2020. Advanced clean-coal power generation technologies are used starting in 2010. Hydropower, nuclear power, IGCC and wind power all expand rapidly. Implementing measures to the Energy Conservation Law are adopted and improved upon, and the energy efficiency of technologies in all sectors and industries, including process equipment and cross-cutting technologies like motor systems, is on the way to reaching levels currently prevailing in advanced industrialized countries by 2030.

Domestic oil supply shortages are met through oil imports. The development of domestic natural gas resources and related infrastructure construction is successful, creating a strong market for natural gas. In 2020, domestic output of natural gas is assumed to be 120 bcm and imported gas to be 50 bcm. China's overall energy security strategy is to diversify energy imports and utilize high quality foreign energy resources.

In this scenario, existing environmental standards continue, and new regulations are added. Air pollution control measures in Acid Rain Control Regions and key cities are implemented by 2005, with SO₂ emission standards met by 2010, and all standards met by 2020, meeting the Government's

¹ For this study, 1 bcm of natural gas = 37.3 PJ (low heat) = 35.3 billion cubic feet.

targets for controlling acid precipitation. New air pollution policies are implemented to target PM₁₀ and PM_{2.5}. Air quality in large cities is also improved by increasing the supply of gas fuels. Public awareness of energy conservation and environmental protection is moderate.

Scenario 3: Green Growth

Green Growth assumes that sustainable development will be a policy priority for the Government and that extensive environmental and energy policies will be implemented to achieve this goal. This scenario illustrates the energy consumption trajectory that would result from aggressive policies to promote energy efficiency, development of renewable energy, and other policies to promote sustainable development across all sectors.

State birth-rate control policies are strictly implemented such that China's national birth rate declines annually. Urbanization goals promote the development of western China with many new small and medium-sized cities, and the continued growth of large cities. Global economic integration and continued enterprise reforms promote efficiency improvements across sectors.

Consumer purchasing power continues to increase, resulting in an increase in demand for energy services, which are met in a more sustainable manner compared to the other scenarios. Programs to promote environmental awareness result in consumers preferring environmentally sustainable means of transportation. Residents in large and medium cities rely primarily on public transportation. Intelligent Transportation Systems, which use information and communications systems to manage urban transport systems, are established in major cities. There is considerable technological advancement in the automobile industry. Clean fuel substitution technologies are widely applied to both public transportation and private cars. Euro-III vehicle emissions standards are implemented in key cities.

Domestic energy consumption moves towards high-quality energy resources, including gas fuels and electric power. There is a large increase in the consumption of natural gas in cities. The replacement of older household appliances with more efficient models is accelerated in urban households. In rural areas, the proportion of electricity and LPG use in the total fuel mix increases. Renewable energy technologies are commercialized to a greater extent than in the other two scenarios.

In the electric power sector, desulfurization devices are extensively applied to coal-fired power plants. Clean energy technologies such as supercritical generating units and IGCC are applied in some areas. Hydropower continues to be developed at the current rate, nuclear power and IGCC growth rates are higher compared to the other scenarios, and wind power increases rapidly.

In energy efficiency policy, there is comprehensive implementation of new financial incentives and an energy-pricing system to promote energy conservation. Implementing measures to the Energy Conservation Law are successfully adopted and improved upon. As in *Promoting Sustainability*, energy efficiencies of technologies across the board are on the way to reaching today's advanced levels in industrialized countries by 2030.

As in the other scenarios, the gap between domestic oil supply and oil demand is met through oil imports, but efficiency improvements relative to the other scenarios allow oil imports to be smaller. In addition, the natural gas pricing system is improved and demand for gas grows quickly, resulting in an increase in imported natural gas. In 2020, domestic output of natural gas will be 120 bcm and imported gas will be 80 bcm. China's overall energy security strategy is to diversify energy imports and utilize high quality foreign energy resources.

Current environmental regulations are implemented and new, more stringent policies are added, particularly in large cities. Stricter NO_x emission

standards are implemented. Substitution for coal occurs in big cities as well as some wealthier medium cities. A more stringent legal system to enforce environmental regulations is established. Stricter SO₂ emission standards for power plants are

implemented to reinforce the adoption of desulfurization technology in power plants. Public awareness of energy conservation and environmental protection is higher than in the other scenarios.

QUANTIFYING THE SCENARIOS

The three scenarios were implemented in a detailed, bottom up computer model developed using LEAP, and based on the best data available. The model is a closed representation of China's energy system that covers all energy consumption, production and conversion sectors. The calculation of the demand for energy consumption is based upon the physical energy-consuming processes in each sector. Particular detail is used in depicting the technological processes of energy-intensive sectors for accurate accounting of energy consumption, primarily the industrial sector. These energy-intensive sectors will considerably influence the direction of China's energy systems for the next several decades. Minor energy-consuming activities are treated in less detail. The overall structure of the model is shown in Figure 3. The industrial sector is divided into 11 subsectors, as shown in Figure 4. The structures of the transportation and buildings sectors are illustrated in Figure 5 and Figure 6, respectively.

After designing the basic model structure, the project team populated the model with base-year (1998) data. The team used integrated mathematical models to calculate final energy consumption from primary energy data.² Adjustments were made to total energy consumption and sectoral composition so that the base-year data would be consistent with the official

national energy balances published by China's National Bureau of Statistics (NBS). Sectoral definitions were revised in accordance with international practice. In addition, in-depth consultations were held with experts in a wide variety of fields to ensure that base-year data on energy consumption, technological structure and specifications, and economic parameters were as accurate as possible, given existing data systems.

Projections of values of driver variables (e.g., GDP by sector, population, rates of urbanization, output of various manufactured goods) and of technical variables (e.g., energy efficiencies of particular processes and equipment, availability of different fuels, shares in total activity levels of more and less-efficient technologies) were determined in most cases for 2000, 2005, 2010 and 2020. The values were estimated from government planning documents and extensive consultations with experts in the various sectors. Differences in implementation of policies to promote sustainable development among the scenarios were simulated by varying the trajectory of key driver and technical variables. Sectoral models were constructed and verified, and the sectoral models then were integrated into a single model. Quantification of the scenarios was iterative, at both the level of the sectoral models and the integrated model, to ensure internal consistency within the models and consistency with base-year data.

² Primary energy consumption is calculated assuming generation efficiencies of nuclear power and hydropower are 33% and 100%, respectively. Standard Chinese conversion factors are used in this project, i.e.: 1 kWh = 0.1229 kg of standard coal equivalent (kgce) for final energy values; 1 ton of oil equivalent (toe) = 7.33 bbl = 1.4286 tons of standard coal equivalent (tce); and 1 tce = 29.31 GJ. By extension, 1 EJ/yr = 23.90 Mtoe/yr = 480 thousand bbl/day.

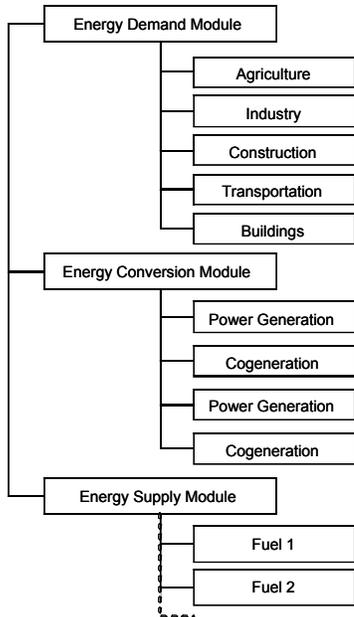


Figure 3. Overall division of sectors in the model

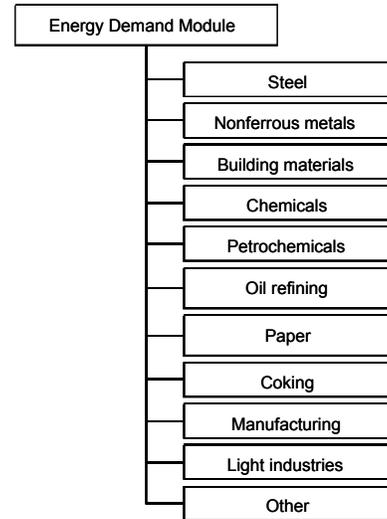


Figure 4. Subdivision of the industrial sector

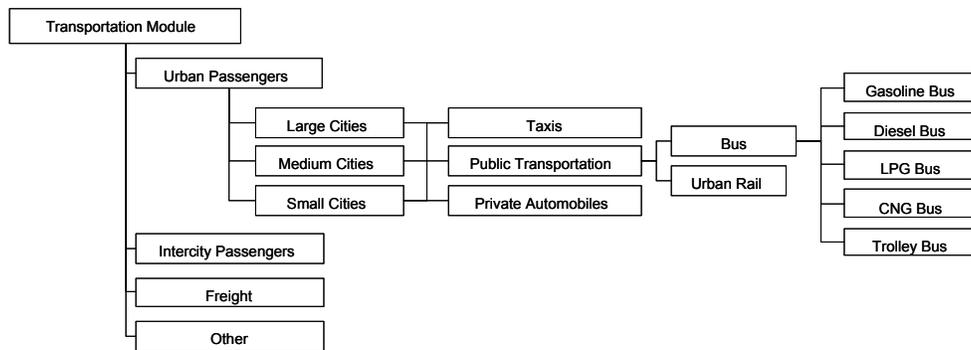


Figure 5. Subdivision of the transportation sector

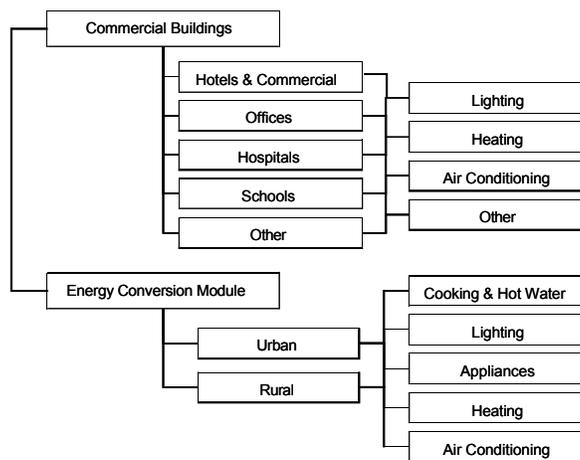


Figure 6. Subdivision of the buildings sector

RESULTS OF THE SCENARIOS

Energy Consumption

The scenario analysis shows that technological improvements and restructuring China's economy, along with the adoption of sustainable development measures in the energy sector, could cause China's energy demand to grow relatively slowly over the next 20 years and not adversely impact economic growth targets. Such an achievement would require significant policy measures to support industrial reform and energy efficiency improvements, and expansion of the supply of natural gas and electricity to support intrinsically more-efficient processes.

Figure 7 illustrates the differences in final energy consumption among the three scenarios by fuel from 1998 - 2020. According to the scenario results, energy demand in China in 2020 could range from 67 EJ to 90 EJ, while GDP remains fixed at an average growth rate of 7% per year. Growth in primary energy use from 1998 to 2020 could range from 2.2% per year (in *Green Growth*) to 3.8% per year (in

Ordinary Effort).

The energy consumption elasticity of GDP from 1998 to 2020 could range from 0.35 to 0.54, similar to historical values (Figure 8). Energy elasticity is the ratio of the rate of change in energy use to the rate of economic growth. If it is greater than one, which is typical for a developing country, then energy growth is faster than economic growth. If it is less than one, then growth in energy is slower, indicating falling energy intensity.

Figure 9 illustrates the declining energy intensities of the three sectors. *Ordinary Effort* reaches an energy intensity of 2.6 MJ/yuan of GDP in 2020, while *Green Growth* reaches an energy intensity of 1.9 MJ/yuan in that year. The range of these results indicates that there is huge promise for suppressing growth in energy consumption by introducing new energy technologies, adjusting the current energy structure, and implementing new energy conservation and environmental protection policies.

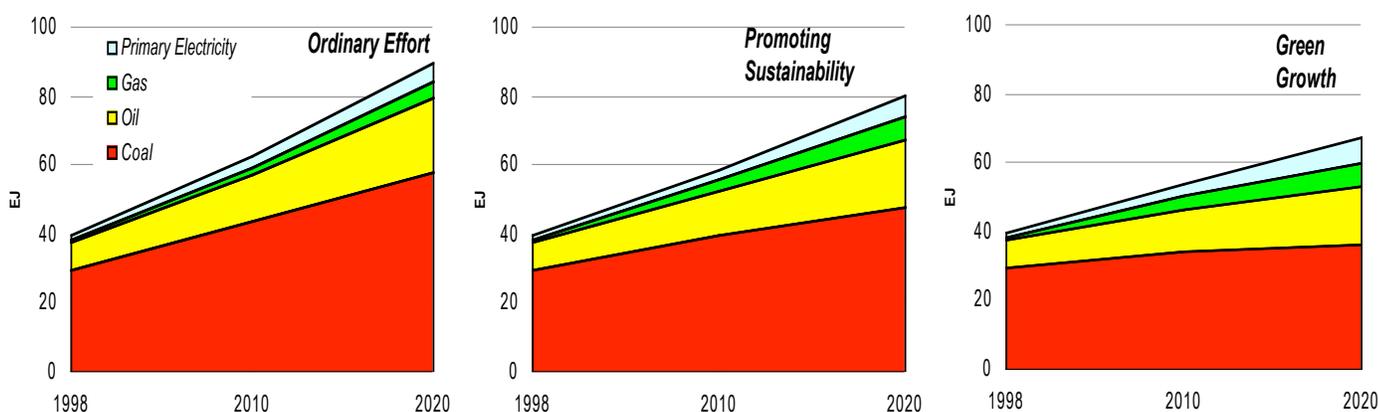


Figure 7. The fuel structure of primary energy consumption in the three scenarios from 1998-2020 differs mainly in the growth of coal and gas.

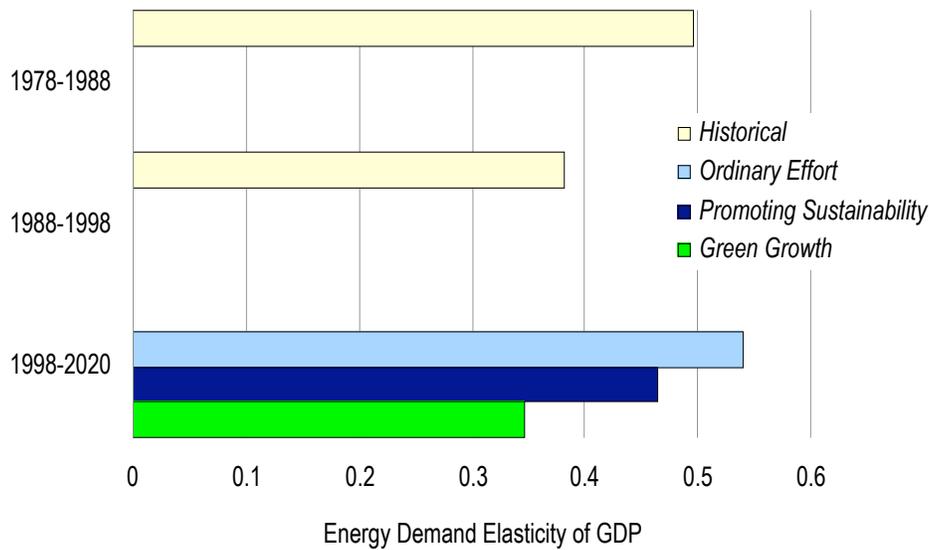


Figure 8. In Promoting Sustainability, energy demand elasticity lies between the values seen in the 1980s and the 1990s. In Ordinary Effort, elasticity is higher than current historical values, and in Green Growth it is lower.

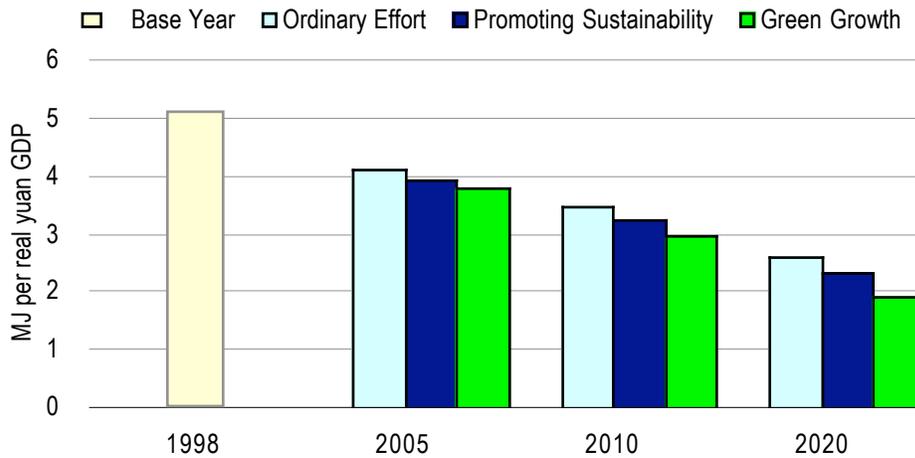


Figure 9. Energy intensity, in MJ per real yuan GDP, falls in all three of the scenarios so that by 2020 it is 38% to 51% of its 1998 value.

Historically, energy consumption in China has been dominated by industry, while transportation and building energy consumption have represented smaller percentages. In developed countries, building and transportation energy consumption comprise a much larger portion of total energy consumption, and this is expected to become the trend in China as

living standards increase. Rising numbers of housing units and per capita building area in urban and rural settings will result in rapid growth of building energy use. Demand for space heating and air conditioning is set to rise, as is ownership of household appliances. Energy use in commercial buildings is rising as services become an ever-increasing portion

of GDP. Growth of transportation energy use will come from the rapid development of service industries requiring transportation, the increasing demand for personal automobiles, and changing patterns of land use. This in turn will spur demand for steel, plastics, oil refining capacity, roads, and

other industrial and social infrastructure. These shifts in sectoral energy consumption are in line with global social and economic development trends and thought to be an inevitable outcome of further stimulating domestic demand. Energy consumption rates by sector are illustrated in Figure 10.

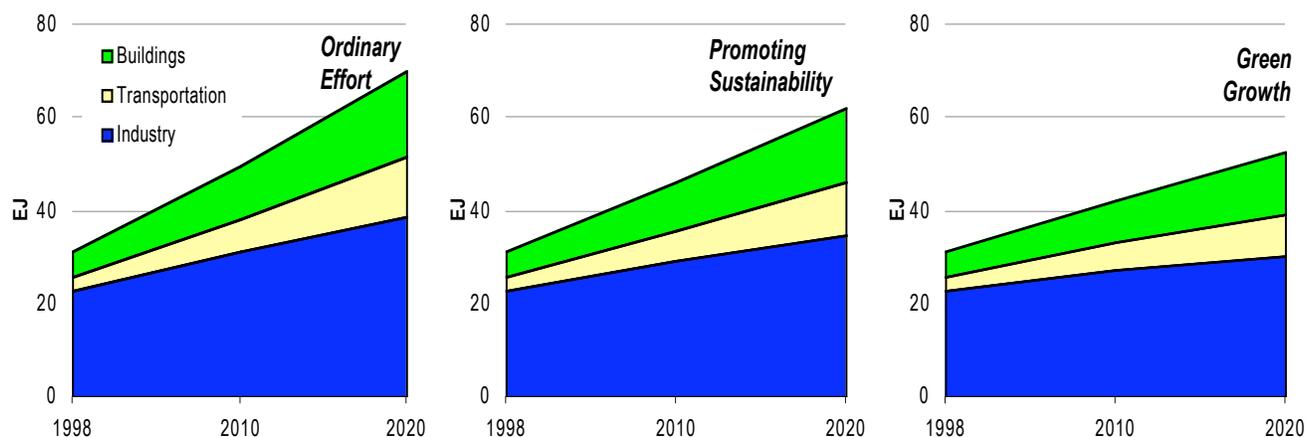


Figure 10. In all scenarios, industry remains the main energy consumer, still accounting for 56% to 58% of all final energy in 2020.

Industry

The sustainable development strategies affecting the industrial sector proposed by the Tenth Five-Year Plan include structural adjustment policies aimed at continued urbanization, new infrastructure construction, and the developing of the west. Figure 10. shows that industry will continue to remain the most energy-consuming sector through 2020, although the highest energy consumption growth rates will be seen in the transportation sector. Output of intermediate industrial products such as steel, cement and fertilizer is assumed to grow in all three scenarios, but at varying rates. Industrial subsectors with high value-added, such as the information, electronics and high-tech industries (within the machinery and equipment subsector), are expected to grow especially rapidly in all scenarios.

To meet economic development goals, basic feedstock industries will continue to grow at average

annual rates of around 4.5%. Processing industries, transportation, communications, and electronic equipment manufacturing industries are expected to grow rapidly, averaging about 7% per year, as improved living standards drive consumer demand for transportation, communication and information.

Over the term of the scenarios, traditional energy-intensive industries are expected to comprise a smaller percentage of total industrial energy consumption as manufacturing and light industry take an increasing share (Figure 11). The steep rise in output in the energy-intensive industries that began in the 1990s is not expected to persist as the proportion of products with higher value added increases. The analysis for all scenarios assumes that the output of energy-intensive products such as building materials, chemicals and steel will increase by 5% over the next 20 years, with an average annual growth rate of 4%.

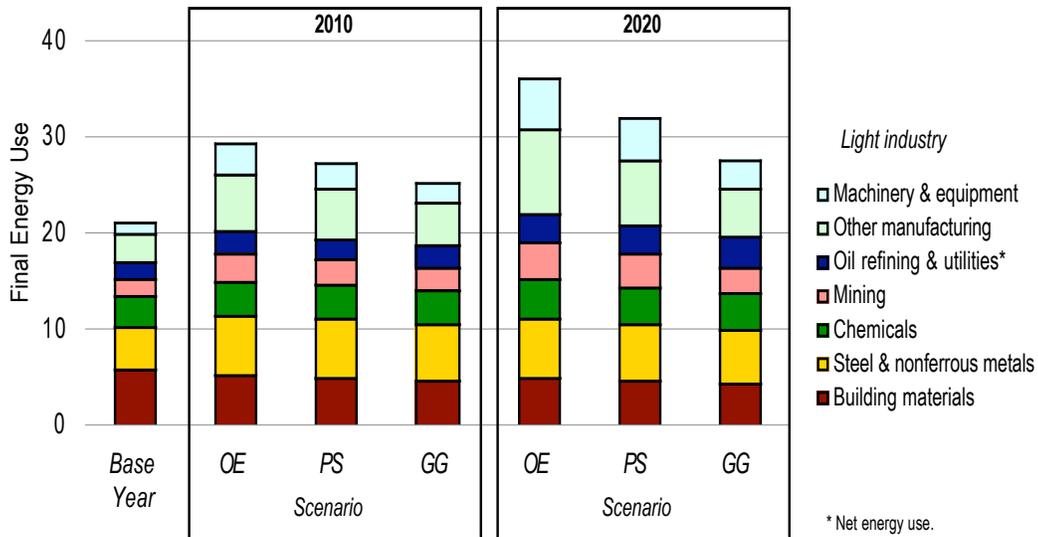


Figure 11. Although heavy industries like building materials, steel, and chemicals will still dominate energy use in 2020, consumption in light industries (machinery and other manufacturing) will grow from about 20% in the base year to 30% or 40%.

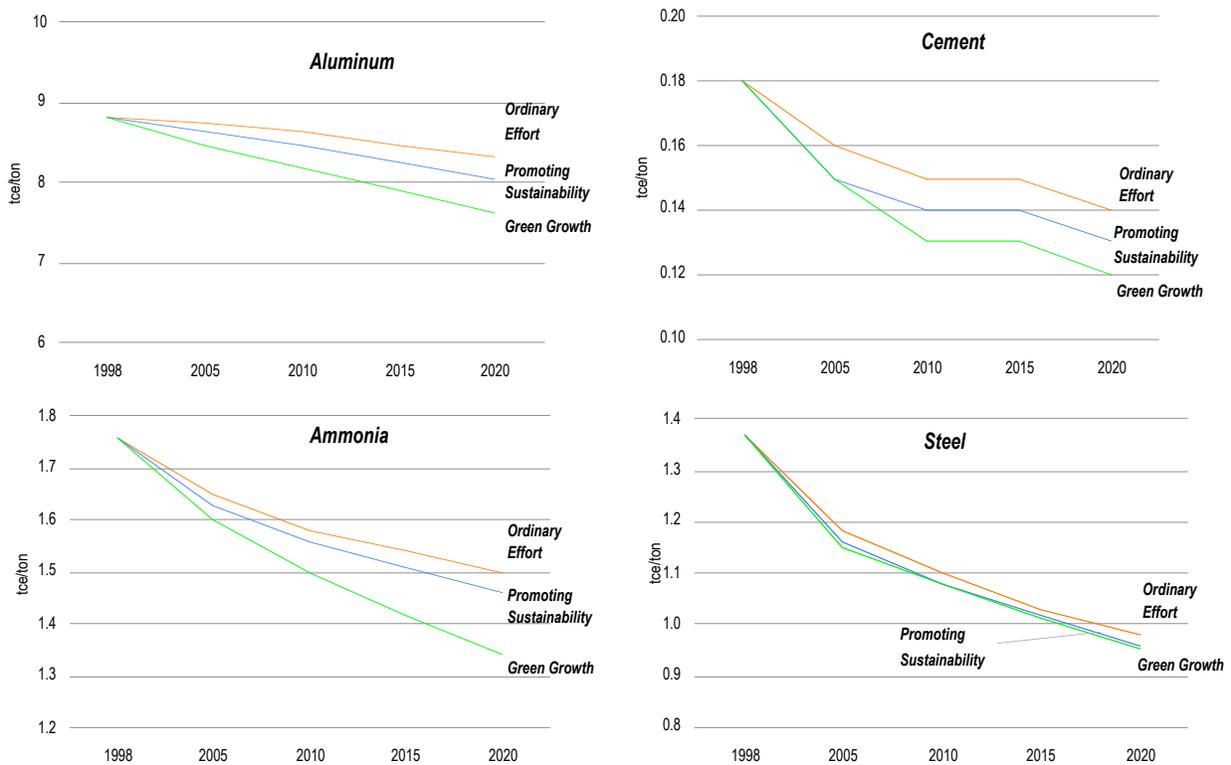


Figure 12. Primary energy intensities of major industrial products will decline, approaching levels currently prevailing in industrialized countries. Most opportunities for greater efficiency are presumed to be taken in the steel industry, even under Ordinary Effort.

While the amount of energy consumed by manufacturing and process industries rises in all scenarios, the overall proportion of energy-intensive industries in the total decreases. Internal structural adjustments in each industry also lead to significant energy efficiency improvements, particularly in the energy-intensive industries. Figure 12 shows the decreasing energy intensities (energy consumed per ton of product produced) for several major industrial products including steel, cement, ammonia, and aluminum.

Currently, industrial sector energy consumption accounts for around 70% of total national energy consumption, and the highly energy intensive industries such as steel, nonferrous metal, chemicals and construction materials make up over 70% of total industrial energy consumption. Internal adjustments at multiple levels within the industrial subsectors can tap into the latent capacity for energy conservation in China's industries, thereby affecting China's total future energy demand. The modeling results for the three scenarios indicate that the annual average growth rate of final energy demand of the industrial sectors during 1998-2020 could be as low as 1.3% in *Green Growth*, or as high as 2.5 % in *Ordinary Effort*. Some energy-intensive industries such as steel, chemicals and construction materials could achieve a state of increasing output while only slightly increasing energy consumption.

The low rate of energy growth in industrial subsectors seen in *Green Growth* requires more vigorous action than the other scenarios in eliminating obsolete technologies, promoting recovery and utilization of waste heat and energy, rationalizing the process chain, improving control systems, increasing product quality, and increasing the scale of equipment and systems. These measures would permit China to increase industrial output and output value while only slightly increasing energy consumption.

Achieving this will require substantial restructuring of industrial subsectors. The proportion of energy-

intensive industries in the industrial sector would need to be reduced significantly, while growth would have to be accelerated in high value-added industries like high-tech and telecommunications. Growth in output of key energy-intensive products (e.g., steel and cement) would have to occur at less than twice the level of the base year. Within energy-intensive industries, value added would have to increase by improving the quality and variety of products.

Transportation

Transportation energy consumption is expected to grow very rapidly over the next couple of decades, and this is reflected in the scenario analysis. Transportation comprised about 11% of total energy consumption in 1998, and according to the model will rise to 17% to 18% in the three scenarios. Results indicate that the average annual growth rates of final energy demand of the sector would range from 4.6% in *Green Growth* to 6.3% in *Ordinary Effort*. *Green Growth* has total transportation energy consumption that is 3.7 EJ (equivalent to 91 Mt of oil products) lower than *Ordinary Effort*, and 2.5 EJ lower than *Promoting Sustainability* (Figure 13).

In all scenarios, transport energy end use is dominated by freight transport, comprising between 60% and 64% of the total. Intercity passenger transport ranges from a high of 21% in *Ordinary Effort* to 16% of the much lower total in *Green Growth*. In the two scenarios, urban passenger transport energy use accounts for 16% and 21% respectively. Because freight is responsible for such a large share of transport energy use, a great deal of the variation between scenarios (nearly 60% of the disparity between *Green Growth* and *Ordinary Effort*) is due to improvements in the efficiency of that subsector. This comes not just from better technologies for trucks, but also modal shifts that put more freight on railways and waterways.

Ownership of private vehicles rises rapidly in all the scenarios, from 1.8 to 28 per thousand persons from 1998 to 2020, and total automobile stock rises from

13 million to 77 million, leading to rapid growth in passenger transport energy use. Significant energy savings in transportation can be achieved through expansion of public transport and higher fuel efficiency standards. Comparison of scenario results shows that modal shifts in transportation could substantially slow growth of transport energy demand, especially urban passenger transport. In large cities, establishing rail transportation systems and opening dedicated lanes for public transportation can not only reduce traffic congestion but also lower the demand for fuel. In smaller cities, better transportation planning and improvement of public transportation systems can also address both types of problems. Major reasons for the difference between urban transport fuel use in *Green Growth* and the other scenarios—all of which serve approximately

equal levels of transport service—is evident in Figure 14. Private cars and taxis, which are considerably more energy intensive than public transport, together are responsible for 5% of energy use in *Green Growth*, compared to 12% in *Ordinary Effort*. In public transport, the latter scenario has a much higher share of energy demand attributable to minibuses, which are about three times as energy intensive per passenger-km than full-size buses. By comparison, improvements in efficiency in public transport equipment are relatively small (3% to 5% difference between the most and least-efficient scenarios) and contribute little to the large difference in energy demand. Since vehicle populations rise in all scenarios, vehicle emissions standards and fuel specifications will become essential if deterioration of urban air quality is to be prevented.

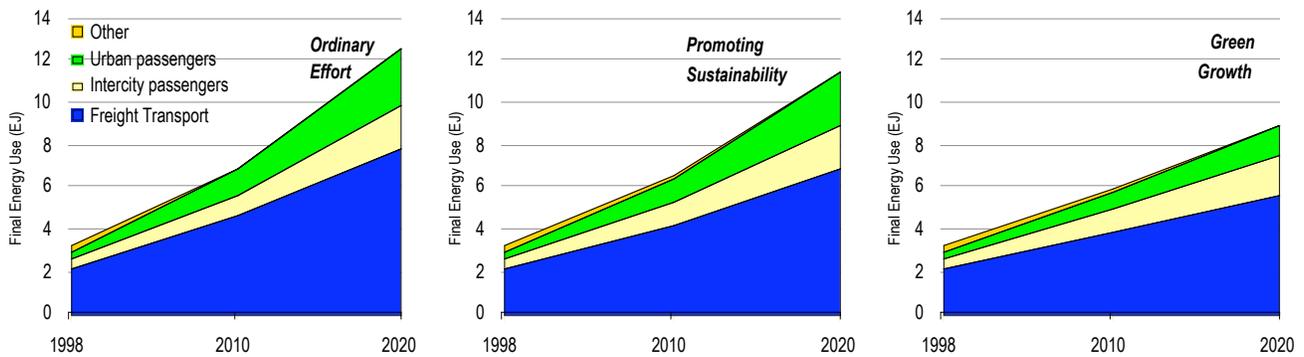


Figure 13. In *Green Growth*, improved efficiency and modal structure results in transport energy use nearly 30% lower than in *Ordinary Effort*.

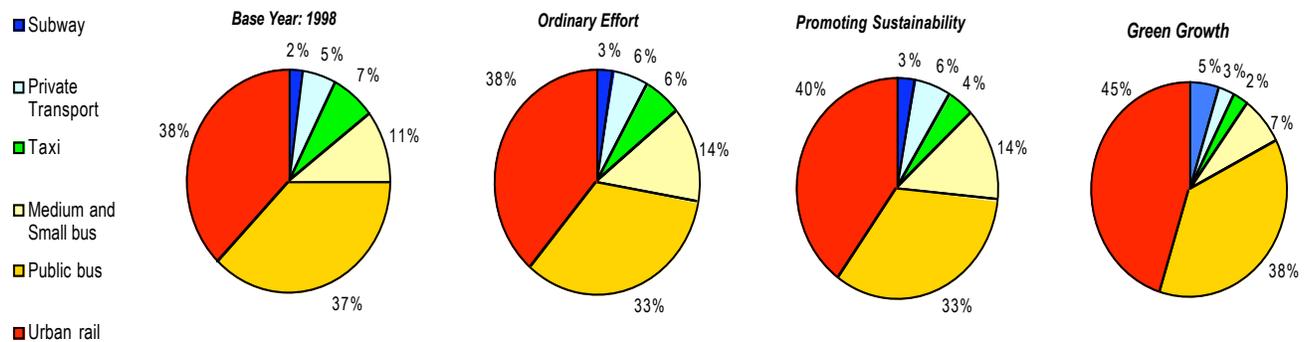


Figure 14. Differences in urban passenger trips by mode (in cities with over four million residents) may seem small, but have important consequences for fuel use and air quality.

Highway transport will comprise a large portion of transportation energy demand, so increasing vehicle fuel efficiency will be crucial to slowing growth in consumption. The scenarios assume different implementation of policies to influence the energy economy of key transportation technologies, particularly automobiles. The approaches include fuel taxes, incentives to manufacturers to develop and market better technologies, and minimum fuel efficiency standards. Phasing in of newer technologies, like hybrid vehicles and eventually fuel cell vehicles, also contributes to the improved energy and environmental performance of *Green Growth*.

Among the three scenarios, the main fuels—gasoline, diesel and kerosene—are used in different proportions. With increased demand for both passenger and freight air transport, demand for jet fuel grows rapidly in all scenarios, becoming the third-largest oil product for transport after gasoline and diesel. This pattern will cause shifts in the structure of China's petroleum industry.

Buildings

Energy use in the buildings sector, defined in this study as both residential and commercial buildings, is poised to grow very rapidly over the next two decades. In 1998, building energy consumption comprised about 17% of total energy consumption, while in 2020 it is expected to reach about 26% in each of the three scenarios. Energy consumption growth in the sector ranges from 4.4% per year in *Green Growth* to 5.9% in *Ordinary Effort*.

At present, only one half of one percent of existing residential buildings in China meet energy efficiency design codes. Among newly constructed buildings, less than 7% are in compliance with energy standards. To show the consequences of more or less vigorous implementation of building efficiency policies, *Green Growth* assumes that 50% of current energy consumption can be effectively saved, while *Ordinary Effort* assumes that less than 30% can be saved. The result is that in 2020, total building

energy consumption in *Green Growth* is 5.1 EJ less than in *Ordinary Effort* (Figure 15).

Space heating currently accounts for 54% of energy use in the buildings sector. Demand for space heating will grow rapidly as indoor comfort becomes more of a priority. Many regions of China have until recently had no heating systems in urban buildings, owing to policies instituted when energy supplies were limited. Now, however, new heating equipment is being installed in these areas, and buildings in regions where space heating is the norm are being fitted with newer systems. In addition, space heating is being used more frequently. This study therefore examines both penetration of space-heating technologies, and total number of days heat is used, with levels of service assumed to be equivalent in all three scenarios. Use of space heating is assumed to rise faster in the countryside than in cities. Demand would also rise more rapidly in transitional climate zones (the East-West band running along the middle of the country) than in the North. If heating systems and building envelopes—wall and insulation materials, windows and doors—are slow to change, then energy demand for heating could rise sharply, from 2.9 EJ in the base year to 11.3 EJ in 2020 under *Ordinary Effort*. Vigorous promotion of building energy standards and reform of heat pricing would result in space-heating demand of 6.6 EJ under *Green Growth*, accounting for most the difference between the two scenarios (Figure 16).

There is also a great deal of latent demand for space cooling. As a share of building energy use, it expands from the current 4% to between 9% and 10% in 2020, depending on the scenario. Meeting this demand helps push up electricity consumption from 240 TWh in 1998 (20% of total electricity use) to about 1,300 TWh in 2020 for all three scenarios (35% of all electricity in *Ordinary Effort* to 38% in *Green Growth*). Electricity use for lighting and appliances rises more slowly. These trends occur in all scenarios, as similar assumptions are made about implementation of efficiency standards.

The correlation between residential building energy consumption and several socioeconomic indicators illustrates how government programs to direct consumers towards energy-efficient products will be crucial in building energy consumption. This study assumes that natural gas, electric power and LPG all

increase in residential energy applications to their convenience and efficiency, particularly for cooking and hot water heating. In commercial buildings, the degree of optimization of heating and cooling systems is a crucial determinant of energy consumption.

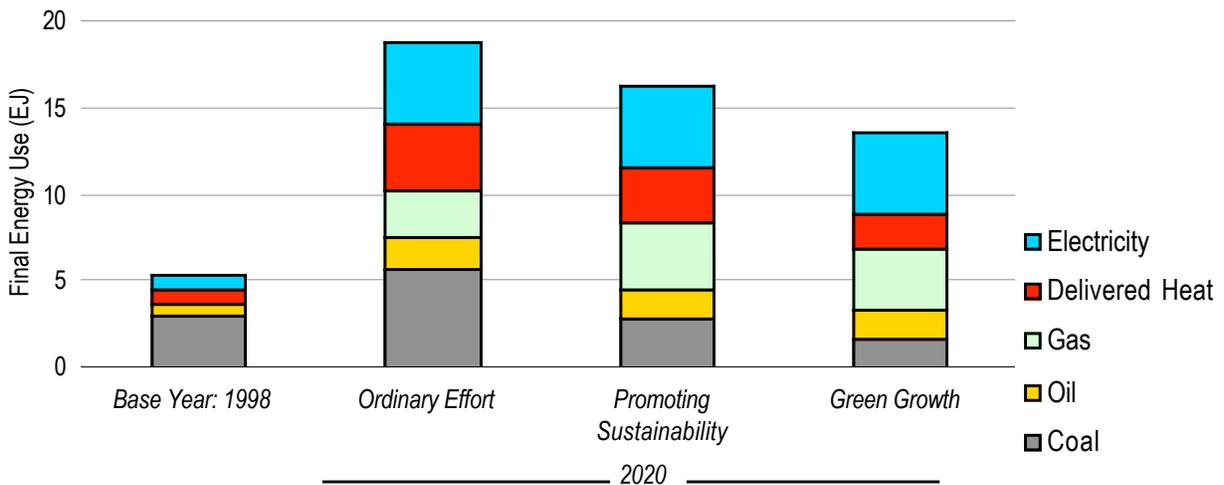


Figure 15. In Green Growth, building energy use more than doubles from 5.3 in 1998 to 13.7 EJ in 2020, but, due to improved efficiencies of equipment and systems and greater use of gas, total energy use is 27% lower than in Ordinary Effort.

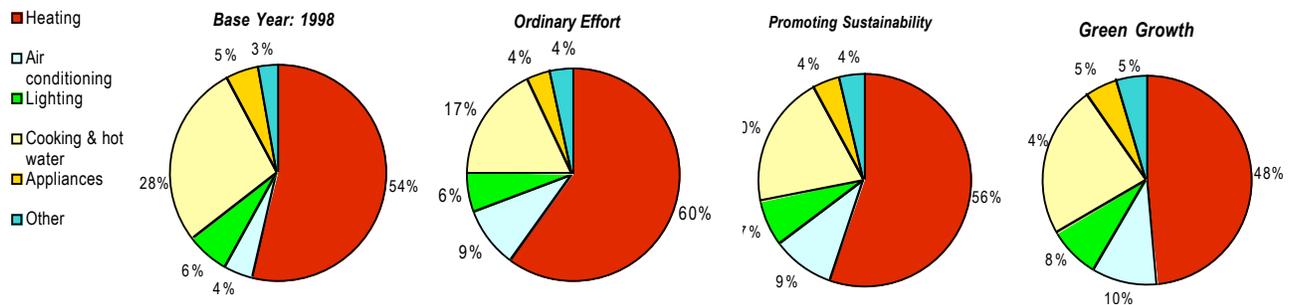


Figure 16. Building energy use in 2020 differs between the three scenarios mainly due to differences in coal and delivered heat used for space heating.

Energy Supply

As has been seen throughout the course of industrialization of other countries, an increase in the proportion of high quality energy is inevitable. Since China began reforms in its finance, taxation, pricing and circulation systems in 1992, the role of the market in allocating resources is being constantly strengthened. The proportion of high quality energy in end uses in China began to increase in the early 1990s. Figure 7 shows the contribution of different energy types to final energy consumption. Biomass fuels for household use will continue to be important for millions of rural households, but they are small in total relative to commercial energy forms, and have been omitted from this analysis.

All scenarios analyzed require the supply of natural gas and of petroleum products to increase substantially in China over the next two decades. However, even while increasing the use of oil and natural gas, coal will still comprise at least 55.5% of the primary energy consumption structure (*Green Growth*) and as much as 65% (*Ordinary Effort*), with coal use ranging from 35.6 to 58 EJ.

Oil

Trends in the transport sector discussed above will push up oil demand for oil, with annual increases ranging from 3.3% in *Green Growth* to 4.6% in *Ordinary Effort*. In all three scenarios oil represents about 25% of total final energy consumption in 2020.

This study assumes that the output of petrochemical feedstocks for synthetic materials will rise substantially to replace imports. The oil refining industry is expected to broaden its range of oil products to meet market demand. New pipelines will be constructed to reach more markets more cheaply. By 2020, growth in oil demand will remain strong, and the gap between domestic supply and domestic demand will mean China will likely become a primary importer of oil in the Asia-Pacific region. The scenario analysis finds that oil consumption in 2020 has the potential to range from 21.8 EJ/yr (about 520 Mtoe/yr) in *Ordinary Effort* to 16.6 EJ/yr (about 400 Mtoe/yr) in *Green Growth* (Figure 17). In the former scenario, implied imports would be over 320 Mtoe/yr. The latter scenario would require imports of about 200 Mtoe/yr. More-stringent efficiency measures not considered in the scenarios potentially could reduce oil imports by even more.

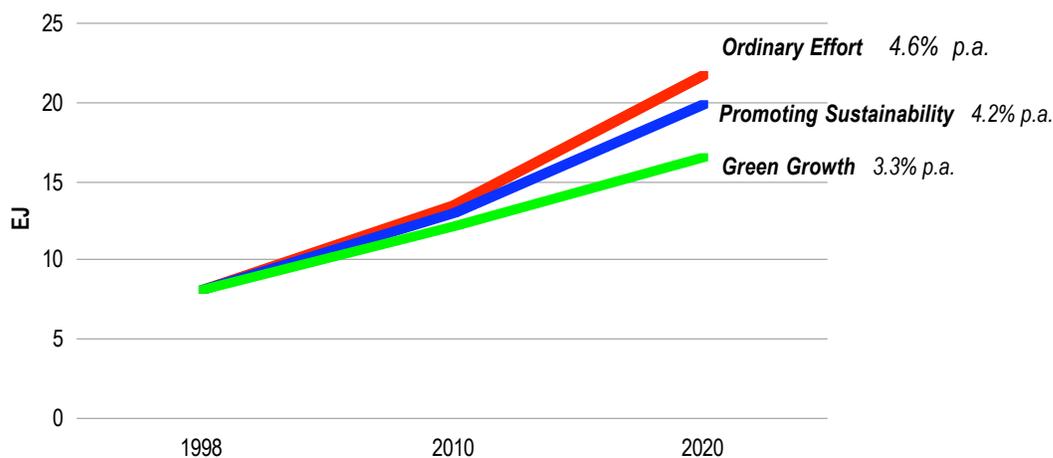


Figure 17. Growth in oil use in all three scenarios rises faster than growth in total energy use.

Natural Gas

The scenarios highlight the likely rapid development of natural gas in China to meet new demand from the chemicals industry, power generation, and urban households. Availability and affordability will affect the growth of natural gas use. Natural gas resources are primarily located in western and central China and demand is mainly in eastern regions. As a result, the construction of long-distance pipelines and LNG terminals is needed for the development and utilization of gas in large scale. Limitations of transport and end-user affordability will result in pipeline gas being supplied primarily to the Yangtze Delta area and the Sichuan Basin. Gas imported from Russia can promote the utilization of natural gas in northeastern and northern China. Southern China will likely need to rely on imported LNG and offshore gas.

More than ten gas supply projects will be undertaken in conjunction with the present West to East Gas Pipeline Project over the next decade. Although natural gas use will most certainly increase over the

next two decades, many factors could affect its penetration into the energy mix. Annual gas consumption in 2020 could range widely, from 4.5 EJ (120 bcm) in *Ordinary Effort* to 7.3 EJ (190 bcm) in *Green Growth*, comprising 5% to 11%, respectively, of final energy consumption in 2020 (). Although domestic gas development proceeds more rapidly under *Green Growth*, it cannot keep up with demand such that imports in 2020 will amount to 80 bcm/yr, and in *Ordinary Effort* implied imports are 40 bcm/yr.

There are currently no plans to build natural gas infrastructure in rural areas, so its use is likely to be predominantly in urban areas. Under the scenarios, penetration of gas fuels in urban areas changes little from current levels, but piped gas replaces LPG (Figure 19). Methane (biogas) utilization, integrated with aquaculture and plantations, has become a relatively mature technology in rural residential applications, but in all scenarios penetration of gas into rural households is mainly from expanded use of LPG.

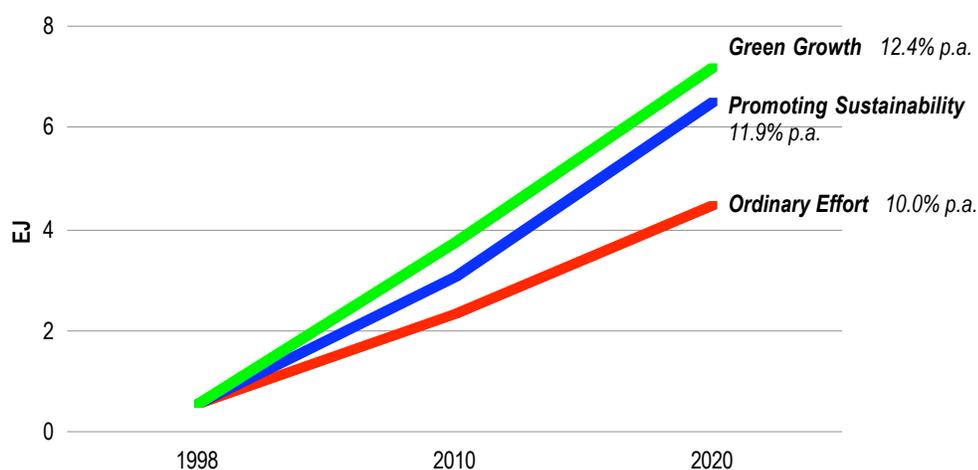


Figure 18. Annual consumption of natural gas is 60% higher in 2020 under Green Growth compared to Ordinary Effort, and imports are twice as high.

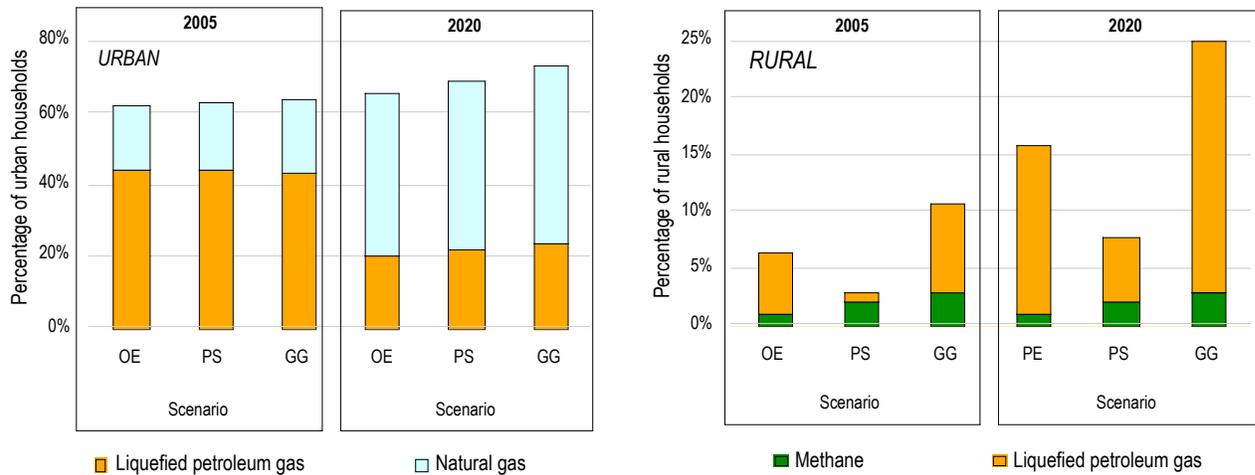


Figure 19. Nearly two thirds of urban households already use gas for cooking and water heating, but many more of them will be using natural gas by 2020, necessitating very large investments in gas distribution. By that time, levels of LPG use in rural areas will have risen significantly.

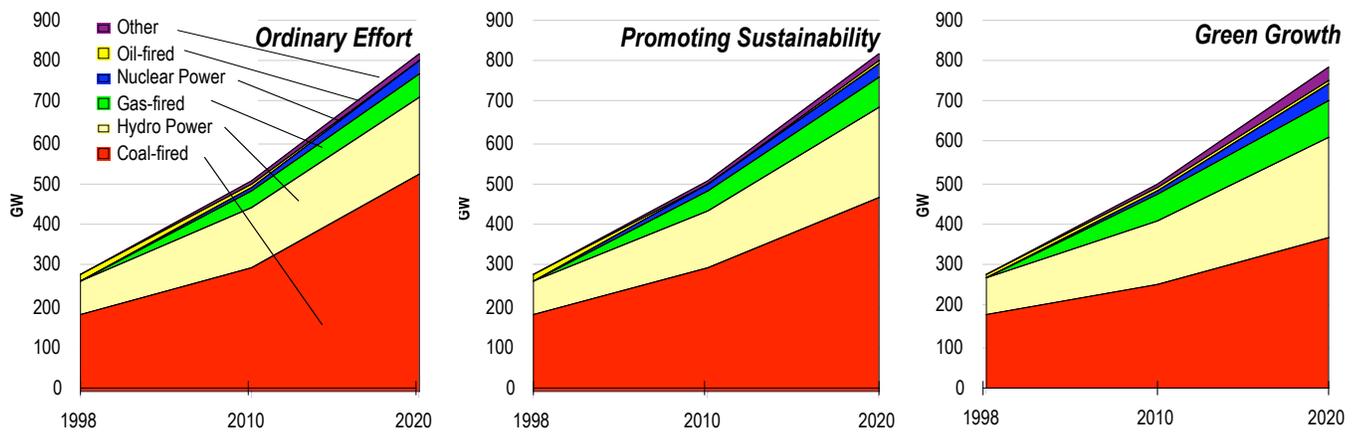


Figure 20. While the total installed capacity in 2020 is similar for all three scenarios, they differ substantially in generation structure.

Industrial uses of natural gas will take second place to households. Ammonia synthesis for fertilizer production will be the main consumer, and replacing coal feedstock with natural gas is key to improving the efficiency of that subsector. Power generation use of natural gas is subject to availability after households and industry have received their shares, so expansion of gas-fired capacity is highest by far in the *Green Growth* scenario.

Power Generation

With ongoing reforms to the electric power sector in China, the market will play an increasingly large role in deciding which generation technologies are economically competitive. Generation technologies that are currently more expensive than coal-fired power, including hydropower, nuclear power, non-

hydro renewables and natural gas, will require policy support and, in the short term, probably subsidies if they are to contribute significantly to electricity supply. The three scenarios follow government plans for the development of the electric power sector over the next two decades, but vary in the degree to which these plans are effectively implemented (Figure 20).

Hydropower

The share of hydropower capacity in total installed capacity has been falling since 1985. Recently, the West to East Power Transmission Project has promoted new hydropower development. However, large and medium hydropower resources are often dispersed in remote regions which are far from load centers, and long-distance transmission of power will both increase the cost of power supply and make it more difficult to promote investment in hydropower. Without continued government support, the development of large-scale hydropower cannot be maintained in the long run. As the Three Gorges Project comes on line, annual additions to hydropower capacity nationwide will be about 4 GW. In 2005, current plans call for installed hydropower capacity to be 95 GW. Rivers that will likely be dammed include the Hongshui River, the Yangtze River, the Yellow River, the Lancanjiang River and the Wujiang River. Additionally, more than 1 GW of small hydropower is likely to be added annually, representing about 110 GW by 2010. Installed capacity of large and medium hydropower units is expected to amount to 170 GW by 2020.

Coal-Fired Power

Even under *Green Growth*, the largest additions to generating capacity will be fueled by coal, accounting for 38% of net new capacity between 1998 and 2020. In *Ordinary Effort* the corresponding share is 65%. The key task in this segment of the power industry is to build new power plants that use coal more efficiently and emit less pollutants than current plants.

According to government plans, new coal-fired power plants should be 300 MW or larger. It is expected that by 2020, new coal-fired power plants will have an efficiency of 39%, and those with desulfurization units will be 38%. Existing domestically made 200 MW and 300 MW coal-fired units will be upgraded and modified to reduce coal consumption by 10 to 15 gce/kWh on average. Around 2010, efficient, clean coal power generation technology will be put into operation for demonstration purposes, and IGCC will be commercialized by 2015 with an efficiency of 45%. It has been mandated that all units under 50 MW belonging to the State Power Corporation will be retired from service prior to 2005, and all such units nationwide will be scrapped prior to 2010. By then, all coal-fired units whose gross heat rate exceeds 400 gce/kWh (i.e., with efficiency under 31%) will be shut down.

Under all scenarios, power plant emissions are assumed to comply with current national standards by 2010. Coal-fired power plants in Acid Rain Control Regions that are newly built or modified will be equipped with desulfurization units. Currently existing coal-fired power plants in the Acid Rain Control Regions using coal with a sulfur content greater than 1% will be required to install desulfurization units. Other than the cogeneration plants that generate power as a byproduct of heat supply, no new coal-fired power plants will be permitted in city centers or even on the outskirts of larger cities. By 2005 the capacity of coal-fired generating units with desulfurization technology will amount to 26 GW, and the share of such units among all coal-fired power plants will rise to 50% by 2020. The proportion of cogeneration capacity is expected to remain relatively constant at about 10% of total installed electricity generation capacity.

Natural Gas Power

The development of highly efficient combined cycle gas turbines for power generation will depend on future availability of supplies of natural gas,

including the West to East Gas Transmission Project, the development of distribution networks, and conditions on international natural gas market conditions. Natural gas will primarily be used for household and industrial end uses, with relatively little available for power generation. *Green Growth* assumes the greatest availability of natural gas, so it has the largest share of gas-fired capacity in 2020, 92 GW out of 784 GW. By contrast, *Ordinary Effort* results in only 54 GW out of 818 GW.

Nuclear Power

In 2005, when the 6.6 GW of nuclear power generation that has been recently completed or which is currently under construction is put into operation, total installed nuclear capacity will rise to 8.7 GW. If all nuclear power stations that have been planned to date are completed, total installed capacity will exceed 10 GW in 2010, and total approximately 32 GW in 2020. *Green Growth* assumes even greater expansion of nuclear capacity, to 40 GW in 2020, or 5% of total generating capacity.

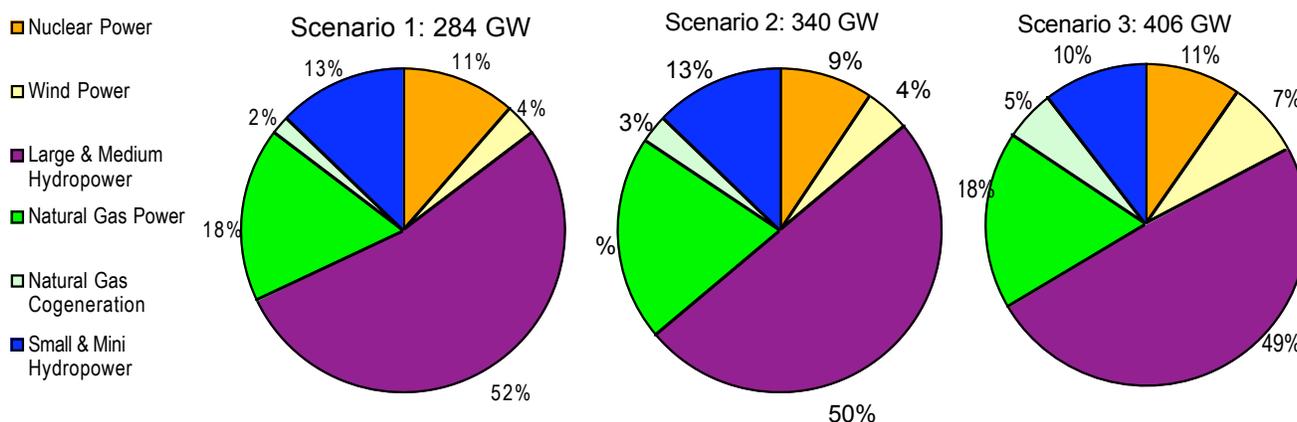


Figure 21. Installed capacity of natural gas-fired and non-fossil fuel power generation in 2020 will be considerably larger under *Green Growth* than under the other two scenarios.

Renewable Power Generation

The current goals of the Chinese Government for development of renewable energy resources (other than large-scale hydropower) include expanding wind power on a large scale and applying solar, geothermal, biomass and tidal power in niche applications. Current targets call for 1,180 MW of wind capacity by 2005 and 2,500 MW in 2010. Wind power technology is mature and providing low-cost electricity in many countries, but, as elsewhere, widespread application in China will require policy action to promote wind development. In *Promoting Sustainability*, wind power reaches 15 GW by 2020,

but under *Green Growth* rises to twice that level).

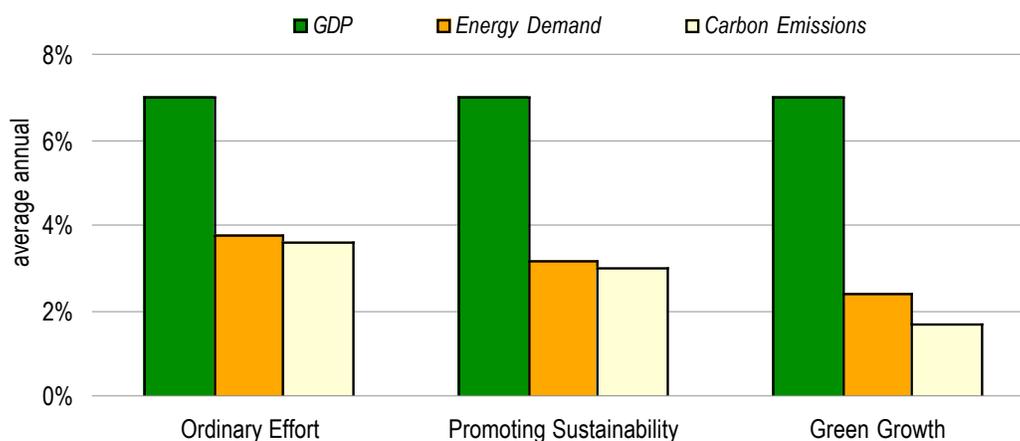
Implications for Carbon Emissions

If energy use were to grow at the same rate as the economy, then by 2020 demand for primary energy would amount to 174 EJ. If energy intensity in China were to decline by 1.1% annually—the global average rate over the past 30 years—then energy demand would still increase at an annual rate of 6% and the aggregate demand for primary energy in 2020 would amount to 141 EJ. However, the scenarios display energy demand elasticities of GDP growth from 0.54 in *Ordinary Effort* to 0.35 in *Green*

Growth (Figure 8). These are similar to China's recent experience, i.e., under 0.5 in the 1980s and under 0.4 in the 1990s. Thus, in these scenarios, energy demand grows by 2.4% to 3.8% per year. Carbon emissions grow more slowly, and in the case of *Green Growth* they rise nearly 30% more slowly (Figure 22).

Since energy supply develops along a different path in each scenario, carbon emissions differ by more

than would be suggested by the different rates of energy growth alone. In 2020, carbon emissions total 1,900 Mt-C in *Ordinary Effort*, 1,700 Mt-C in *Promoting Sustainability*, and 1,300 Mt-C in *Green Growth* (Figure 23). Carbon emissions grow half as fast in the last scenario as in the first. Resulting per capita emissions in *Green Growth* are 0.9 t-C per person in 2020, whereas they are 1.3 t-C in *Ordinary Effort* (Figure 24).



Scenarios	Annual Growth Rates			Carbon Emissions Elasticity of Energy	Carbon Emissions Elasticity of GDP
	Energy Demand	GDP	Carbon Emissions		
<i>Ordinary Effort</i>	3.8%	7.0%	3.6%	0.95	0.51
<i>Promoting Sustainability</i>	3.2%	7.0%	3.0%	0.94	0.43
<i>Green Growth</i>	2.4%	7.0%	1.7%	0.71	0.24

Figure 22. Carbon emissions grow nearly as fast as energy in *Ordinary Effort*, but promotion of natural gas, renewables, and nuclear energy in *Green Growth* permits carbon emissions to rise more slowly than energy use.

The development of the energy consumption structure in China in the 1990's shows that an improved energy structure has already played a positive role in decreasing the total quantity of energy consumption and in improving environmental conditions. Of particular importance is a reduction in coal use and an increase on oil and gas use. From 1998 to 2000, emissions of SO₂ and CO₂ were reduced by 1.98 Mt and 37.89 Mt, respectively. Accelerating the course of the structural optimization of the energy sector is therefore an urgent task not

only from the perspective of energy supply but also from an environmental standpoint.

In the scenarios, China's GDP will nearly quadruple by 2020, achieving the goal of building a well-off society. Ownership of household appliances and cars, and per capita area of residential and non-residential buildings will all rise considerably. Increasing urbanization and stringency of environmental requirements will result in the use of more efficient, clean energy in and near cities. In two scenarios,

Promoting Sustainability and *Green Growth*, the quantity of coal directly burned in buildings declines. In fact, under *Green Growth*, total coal in final applications falls slightly, and its share of in end use falls from the present 60% to 33% in 2020. This evolution of the role of coal, from an ubiquitous energy form at the point of end use to a fuel used mainly in utilities and large-scale industrial applications, is one of the most fundamental transformations that China's energy system may

experience over the next two decades, and is key to achieving the trajectory of carbon emissions depicted in *Green Growth*.

If China continues both to achieve rapid economic growth rates and simultaneously control greenhouse gas emissions, this will provide a model for other developing countries and a great contribution to the international community working to reduce global CO₂ emissions.

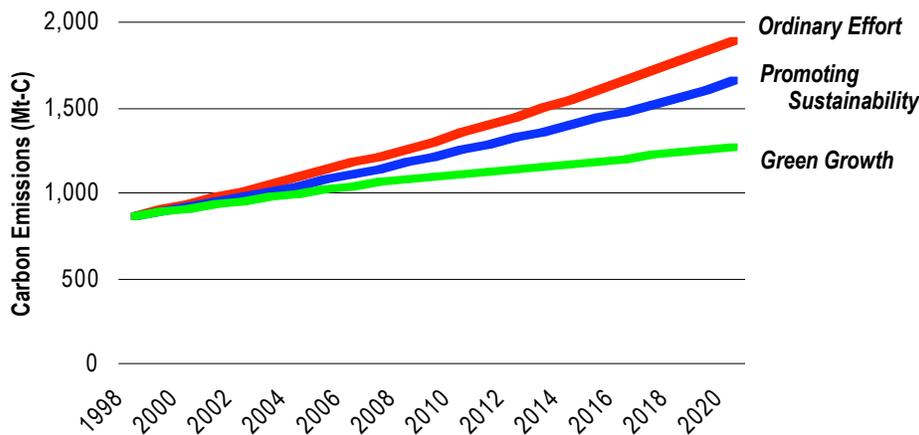


Figure 23. Carbon emissions more than double between 1998 and 2020 in Ordinary Effort, but grow by only about half in Green Growth.

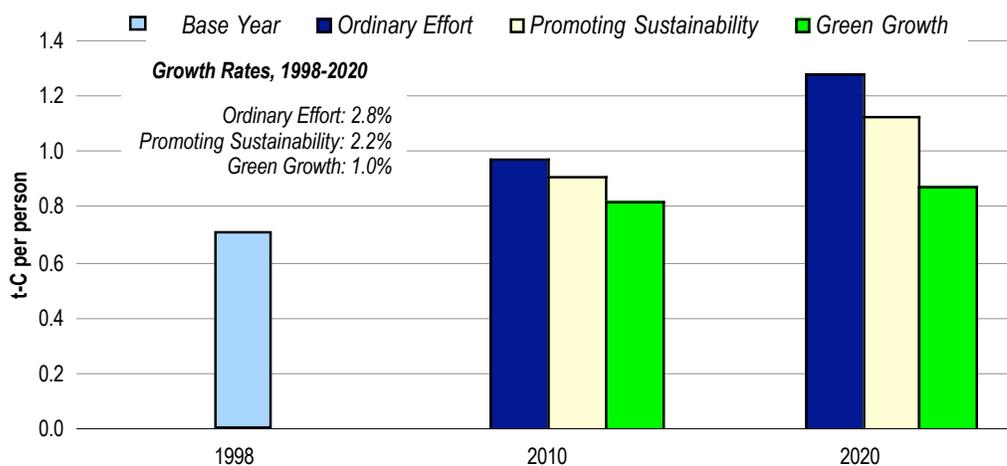


Figure 24. Per capita carbon emissions in Green Growth in 2020 are nearly a third lower than in Ordinary Effort.

CONCLUSIONS AND NEXT STEPS

As China becomes wealthier and more populous, demand for energy-using products and services, including appliances, space heating and cooling, personal and freight transportation, and all the intermediate industrial products needed to produce them, will continue to grow. This presents a fundamental challenge, since, without changes in energy efficiency and energy supply structure, economic growth will drive up energy demand and consequently pollution.

The primary goal of this project was to give Chinese policy-makers detailed information about whether the stated goal of achieving a four-fold increase in GDP with only a two-fold increase in energy consumption is indeed possible. The results of this study have convinced the project team that such an achievement will not come easily to China, but it is feasible given aggressive implementation of policies across all sectors to increase energy efficiency, to rapidly switch to cleaner fuels, and to restructure energy-intensive sectors and activities.

It must be emphasized that even the “greenest” scenario, *Green Growth*, will require tremendous development of the energy supply infrastructure to support rising levels of activity and associated energy demand. Particularly important will be investment in natural gas pipelines and terminals, electricity transmission and distribution networks, nuclear and wind generating capacity, cleaner, more-efficient coal power technology, and public transportation.

While industry must remain a focus of policy makers' attention, transportation and building energy consumption are already expanding rapidly, and will continue to increase very quickly in the coming years. Therefore, it is vital that energy efficiency policies be strongly promoted in these areas as soon as possible.

A large uncertainty that could significantly affect

China's pollutant emissions path (including carbon emissions) is the magnitude of the role that natural gas will play in the energy mix over the coming decades. It will be very important for China to promote rapid substitution of energy-dense fuels, like oil and gas, for the lower-energy-content solid fuels currently used in most applications.

The project team believes that one limitation of this study is the fact that costs are not included in the model. If cost data were included, comparisons of the costs of certain development paths over others could be compared. Although the final accounting results of total CO₂ emissions resulting from an energy development trajectory are indeed important to the Chinese Government, costs are important factors to assess at each stage where a decision is made to introduce a new technology or a new policy program.

Analysis of other benefits of alternative energy-development paths also needs to be evaluated. Integrated assessment work could quantify the benefits of greater efficiency and better fuels in terms of reduced damages to the environment and human health. Integration with macroeconomic analysis could potentially gauge employment impacts as well. Benefit-cost calculations could assist in prioritizing areas in which to promote investment.

Sensitivity analysis would allow policy makers to understand the different effects of various policy options. Analysis could focus on the effects of introducing varying levels of efficiency standards for vehicles or household appliances at different times, and the impacts on different regions and demographic groups.

All such future work should keep clearly in view the goal that has guided the work in this study: to find practical ways to achieve China's goals for improving the welfare of its citizens in an environmentally, economically, and socially sustainable manner.

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ABBREVIATIONS

bcm	billion cubic meters
CO ₂	carbon dioxide
EJ	exajoule (10 ¹⁸ joules)
ERI	Energy Research Institute
gce	gram of standard coal equivalent
GDP	gross domestic product
IGCC	integrated gasification and combined cycle
LBNL	Lawrence Berkeley National Laboratory
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MJ	megajoule (10 ⁶ joules)
Mt	million metric tons
tce	metric ton of standard coal equivalent
toe	metric ton of oil equivalent
Mt-C	million metric tons of carbon
NBS	National Bureau of Statistics
NDRC	National Development and Reform Commission
NO _x	nitrogen oxides
ORNL	Oak Ridge National Laboratory
PM _{2.5}	suspended particulate matter, diameter ≤ 2.5 microns
PM ₁₀	suspended particulate matter, diameter ≤ 10 microns
SDPC	(former) State Development Planning Commission
SETC	(former) State Economic and Trade Commission
SO ₂	sulfur dioxide