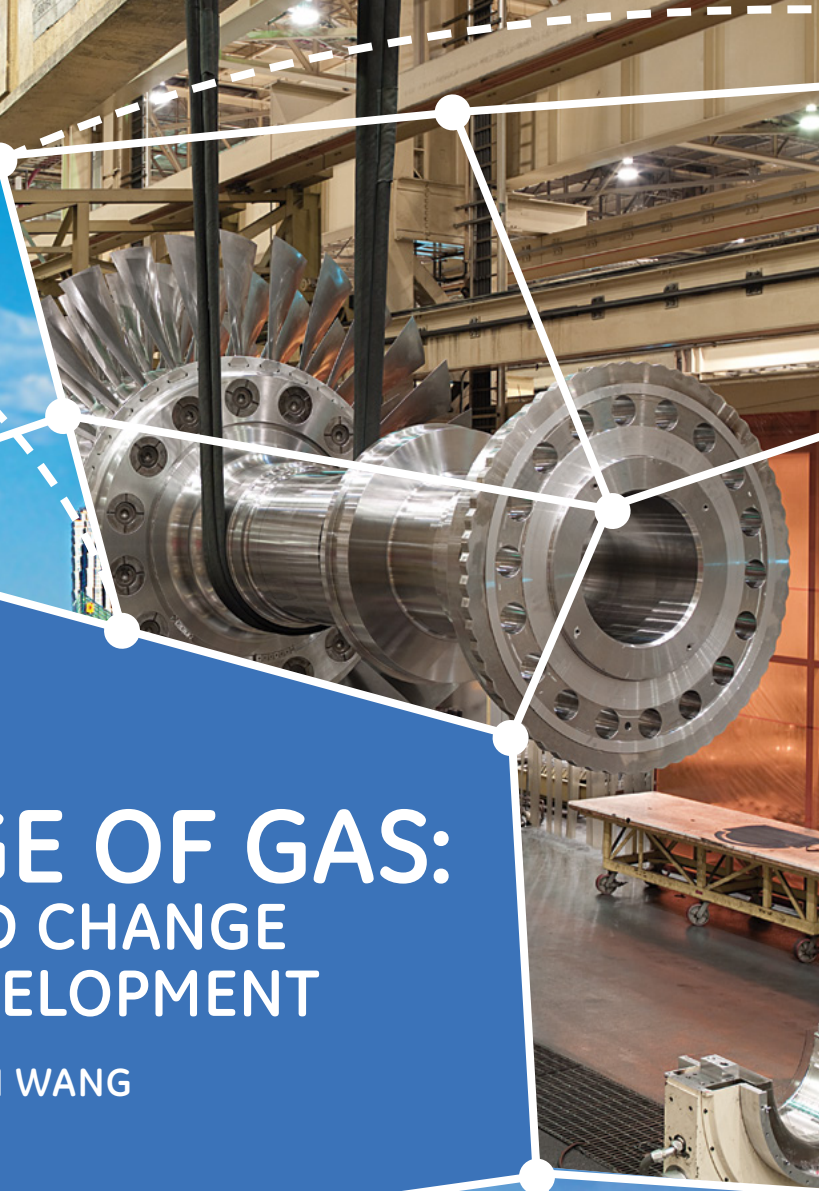
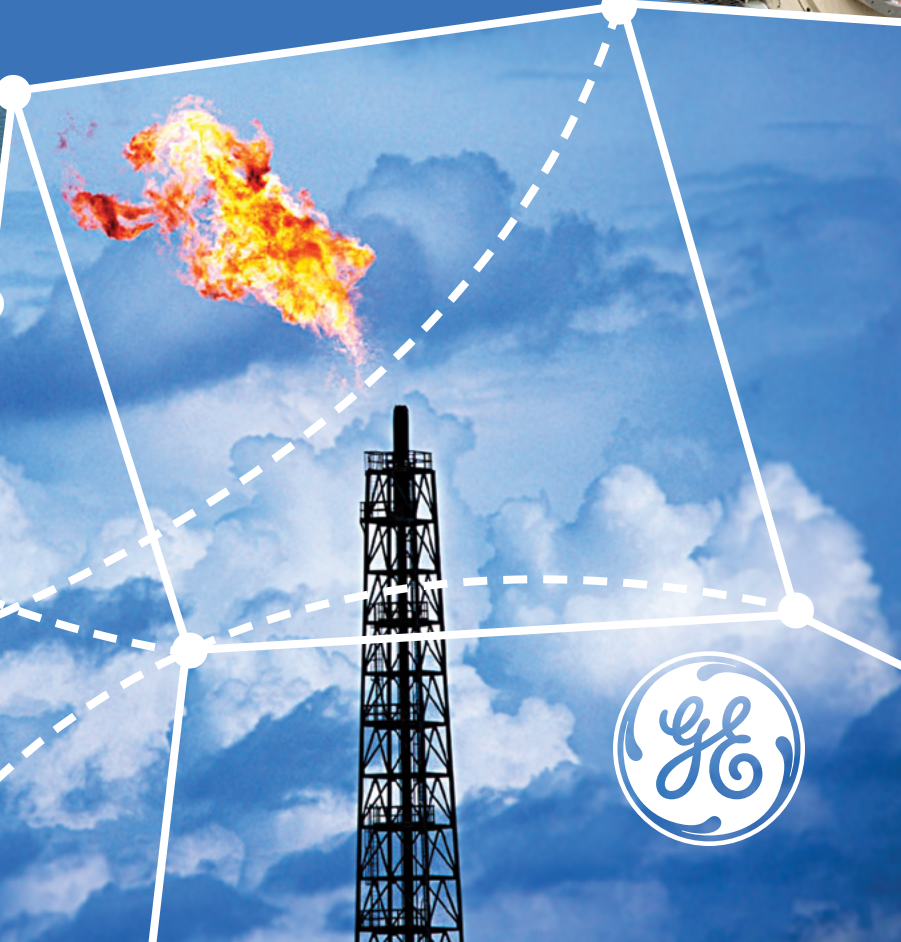


CHINA'S AGE OF GAS:
INNOVATION AND CHANGE FOR ENERGY DEVELOPMENT

MICHAEL F. FARINA & ADAM WANG



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I. EXECUTIVE SUMMARY

Over the last decade, the China's energy strategy was largely focused on coal and oil. Indeed, coal and oil use has supported China's economic development miracle. However, rising energy-related issues, such as air pollution and need for greater energy efficiency, have caused China to look for other options. It is within the context of these changing conditions that we see natural gas becoming the new focal point of China's energy strategy over the next fifteen years.

The combination of increasing supply options and significant benefits to energy consumers makes gas a wise option to diversify China's energy options. Gas supports China's industrial development with high efficiency energy; it can reduce harmful emissions, support energy security, and provides resiliency. At the same time, it is good partner to other low-emissions sources like nuclear and renewable energy. Gas is a great diversifier.

In GE's Age of Gas outlook, in 2025, China's gas market will be 2.5 times larger than it is today. Demand is forecast to grow at 8 percent per year reaching almost 400 billion cubic meters per year (Bcm) in 2025, an increase of 250 Bcm from today. The share of gas in primary energy consumption is expected to double from 4 percent today to 8 percent in 2025. Non-hydrocarbon resources are expected to grow to 17 percent of primary energy. As a result, carbon emissions grow at roughly one-third the rate experienced over the last decade. In addition, sulfur dioxide (SO_2) emissions are expected to fall by 15 percent from current levels.

Choices in the power sector will have a big impact on the gas industry. Gas is projected to account for 6 percent of power generation in 2025 — 3 times current levels. Gas supply will be split evenly between domestic and international sources with shale gas representing 7 percent of gas supply in 2025. These figures are less than some recent Chinese government targets, but they reflect the challenge of diversifying and growing energy sources in a large economy.

Under more aggressive assumptions about shale gas and gas-fired power development, natural gas could represent 12 percent of primary energy and 15 percent of power generation. In this more aggressive scenario, China's CO_2 emissions growth slows to 1 percent per year by 2025 — recently they have been growing by 9 percent per year — and SO_2

emissions fall to 30 percent below current levels. To create this kind of dramatic shift, China's gas market would be 40 percent larger in 2025 than the Age of Gas outlook — or 80 percent of the size of the US gas market today.

Even though China's government and business leaders have been focused on diversifying China's energy future and capturing the benefits of gas, China's gas future is uncertain. New supply sources hold promise, and there is strong potential to capture the benefits of gas in urban areas, but institutional forces could slow growth. Concrete steps need to be taken to shape the gas industry of the future and enhance the competitiveness of gas.

To achieve that goal, in our view five areas of focus will be critical to achieve the Age of Gas in China:

- **Prices matter.** China's pricing policies need to be aligned so that supply and infrastructure investments are viable, while allowing gas to remain competitive with other fuels.
- **Unleash the innovators.** Find the policy tools to allow experimentation in new technology and business models.
- **Harness the power of networks.** As gas networks grow they become more valuable. China has a unique opportunity to build and integrate its energy networks; however, this will require supporting infrastructure investment while insuring access to the network.
- **Keep it clean.** Gas is a cleaner energy source only when it is produced, transported and used wisely. Sustainability benefits of gas only happen with good regulatory oversight and monitoring.
- **Build the service eco-systems.** Many aspects of the gas industry take special expertise. Focus on the development of high quality support services will be important.

Success in these areas will likely allow gas to take a more fundamental role in China's energy system. However, we recognize these solutions must be tailored to fit the unique aspects of China's market. This means the finding the right collaborative partnerships to drive technology innovation and improved business practices.

II. THE AGE OF GAS AND CHINA

The role of natural gas as a global energy source is expanding in China and around the world. Growing constraints on incumbent fuels like oil and coal are increasing at the same time energy demand growth remains strong. The potential for growth in new supply, triggered by advances in development of shale-derived oil and gas, has dominated industry discussion. This is forcing countries to rethink the role of gas in energy systems.

The development and utilization of natural gas has multiple benefits. Natural gas can support national competitiveness, helping countries diversify their energy needs from imported fuel. Gas, if developed with good environmental practices, creates less air pollution and uses less water than coal. Furthermore, while often in competition with other fuels, natural gas is unique in that it also complements other energy sources such as wind, solar, and nuclear as a flexible energy option. Gas is the "great diversifier."

New technology options are expanding supplies while increasing the range of uses. The use of smaller-scale gas resources close to demand centers creates benefits in terms of energy system resilience. We believe the flexibility, versatility, and the relative cleanliness of gas as a fuel will be critical to meet the growing energy needs of China and many other developing economies.

Economic and environmental forces are expected to drive increased fuel substitution away from oil and coal toward natural gas and renewables. Natural gas could account for 26 percent of global energy supply by 2025. There is reason to believe we are entering an "Age of Gas." [1] However, the choices China makes are critical. China is forecast to account for 20 percent of global gas demand growth by 2025. If China's efforts to expand natural gas use fall short, then the global growth of gas will be necessarily curtailed. Given the significance of China to the natural gas industry, this paper highlights China's gas future. What are the benefits of gas in China? What are the challenges within China's gas industry that must be overcome? We turn first to the historic role of gas in China's energy mix.

China's Gas Story

The natural gas history in China can be traced back to almost two thousand years ago, when early innovators in Sichuan region used natural gas from shallow wells to boil the salt from water. China's modern gas industry started with crude oil development. Initially, most gas supply was a byproduct of oil production. Gas production areas were scattered and relatively small. Lack of infrastructure to transport gas to large cities meant supply was used near where it was produced. Gas used as a feedstock for fertilizer and other petrochemicals, or as local city gas for residential and commercial users. Industrial users consumed the biggest share of gas production. In some cases, lack of gas networks meant gas was flared.[2]

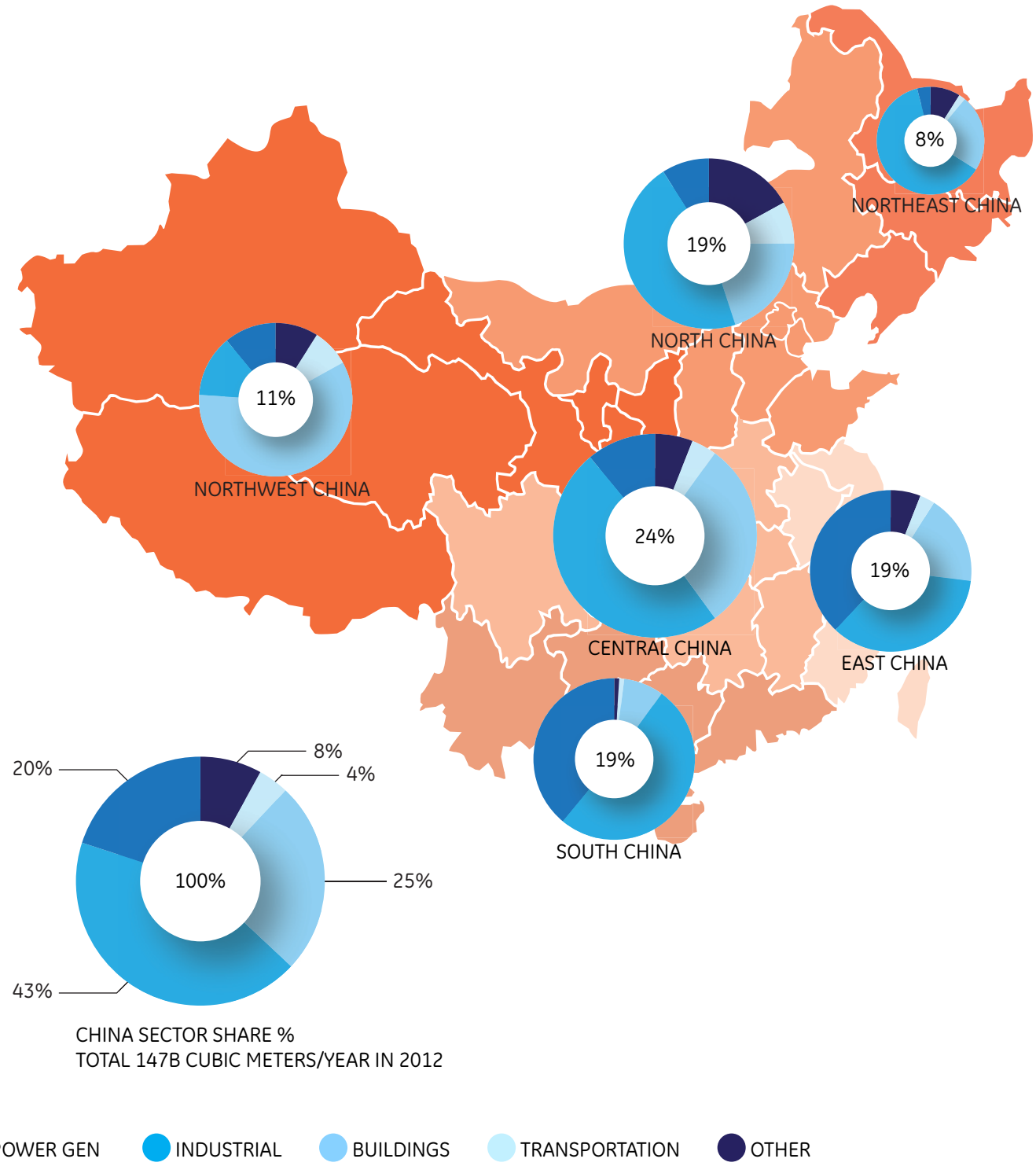
Large populations in the coastal cities created tremendous demand. Manufactured gas derived from coal and fuel oil became a key source of supply. During the 1960's-1990's, city gas networks were built to utilize these supplies. In Beijing for example, the core area of the city was supplied by the three main manufactured gas producers including the Shougang Group, the 751 Factory, and the Beijing coking plant. By 1990, the total manufactured gas supply in Beijing counted around 0.6 Bcm. At the time, residential users represented 70 percent of Beijing's gas demand.

Huge gas discoveries in Ordos basin and Tarim Basin launched the next phase of industry development. The big finds opened the way for continental scale pipeline development.[3] After the completion of the first West to East pipeline in 2005, gas consumption increased sharply. Gas demand growth has averaged 18 percent per year since 2005. Surging demand has also stimulated the upstream gas development. New gas fields such as Puguang in Sichuan province and Changqing in Ordos basin were brought into production. By 2012, gas production in China reached around 110 Bcm, more than double 2005 levels.

In recent years, more new pipelines are expanding access to domestic resources and international markets. In addition, China has begun to aggressively import liquefied natural gas (LNG) in the coastal regions. Four years after the first West to East line was put into operation, the second West to East Line II was completed. This pipeline, with the capacity of 30 Bcm per year and total length longer than 8000 km, is one of the longest gas pipelines in the world. On completion, the plan for the third West to East Line was presented to national authorities. After decades of

Figure 1: China's Regional Gas Demand

Source: GE analysis. Regional sector shares estimated from 2011 data or latest available data China Statistical year book, IHS-CERA, IEA



construction, isolated pipeline systems are being integrated into a national gas network. By the end of 2011, the trunkline portion of the national grid totaled 40,000 km.

Role of Natural Gas in China today

Years of development have changed the gas market. In 2012, the natural gas demand reached 147 Bcm per year. The demand structure of natural gas also changed dramatically. For example, the city gas sector has grown from a small segment to become a significant part of the gas market. City gas demand for buildings in heating and residential uses currently is 25 percent of total demand. Natural gas in the industrial sector has evolved from being primarily fertilizer and chemical feedstock being increasingly a broad-based industrial fuel. In 2012, industrial demand accounted for nearly 43 percent of total gas demand. Power generation, including some combined heat and power (CHP) uses, is 20 percent of total gas demand.[4]

Gas demand, historically located near production fields, is growing fast in coastal regions. In production regions, like Xinjiang and Sichuan province, lower cost is used in industrial applications. Central China accounted for 44 percent of gas demand in 2000, but this has fallen to 24 percent today as national gas networks have expanded. Demand is growing in the coastal areas of eastern China including the greater Beijing-Tianjing region. This region now represents 19 percent of national demand. On the coast, the East China region including Shanghai, accounted for less than 2 percent of regional gas demand in 2000. With the completion of the West to East pipeline in 2005 and Puguang-Shanghai pipeline in 2010, demand grew. The east region now represents 19 percent of total demand. In the southern region, demand is centralized near the industrial regions of Guangdong. This region currently represents about 19 percent of national demand. See Figure 1.

Recently, gas demand has been rising faster than domestic production resulting in shortages, especially in the peak winter months. As a result, China has turned to gas imports. Imports have increased from 1 Bcm in 2006 to nearly 43 Bcm in 2012. To help ease shortages, China now has five operating LNG receiving terminals and two international gas pipelines (Caspian region and Myanmar).

Despite the strong growth trend, China's natural gas industry is still in an early stage of development. Today, natural gas represents only 4 percent of total primary energy supply. In contrast, coal represents almost 66 percent of energy use and oil represents 18 percent. The low penetration of gas implies tremendous growth potential in the future. However, it also highlights the tremendous challenge that natural gas faces in China.

China's gas future is uncertain. New supply sources hold promise, and there is strong potential to capture the benefits of gas in urban areas, but institutional forces and entrenched interests could slow growth. Before examining what China's Age of Gas might look like, we first discuss why natural gas is an important option for China.

III. WHY NATURAL GAS? ... GAS IS A GREAT DIVERSIFIER

China's rapid growth has driven huge increases in energy requirements. Recognizing the need to move quickly to increase supply, expanding domestic coal use has been the first option. While meeting the needs of the economy will remain essential, a wider range of options should be considered as environmental and logistical constraints increase. China's leaders are expanding their focus beyond purely driving energy growth, but are carefully considering other sources of the equation including:

- Efficiency
- Sustainability
- Energy security
- Resilience

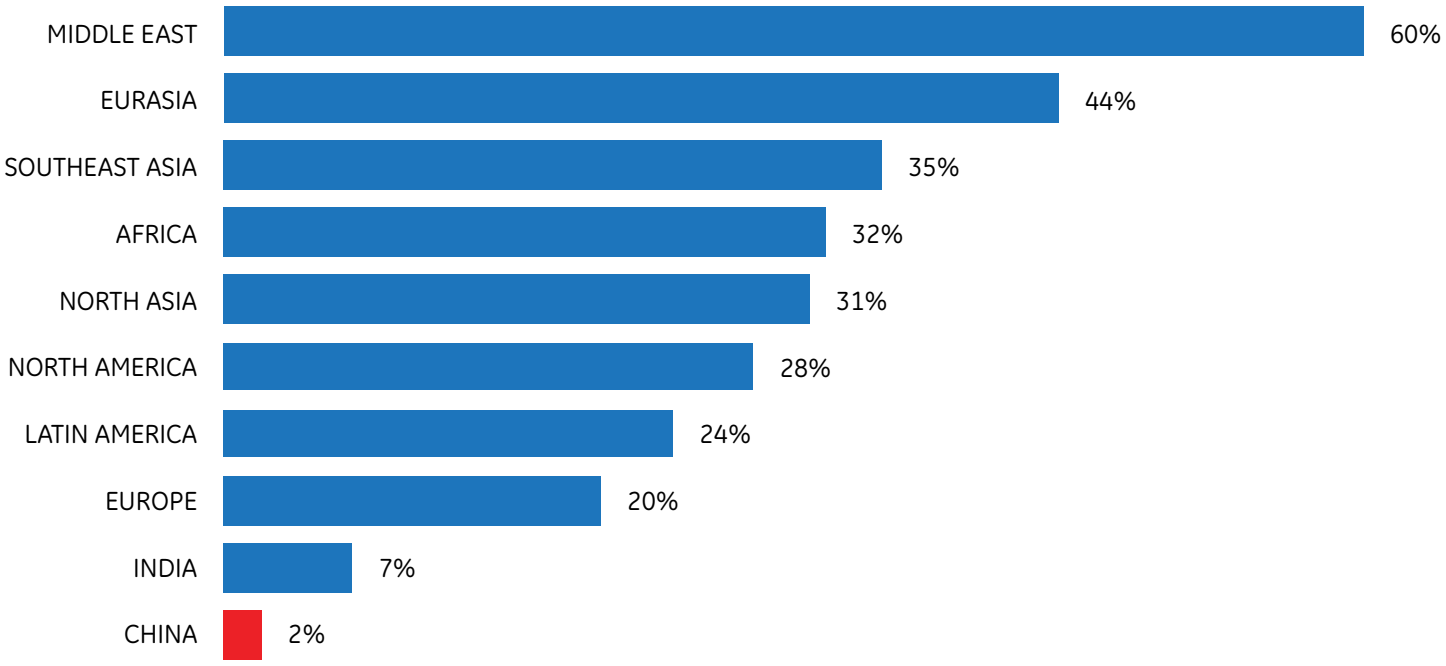
There are multiple solutions to these issues, but one energy option that holds great promise is natural gas. An increasing range of supply sources, flexibility and versatility, and a broad range of end-use technologies make gas a great option to diversify energy sources. However, in China and other parts of the world, traditional analysis undervalues some of these benefits.

Traditional economic analysis undervalues natural gas

Natural gas is underutilized in China today especially relative to other advanced and rising countries in Asia. Today, gas accounts only for 4 percent of China's total primary energy consumption, 19 percentage points below the world average. Natural gas as a source of primary energy in Asia, excluding China, is 20 percent. Even in India, where coal is also a dominant fuel, gas is 8 percent of primary energy production.[5] In China's power generation mix, the role for natural gas is even smaller. Natural gas in 2012 represented only 2 percent of China's power generation. This is far lower than many other regions, including other parts of Asia. See Figure 2. In 2012, 75 percent of China's electricity production came from coal-fired power units.

Figure 2: Share of Natural Gas in Power Generation 2012

Source: GE Global Strategy and Analytics 2013.



Note: North Asia includes Japan, Chinese Taipei, and Korea. Southeast Asia excludes India.

There are many reasons driving high coal use including constrained gas supply, abundant domestic coal and underdevelopment of the gas network and other infrastructure. However, the key factor is economic valuation of natural gas use projects. Although natural gas is cleaner and more efficient, natural gas is considered an expensive energy in China. Wholesale coal prices can be half the price of imported natural gas.

For most of the project owners, fuel price is the primary concern when making technology choices. However, there are values beyond strictly fuel price that can be considered. Factors like efficiency, security, environmental benefits, and resilience enhance the value proposition of natural gas. An alternative way to look at this issue is that the full cost of coal is not always factored into project economics.

The study of these external costs, externalities as economists describe them, is a fundamental part of cost-benefit analysis in energy. The basic idea is that there are costs that may accrue to society outside the project

boundaries in terms of environmental degradation, poor health, and lost productivity. Determining the impact on the society is a complex question. Many other rapidly industrializing nations have battled these questions. The response has typically not been to abandon coal, but utilize it as cleanly as possible and diversify energy sources. This is where natural gas can help.

National efficiency goals

The Chinese government has prioritized more efficient energy use. By the end of 2010, the primary energy consumption per unit of GDP decreased by more than 19 percent.[6] Going forward, China plans to cut energy consumption per unit of GDP by another 16 percent by 2015. Between 2006 and 2010, the government launched a program to shut down the small coal units and replace them with large ones in the power and steel sectors to improve energy efficiency. The results have been dramatic and positive. The installed capacity of units larger than 300 megawatts (MW) represented more than 70 percent of capacity by 2010. In addition, the average thermal efficiency of coal units has been increased from about 26 percent to nearly 38 percent.[7] However, the thermal efficiency of coal plants is still much lower than what can be achieved with natural gas.

Gas-fired power technologies, such as combined cycle power, combined heat and power (CHP), gas furnaces and boilers, and gas-fired distributed power, offer efficiency advantages over coal. In large-scale combined cycle power generation, gas can achieve thermal efficiency up to 61 percent. In CHP systems where residual heat is utilized, conversion efficiencies can exceed 80 percent. Smaller distributed gas options, like gas engines or aero-derivative gas turbines, can achieve direct conversion efficiencies of 45 percent.

Distributed CHP systems hold particular promise in the Northeastern regions to simultaneously use energy more efficiently and reduce environmental impact. An example is the first distributed CHP project in Guangxi province, Jiangnan Energy Station project, which was commissioned in mid-2013. The project will have thermal efficiency of 75 percent, serving the heating and cooling needs of a nearby technology park and residential complex. China recognizes the value of these systems and is targeting 50 MW of new distributed CHP to be installed by 2020.[8] More efficient gas systems at larger-scale projects are also being prioritized.

Environmental improvement and sustainability

As the cleanest of the hydrocarbon fuels, it is widely acknowledged that natural gas has emission benefits compared with other fuels. Natural gas produces 23 percent of nitrogen oxide (NO_X), 50 percent of the carbon dioxide (CO_2), and virtually no sulfur dioxide (SO_2). If produced with good environmental practices, switching fuel to natural gas is environmentally friendly.

It should be recognized that China's coal industry has made great strides in improving its environmental impact. Substantial investments in desulfurization and denitrification systems have significantly reduced SO_2 and NO_X emission from large coal plants. However, there were still 8.8 million tons of SO_2 and 9.4 million tons of NO_X released to the environment from power plants.[9] These pollutants are the main source for acid rain which can significantly impact crop production. In addition, there are thousands of smaller industrial coal boilers and coal stoves in urban areas. Coal-burning coupled with vehicle traffic in urban areas is creating significant haze and smog problems in China's major cities. High concentrations of these pollutants also contribute to forming $PM_{2.5}$ (dust particles which measure less than 2.5 microns — small enough to get deep inside human lungs), which is believed to cause severe damage to health.[10]

Many research institutes across China are studying the externality costs associated with the heavy dependence of coal for power generation. Various studies have looked at the health impact,[11] agricultural losses, the direct cost of adding emission controls, and the implied costs if carbon taxes were implemented.[12] Based on estimates from these studies as applied to 2010 data, the environmental costs of coal are between 175 billion RMB and 580 billion RMB. If only 40 percent of these costs, representing coal power share of emissions, were allocated to coal prices; the cost of coal would be 7 to 25 percent higher. In addition, going forward, the costs of implementing current end-pipe control technology, mainly including desulfurization, denitrification and dust-removing technologies in coal-fired power plants could cost an additional 350 billion RMB.[13] Producing detailed environmental analysis is beyond the scope of this paper, but our conclusion is even modest accounting for environmental impact can significantly close the price gap between the cost of gas and coal.

Despite the economic and health impact, growth in coal use is expected to continue. Even with state-of-the-art emissions control technologies in

new and existing plants, meeting targets for reducing SO_2 and NO_x will be challenging. China's twelfth five-year plan calls for 8 percent and 10 percent reductions in SO_2 and NO_x by 2015, respectively.[14] Policy direction calls for all the coal-fired boilers, industrial furnaces and captive coal-fired power plants to switch to gas in the cities of the Beijing-Tianjin-Hebei area, Yangzi River Delta, and Pearl River Delta by 2017. To do this, China is targeting reductions in coal use in the most polluted regions of 150 to 200 million tons by 2017.[15] This is part of a larger target of lowering its carbon emissions per unit of gross domestic product (GDP) by 40 to 45 percent by 2020 from 2005 levels. Natural gas will be a valuable fuel to meet all these targets while providing other pollution benefits in urban areas.

Natural gas is even more valuable when the relatively low water requirement of gas-fired power is considered. Natural gas generation typically has one-quarter the water requirements of coal or nuclear plants depending on what type of cooling system is in place. Fresh water supply has been an emerging concern in China's energy sector. Furthermore, China is striving to reduce water input per unit of industrial output. Current targets call for 30 percent reductions in industrial water use. Today in China, 51 percent of the water-reliant power generation resides in areas of medium to extremely-high water stress. In addition, gas-fired power helps reduce electricity vulnerability during drought conditions without unduly taxing rivers and other water systems.

Finally, natural gas also has important indirect environmental benefits. As gas networks expand in China, gas will be a valuable partner to renewable sources. The intermittency of renewables close to load centers can be complemented with the flexibility of gas-fired power. At the same time, gas in remote areas can support renewable generation to insure high utilization of large-scale high voltage transmission systems. In this way, the development of gas can enable the use of more low-emission renewable technologies in a reliable way. For all these reasons, natural gas is a valuable option to lower the environmental impact of energy use in China.

Energy security and diversity

Energy security refers to the same thing as energy independence and is supported by creating supply diversity and finding ways to use energy with more flexibility. Natural gas can help in both of these areas. Natural gas is a flexible fuel. It can be used in a wide variety applications from industrial feedstocks, power generation, or transportation fuel. Through the use of liquefied natural gas (LNG) or compressed natural gas (CNG) systems, natural gas can displace imported oil. It partners well with electricity sources and is a good option for buildings and industry. Natural gas produced close to load centers can be an important part of electricity security in the event of disruptions in the high-voltage network or intermittency related to renewable energy.

On the supply side, lack of domestic resources was traditionally a major issue for natural gas. However, we believe this is changing dramatically in China. New domestic conventional supply sources onshore and offshore are going into full development, as are exciting new unconventional resources derived from coal-bed methane and gas shale. Furthermore, coal-based synthetic gas (syngas) supplies are poised to become an important component of domestic gas supply in the years to come. In addition, external sources of gas supply continue to expand. New pipeline corridors into China are being built and the number of LNG import options continues to increase.

Expanding gas options will be important as China's energy demand increases, and as China increasingly imports more oil and high quality coal from abroad. Since 2010 coal imports have increased by 56 percent. Coal imports are up more than 500 percent from 2008. Oil imports have also grown by nearly 45 percent and are projected to increase by another 50 percent by 2020.[16] Balancing between external energy sources is complex. Exposure to geopolitically sensitive supplies can create disruptions.

Gas diversification is an important option. China is expected to continue to increase diversity by deeply engaging in international energy markets. Recent moves by China National Petroleum Corporation (CNPC) into gas projects in Australia, Mozambique, and Canada illustrate this. The diversity of international gas supply options makes gas an important strategic resource — especially considering the concentration of oil imports coming from the sometimes volatile Middle east. As Winston Churchill said many

years ago, "Safety and certainty in oil lie in variety and variety alone."[17] The expanding range of domestic and international gas supply options coupled with the flexibility of gas in various end-use applications make it a valuable addition to China's energy future.

Resilient and sustainable infrastructure development

The need for energy infrastructure to be resilient is gaining increasing attention. Energy systems need to have the ability to bounce back after a disruption and endure greater stress during shocks.[18] Reliability not only comes from the availability of supply, but it also comes from the robustness of the system. The larger the base of energy infrastructure in a country, the larger the risk from disruptions. Power grids are susceptible to natural disasters. For example, during the winter of 2008, the heavy snow in South China caused massive shut-downs of the power grid. Direct damage from heavy snow was calculated to cost 111 billion RMB.[19] Power outages occurred in 17 provinces. Chenzhou, a city with population of 4.6 million, had no power or water supply for over two weeks, including public utilities and hospitals. A city in Jiangxi (Fuzhou), was without power for about 3 weeks. About 40 gigawatts (GW) thermal capacity was shut down, representing 7 percent of China's total thermal installed capacity at the time. Coal reserves were also down to emergency levels and stockpiles were only sufficient for eight days of power generation in south China. More recently, in September 2013, the typhoon Usagi came onshore in the Guangdong province. Power outages in Shantou and Chaozhou were reported. During the typhoon, 1.8 million households were without power for a period of time. These examples highlight the need to strengthen the resilience of energy systems.

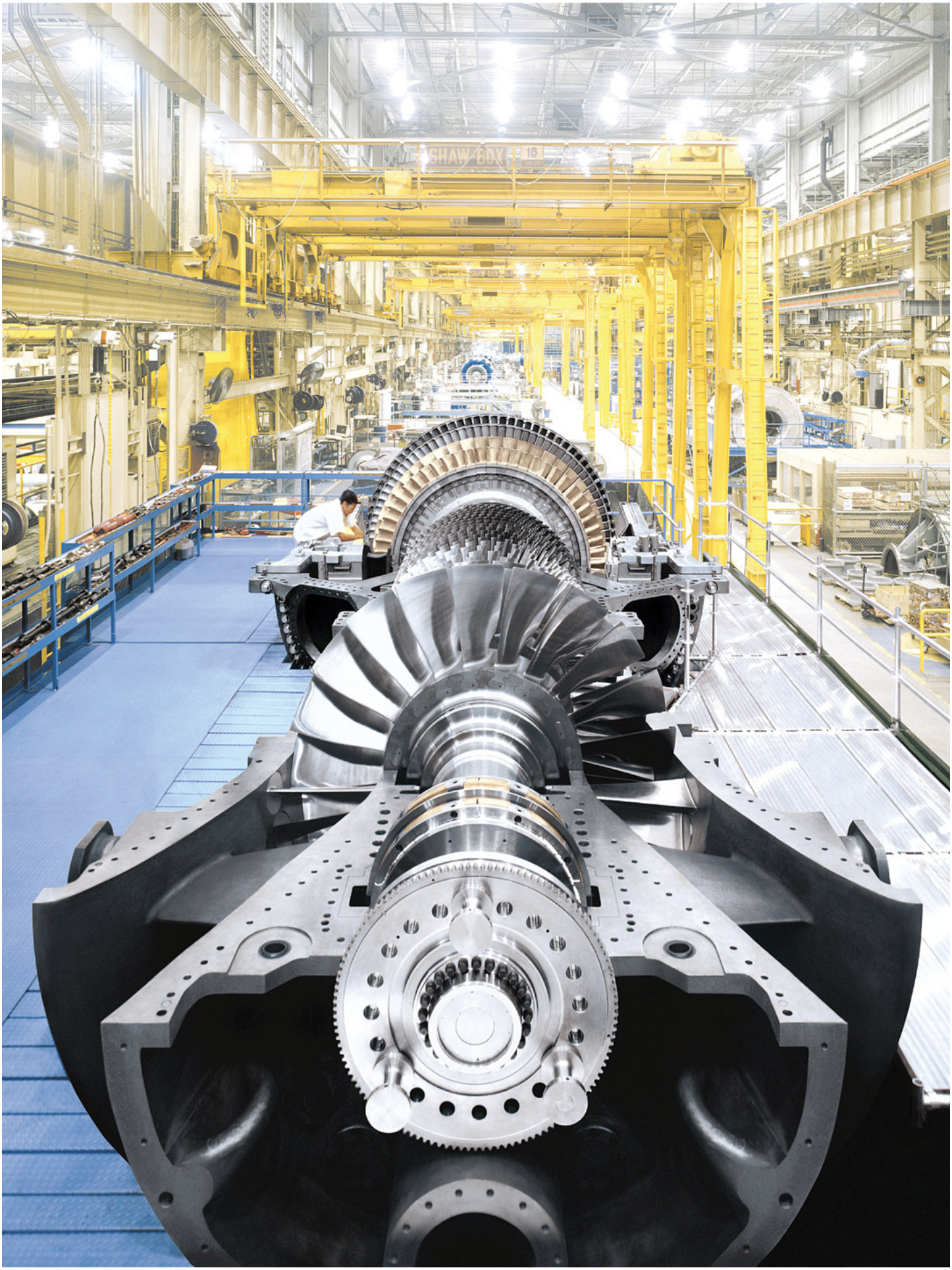
A resilient energy system optimizes the strengths of individual energy networks. It integrates their operations to the benefit of consumers. Gas is well-positioned to work with other energy sources to improve overall energy system resilience in China. Furthermore, as gas systems become more intelligent with new digital and software technologies, these benefits will likely grow. Gas networks, which are often underground, in contrast to road and power grids, can often provide stable service during severe weather events. In this way, gas can contribute broadly to the economic resiliency by providing diversification, redundancy, and backup systems for

China. However, in other events, for example, earthquakes or typhoons (for LNG ships) gas systems may be disrupted. This is why gas, power, and liquid fuel networks need to be optimized to support each other.

Gas technologies are supporting new concepts for grids-within–a-grid and multi-source micro grids to increase resilience and reaction time in the face of disruptions. In addition, distributed power systems built around gas networks can provide fast power recovery for public utilities such as hospitals, waterworks and government agencies, which is very important in disaster relief.

Capturing the benefits of natural gas

The benefits of natural gas are multiple, including efficiency, environmental sustainability, and energy security and resilience. While not all of these benefits, or positive externalities, are currently accounted for in project economics, we believe capturing these benefits has long-term and far-reaching positive impact on China's economy and society. Furthermore, these benefits can already be captured where gas is economically competitive. For China, these benefits may prove to be larger than the investment in resources and infrastructure to increase gas consumption. Accounting for these benefits explicitly may, at least partly, offset the current price differentials between natural gas and competing fuels in China. Assuming that increasing natural gas in China's energy system is beneficial, we turn now to what China's Age of Gas might look like.



IV. CHINA'S AGE OF GAS

As a late mover of natural gas, China has an opportunity to learn from successes and avoid the mistakes made in other countries. China's gas industry is still at an early stage of development. The deployment of advanced technology can be achieved without costly replacement of legacy assets. This will help China add to the competitiveness of its energy system in the future.

The question is what is the future role of natural gas in China? There are many views both inside and outside China. As part of our global study of natural gas markets, GE has developed a forecast of China's gas future out to 2025. This section features results from that analysis. Under certain positive assumptions for the gas market, like rapid growth in shale gas production, more aggressive targets might be possible. In this section, we feature what China's Age of Gas might be, focusing on the role of gas in the economy and how gas could impact the power generation landscape in China.

Outlook for China's gas market

Economic growth in China will continue to drive large increases in energy demand over the next fifteen years.[20] In our view, use of all energy sources will grow. By 2025, coal and oil demand will both grow by about one-third over current levels, but the fastest growth will be in gas, nuclear, and renewables. Gas demand in China will be driven by economic forces, growing urbanization and environmental policy factors. In the Age of Gas outlook, the share of gas in primary energy consumption doubles from 4 percent today to 8 percent in 2025.[21] Gas demand is forecast to grow at 8 percent per year reaching 390 Bcm in 2025, an increase of 250 Bcm. In 2025, China's gas market will be 2.5 times larger than it is today. Along with gas, non-hydrocarbon resources like nuclear, hydro, wind and solar are forecast to increase their share of primary energy to 17 percent, up from about 11 percent today.[22] Even though coal demand grows, energy diversification allows coal's share of primary energy to fall to 59 percent of primary energy. In the outlook, the overall energy intensity of the economy per unit of GDP is forecast to decrease by 40 percent between 2012 and 2025.[23]

Gas demand growth is expected to be broad-based. Industrial use of gas is forecast to double by 2025 up from about 60 Bcm today. The use of gas in buildings for residential and commercial purposes, primarily for space heating and cooking, is expected to triple by 2025 as large populations in urban and rural settings begin to have access to natural gas. As fueling infrastructure expands and prices remain competitive versus oil products, the use of gas as transportation fuel is expected to grow. By 2025, transportation demand grows to 20 Bcm, or 5 percent of total demand. This assumption might be conservative as small-scale LNG fueling projects continue to be built at a rapid pace today and transport sector use is growing rapidly.

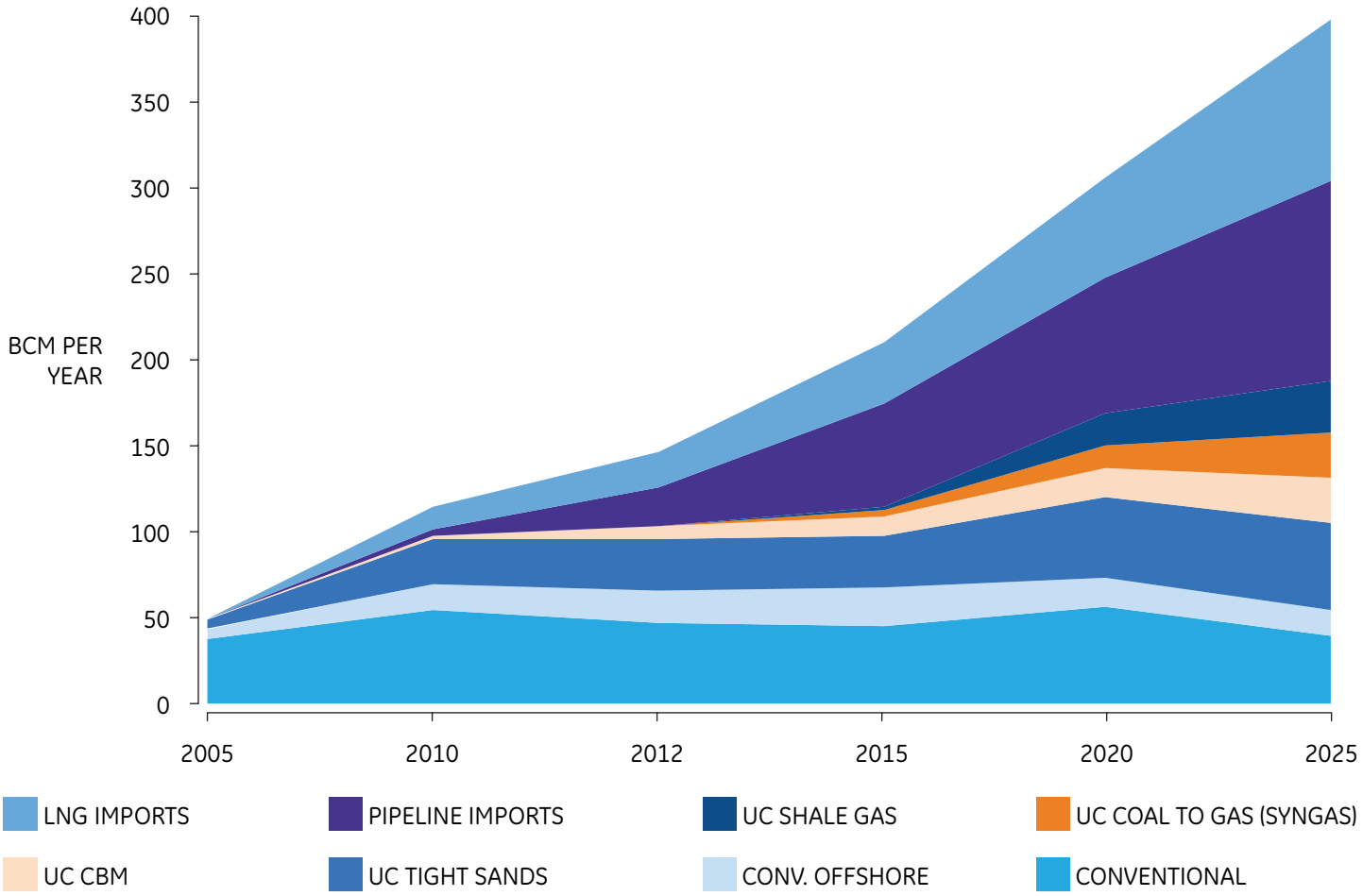
One of the important drivers of gas demand growth will be choices made in the power sector. In the Age of Gas outlook, electricity demand is expected to double by 2025, up from about 4,200 terawatt hours (Twh) today. In the outlook, about 50 percent of new electricity supply in China comes from coal power and 50 percent will come from gas and all other generation sources. This is a more diversified electricity outlook than last decade. Between 2000 and 2012 coal accounted for more than 75 percent of electricity demand growth. The natural gas share of China's power market will triple by 2025, reaching 6 percent of generation. Gas demand in the power sector will increase to 117 Bcm, representing 30 percent of total demand in 2025.

Diversifying into cleaner energy, like natural gas and renewables, will have positive impacts in reducing carbon emissions and other sources of air pollution. Carbon emissions in China grew by 140 percent between 2000 and 2012.[24] In the Age of Gas outlook, they grow by 40 percent between 2012 and 2025 — roughly one-third the rate experienced over the last decade. As a result, the carbon intensity per unit of GDP will decline to 45 percent below 2012 levels. SO_2 emissions will also fall with better environmental controls on coal plants along with more natural gas and renewables. In the forecast, SO_2 emissions decrease by 15 percent between 2012 and 2025 from 9 million tons today. If gas stayed at 2 percent of generation in 2025, as it is today, SO_2 emissions would only decline by 8 percent.

Significant growth in gas demand would not be possible without large and growing sources of supply. As shown in Figure 3, China's gas supply options continue to increase from domestic and international sources.

Figure 3: Gas Supply by Source, Age of Gas Outlook

Source: GE Strategy and Analytics 2013.



Note: UC: Unconventional gas resources.

China's domestic options include conventional sources like central China's giant gas fields or offshore gas resources in the South China Sea. In addition, unconventional gas options are increasing including coal bed methane (CBM), tight sands, and shale gas. Synthetic gas (syngas) derived from coal conversion is another source of domestic supply that will become important over the next decade. Domestic sources of supply, both conventional and unconventional, are forecast to grow by 75 percent by 2025.

Unconventional gas sources including syngas are expected to represent one-third of China's gas supply by 2025. Shale gas is projected to represent

7 percent of gas supply by 2025 or about 30 Bcm of production. This is lower than some recent Chinese government targets for shale gas. Rapid success in shale gas development could create room for the gas market to grow larger than this forecast. Natural gas imports from both LNG and pipeline sources are projected to be 45 percent of supply in 2020 and about 50 percent of supply in 2025. This assumes a new pipeline from Russia will eventually be built and LNG imports of about 90 Bcm (65 million tons per year). In this outlook, China is evenly balanced between domestic and international sources. In contrast oil imports in this outlook are forecast to be about 60 percent of supply in 2025.

Infrastructure development remains a key aspect of the outlook. In the twelfth five-year plan, the Chinese government is targeting to increase the national gas grid by 50 percent. New trunkline pipes by 2015 will add 24,000 km to China's existing network. This includes the third West to East Line, Ordos-Beijing Line IV and Xinjiang-East China pipeline for syngas. Incremental transportation capacity additions are expected to total 150 Bcm by 2015. Our Age of Gas outlook includes a basic estimate of an additional 200 Bcm of new pipeline and LNG capacity between by 2015 and 2025 to support domestic and international gas supply growth.

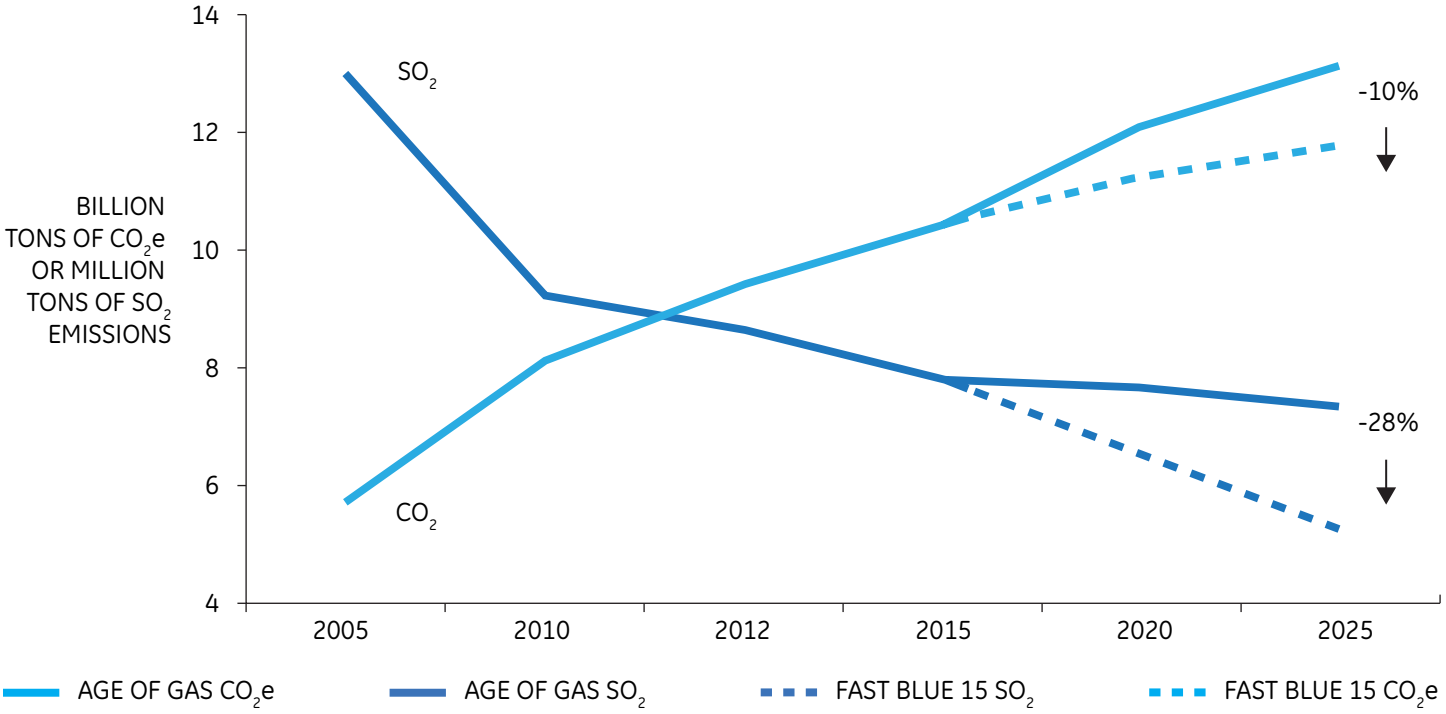
Pushing the boundaries

To explore what an aggressive shift of natural gas in the power sector would mean for China's energy markets we also developed sensitivity on the Age of Gas outlook called Fast Blue 15. In this case, all the basic assumptions of the Age of Gas outlook were the same except natural gas is pushed to represent 15 percent of China's power generation by 2015. In addition, renewable generation was increased so that there was approximately 15 percent more generation by renewables in 2025 over the Age of Gas case in 2025.

In the Fast Blue case, gas demand grows to almost 570 Bcm per year in 2025. Gas demand in power generation grows by 260 Bcm over current levels representing 52 percent of total gas demand in 2025. To meet this significant increase in demand, domestic gas from unconventional sources including shale gas and syngas increases sharply. Shale gas and syngas are assumed to represent 21 percent and 10 percent of gas supply, respectively, in the Fast Blue case.

Figure 4. CO_2 and SO_2 Emission Trends: Age Of Gas and Fast Blue 15 Sensitivity Case

Source: GE Strategy and Analytics 2013.



Note: Carbon emissions from hydrocarbons (coal, gas, and oil). SO_2 emissions from coal power production only. Fast Blue 15: A sensitivity on the Age of Gas outlook where gas increases to 15% of power generation along with approximately 15% more renewable generation over Age of Gas analysis in 2025.

The implications on the broader energy market are significant. Gas increases to 12 percent and coal drops to 50 percent of primary energy. Renewables increase to 23 percent from 17 percent. As shown in Figure 4, CO_2 emissions and SO_2 emissions are reduced to 10 percent and 28 percent below the Age of Gas case, respectively. For CO_2, increasing the gas share of power sector emissions to 15 percent reduced growth to about 1 percent per year. Over the last few years, China's CO_2 emissions have been growing at more than 8 percent per year. A shift toward gas of this magnitude pushes the boundaries of what is possible. China's gas market would be 40 percent larger in 2025 than our Age of Gas outlook — or 80 percent of the size of the US gas market today. While challenging, the Fast Blue case represents a vision of what might be possible if significant efforts are made to support gas industry development.

V. SUPPORTING GAS INDUSTRY DEVELOPMENT: FIVE AREAS OF FOCUS

China's government and business leaders have been focused on diversifying China's energy future and capturing the benefits of gas. These efforts will need to continue for the Age of Gas in China to be realized. To achieve that goal, five areas of focus will be critical to industry development:

- **Prices matter.** China has been working hard to adjust gas pricing mechanisms to match the evolution of the gas market. The challenge will be managing pricing policies so that supply and infrastructure investments are viable, while allowing gas to remain generally competitive with other fuels. As a result, recognizing efficiency value and coordinating policies between the electric, gas and transport fuels sectors are important.
- **Unleash the innovators.** Find the policy tools to allow experimentation in new technology and business models.
- **Harness the power of networks.** As gas networks grow they become more valuable. China has a unique opportunity to build and integrate its energy networks for better efficiency, competitiveness, and reliability. However, this will require careful attention to the mechanisms that allow infrastructure investment while managing access to the network.
- **Keep it clean.** Gas is a cleaner energy source only when it is produced, transported and used wisely. Sustainability benefits of gas only happen with good regulatory oversight and monitoring along with attention to technology options that can help secure and optimize gas operations.
- **Build the service eco-systems.** Many aspects of the gas industry take special expertise. This requires attention to developing the talent and skills to manage a variety of functions across the value chain. These include shale gas operations, small LNG fueling

systems, or the safe and efficient operations of CHP plants. Focus on development of high quality support services will be important.

Success in these areas will likely allow gas to take on a more fundamental role in China's energy system. However, we recognize these solutions must be tailored to fit the unique aspects of China's market. This means finding the right collaborative partnerships to drive technology innovation and improved business practices.

Price competitiveness

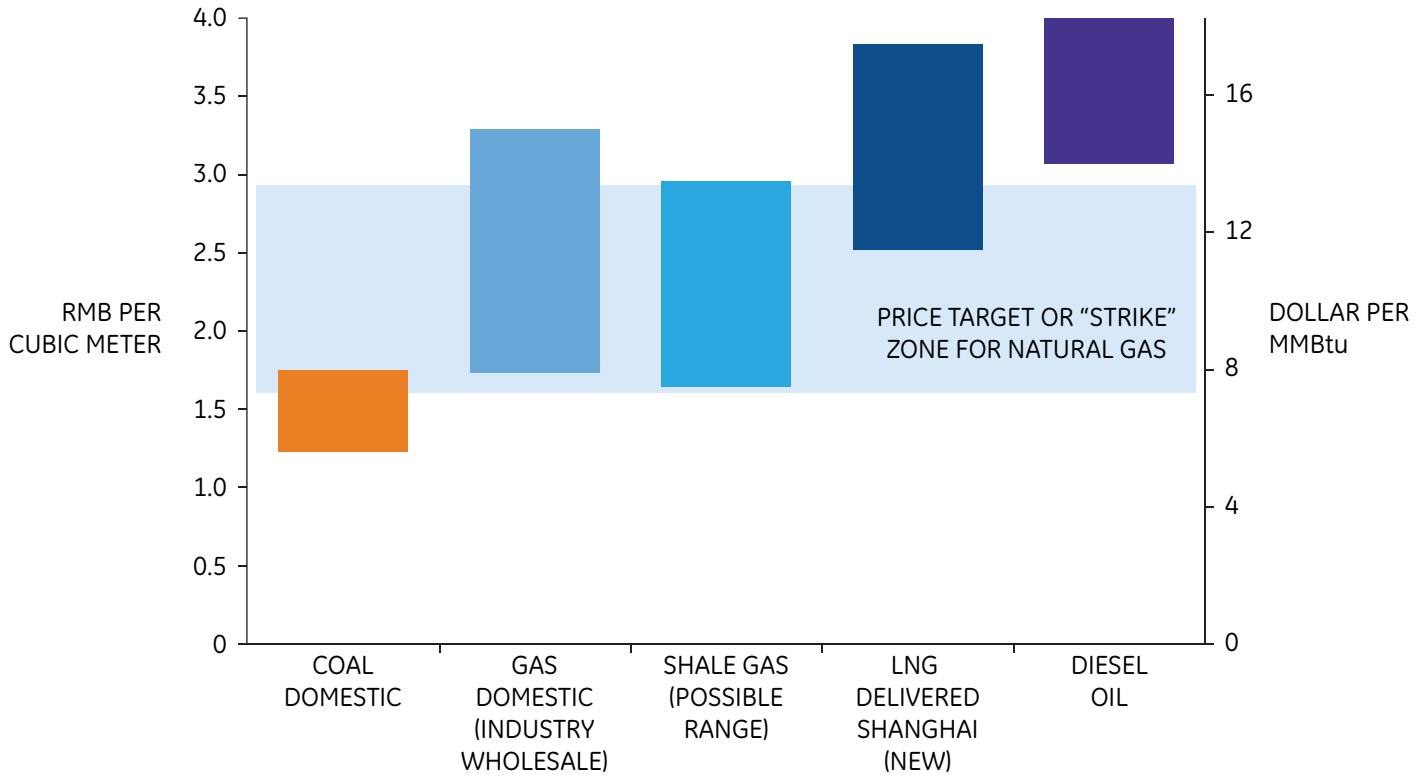
Pricing policies are a fundamental issue driving the pace of gas market growth and network investment. China's government has been working hard to update pricing policies to incentivize infrastructure development while protecting consumers. In June 2013, the National Development and Reform Commission (NDRC) announced further implementation of price reforms. The new policy raised the price of gas to non-residential consumers in the hopes of driving new supply growth, to better align gas prices with the costs of imported supply. Concerns about gas shortages and financial losses on gas sales by China's national oil companies are prompting action.

Average prices at the city-gate for natural gas were raised by 15 percent to about 2.00 per yuan per cubic meter ($9.00 per MMBtu). Prices for incremental demand going into 2014 will be higher as they are based on 85 percent linkage to oil product prices. With oil at $100 per barrel, the price of gas would be about 3.3 yuan per cubic meter ($15.00 per MMBtu). As shown in Figure 5, coal prices are likely going to remain lower than many gas supply options. However, natural gas remains competitive against oil. If gas prices can remain in the target or "strike zone," gas should be competitive enough, given its other benefits, for the industry to grow. A move toward higher gas prices will tend to slow gas demand growth, but aligning the market with the costs of supply will support more resource and infrastructure development.

To grow in the power generation sector, gas prices will need to stay relatively competitive to coal. This may involve targeted subsidies for utilities and simultaneous electricity pricing reforms. The goal is to capture the environmental benefits of gas and recognize the value of natural gas as

Figure 5: Price Competiveness of Natural Gas in China

Source: GE Strategy and Analytics 2013.



a tool to manage variability in electricity loads. Carbon taxes are potentially another way to alter price relationships and capture the benefits of gas. In addition, project developers and utilities should try to reflect the evolution of gas price structures in their planning process to capture the efficiency advantages of large-scale gas generation. Current practice can sometimes undervalue the fuel efficiency of gas technologies by using low fuel prices. This tends to lower the life-cycle value of high efficiency gas plants and heavily weights the upfront capital cost of plants.

There is a window of opportunity for gas to be developed profitably and still compete effectively against coal if it falls within the right competitive price range. Pricing policies will need to evolve with the gas market. Oil-linked pricing is a valuable approach to help secure international gas supplies. Pricing in the domestic market needs to be sensitive to the cost of incremental sources of supply. However, we believe that as international

gas markets mature and gas networks expand, the industry will be increasingly pushed toward a competitive environment with more price convergence. Over time, regional gas prices across Asia will be different because of the underlying cost of supply and transportation, and less because of contractual linkage to oil. Pricing policies in China will need to continue to adapt to changes in the larger market for gas.

Unleash the innovators

Technology innovations have been instrumental in unlocking low cost natural gas in new regions. From a regulatory and policy perspective, fostering an environment for innovation is critical. Early support through tax credits and incentives was instrumental in the success of unconventional gas development in the United States. Continuous improvement in technology and business models will be required in China as well. The early lesson from shale gas developers is that every shale resource is different. Technology and practices need to be adapted to local conditions. From a regulatory and policy perspective, fostering an environment for innovation is critical. Early support through policy shifts and incentives is instrumental in the startup of market development. Beijing's recent experiments on shale gas can be seen as a positive attempt, including financial incentives for shale as well as encouraging more entities to enter the upstream segment.

With the proper supports in place, innovators will be able to focus on acquiring and testing the technology, driving new business models, and getting rewarded for their innovations. This is critical in driving cost down and using market forces to increase efficiency. The government can help open pathways for technology transfer and harmonious partnerships. It is also about finding the opportunities within large national entities to allow experimentation, drive pilot projects, and establish appropriate joint ventures to share risks. The benefit of these efforts will hopefully be more rapid development of valuable domestic resources, at lower cost, and with fewer environmental implications.

Harness the power of networks

Natural gas will only be able to reach its potential if technologies are deployed that can support safe, efficient and reliable operation along

the value chain. Networks become more valuable as they grow. These characteristics facilitate connections with adjacent networks, uncovering hidden opportunities to create value as new links are established. For China this means working to integrate larger mainline networks with smaller distributed gas systems. Gas systems will also become increasingly important to balance variability in growing power grids. Leveraging new digital technologies will be one way to improve integration.

Natural gas and electricity markets will become more connected over time in China. However, integrating networks to create new markets depends on regulatory structure. Uncertain regulation can slow investment, but static regulation that supports entrenched monopolies reduces competition and can slow innovation. Gas networks are natural monopolies and the ability of companies to capture economies of scale tends to reinforce monopoly power. This must be managed through the regulatory process. The challenge will be to drive infrastructure investment, while insuring that new producers and consumers have some ability to access the network.

China has done an excellent job building physical infrastructure. However, focusing separately on gas or power networks is likely to be less efficient than a systems approach. This will require more attention to network regulation, better communication between the industries, and careful analysis of integration costs and benefits. China has a unique opportunity to design new energy systems that increase efficiency, reliability, and reduce transportation costs.

Environmental management

Natural gas development needs to be managed well. If the environmental benefits of burning gas are going to be credited, the industry needs to make sure production and delivery of gas are done in the most safe, efficient, and reliable way possible. This includes issues like well integrity, gas flaring, fugitive emissions, along with water management and disposal. Regulatory practices that can improve emissions monitoring and ensure greater adoption of technologies that can cost-effectively reduce environmental impact, should be pursued.

High population density and poor service infrastructure will make localized environmental solutions important.[25] Limiting truck traffic, reducing noise,

lowering emissions and insuring water quality are critical. For example, small LNG and CNG technologies can be used in remote locations to reduce emissions and provide valuable energy to the field operations. These systems might include pre-treatment, CNG or LNG conversion, storage tanks, and delivery vehicles. Another rising concern is related to water contamination during shale gas operations. Water and other fluids are brought to the surface during the hydraulic fracturing process. This "flowback" water needs to be processed for reuse or disposed of to avoid contamination. There are a variety of filter and processing technologies that can be used to help limit water contamination issues from shale gas.

For unconventional gas operations there will continue to be a learning process as the industry grows. Specifically, this means redefining what is possible in gas operations including: enabling oil substitution, improved water management, reduction of fugitive emissions, and other new concepts for efficiency and electrification. If domestic shale resources are going to become a large part of China's gas supply, attention to environmental issues will be critical.

Build the service systems around the network

Natural gas and power operations are highly specialized. Development of skilled workers to support service businesses connected to the gas industry is an important feature of a mature gas industry. Comprehensive support services are needed to maintain industry growth.

One example comes from shale gas development in the United States. Shale gas wells tend to have high early production rates but decline rapidly. This means a large number of wells must be drilled to maintain production. Shale services include teams that can run drilling rigs, pressure pumping units, water handling and processing systems, sand, chemicals, and drill pipe deliveries. The development of these teams along with core technologies and geologic experience will be critical to expand production of unconventional resources while reducing costs.

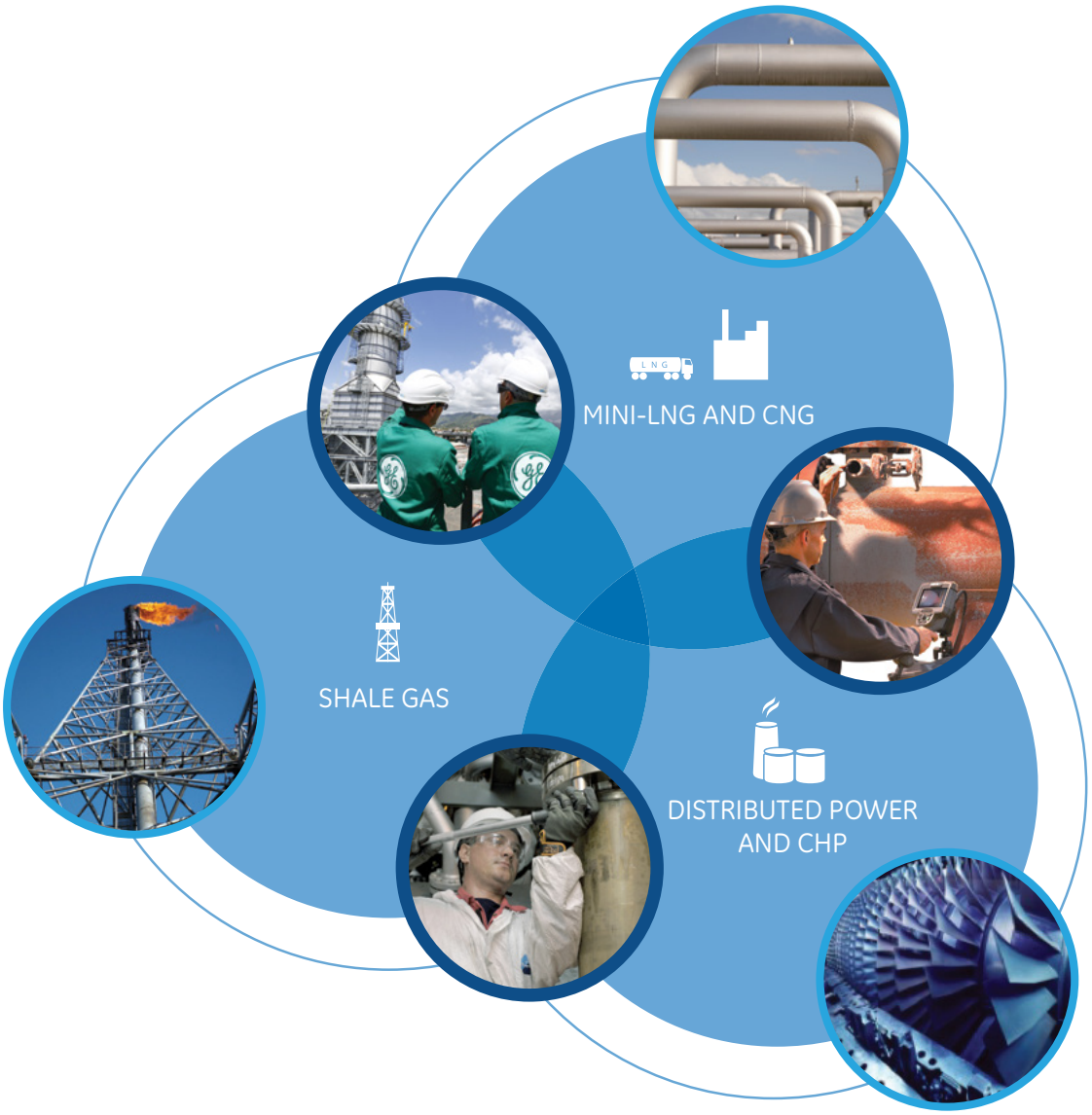
On the consumer side, services for gas-fired distributed power (DECHP) is another example. Distributed power projects using natural gas are relatively new to China. They are smaller than utility scale systems that have their own service options. Instead, DECHP systems can potentially

Figure 6: Building Service Eco Systems

Source: GE Strategy and Analytics 2013.

REQUIREMENTS

EXPERTISE	SERVICES	SCALE OF COMPANIES
TALENT	DESIGN	LARGE
SKILLS	ENGINEERING	SMALL
TOOLS	LOGISTICS	
	MAINTENANCE	



serve a different class of customer including industrial users, hospitals, or airports. These consumers need service support to design, operate, and maintain the small but complex power plant operations. Design is critical to DECHP projects as they integrate power, steam, heat, and sometimes cooling into an integrated design. The advantage of these systems is high fuel efficiency. The challenge is the complexity relative to grid options or simple boilers; and the need for experienced service workers to keep systems running at design efficiency.

There are other examples, like the service systems and skilled workers required for small scale LNG or CNG fuel logistics or offshore support services. Overall, we believe early attention to developing the service eco-systems throughout the gas value chain will help the industry reach its potential.

Conclusion

Many elements are coming together to create the opportunity for a much more significant role for gas, with valuable contributions to national competitiveness, sustainability, and energy system resilience. China's gas supplies are increasing from a variety of sources, both domestic and international. At the same time, the need to diversify energy sources to reduce negative impact from coal use has never been greater. China's Age of Gas is a reflection of how much progress has been made over the last decade, shows the potential for gas to be an important resource for the next phase of China's energy strategy.

With continued focus from China's government and its business leaders, natural gas has a bright future. Innovations in technology and business models will bring changes to China's energy system and offer solutions to the current energy challenges. Our goal is to continue to push the boundaries of thinking on what is possible. China's Age of Gas may be more transformational than anyone can predict today.


SAFETY

ACKNOWLEDGMENTS

Our thanks go to GE colleagues and the many external experts who have contributed to the development of China's Age of Gas paper. We would like to acknowledge, in particular, Peter Evans and Henry Shen for their efforts and insight on the future of China's gas market.

Endnotes

1. Peter C. Evans and Michael F. Farina, "Age of Gas and the Power of Networks," October 2013. The white paper surveys the global gas industry and the factors that could drive natural gas to be the dominant hydrocarbon of the next two decades.

2. Flaring is the practice of burning off excess gas in oil and gas fields if no viable options exist to cost-effectively move gas to market. See Michael F. Farina, "GE Flare Gas Reduction," January 2011, for a detailed discussion of the gas flaring issue and technology solutions available. Accessed at GE Reports http://www.genewscenter.com/ImageLibrary/detail.aspx?MediaDetailsID=3691.

3. For example, in the Tarim basin, the Kela-2 gas field, found in 1997, has the proven reserve of approx. 285 Bcm. In recent years, the production capacity of Kela-2 gas field reached 12 Bcm. The discovery in Kela-2 gas fields supported the construction of West to East Line I.

4. Some analyses include combined heat and power (CHP) in industrial demand. GE's power sector classification Includes utility and independent power generation as well as some industrial CHP and electricity sector use. Our gas demand for power estimates are based on this wider definition of the power sector, which may create differences with other sector forecasts.

5. These statistics are based on International Energy Agency (IEA) world energy balance data for 2010.

6. Based on IEA 2005 and 2010 China energy balances in million tons oil equivalent and China's GDP based on real 2005 Purchasing Power Parity US dollar data.

7. Li Xing and Chen Junqi, *Cornerstone Magazine: World Coal Association*, "Pollution Control of Coal-Fired Power Generation in China: An Interview with Wang Zhixuan," Jul 30, 2013. Accessed at http://cornerstonemag.net/pollution-control-of-coal-fired-power-generation-in-china-an-interview-with-wang-zhixuan/

8. National Development and Reform Commission (NDRC), "Guidance for distributed combined heat and power (DECHP) development in China," 2011.

9. Id. Li Xing and Chen Junqi, 2013.

10. Lung cancer has become the most common form of cancer in China, accounting for more than 30 percent of cancer deaths in 2012. Some believe cigarette smoking is the main reason for lung cancer. However in the last decades, the smoking rate didn't change significantly, but the prevalence of lung cancer has doubled. For more on air pollution and cancer see the Guardian UK,

"Air pollution linked to higher risk of lung cancer and heart failure," July 10, 2013. Accessed at www.theguardian.com/society/2013/jul/10/air-pollution-lung-cancer-heart-failure and Reuters in Beijing, "China vows to tackle air pollution," Sept. 12, 2013. Accessed at www.theguardian.com/world/2013/sep/12/china-vows-tackle-air-pollution.

11. The impact on health is difficult to assess. PM 2.5 emissions are thought to be a key factor impacting health. Based on the China and Community Multiscale Air Quality Model (which was developed by US EPA), the highest PM 2.5 emissions areas are along coastal China, including Jiansu, Zhejiang and Guangdong. Health results come from the BenMAP model, developed by the US EPA and Tsinghua University. The model uses concentration-response functions to map emissions concentrations to health outcomes. It then uses an impact cost methodology based on potential loss of per capita GDP from early deaths and an estimate of the cost of health care services to treat health degradation. See, "Energy Options and Health Benefits: China Case Study," Department of Environmental Science and Engineering Tsinghua University, School of Public Health Peking University, March 27, 2008, pg. 95-97 for discussion on model methodology.

12. Dr. Wei Xuehao and Zhou Hao, "Evaluating the Environmental Value Schedule of Pollutants Mitigated in China Thermal Power Industry," 2003. The analysis calculated an environmental cost coefficient for quick evaluation of coal costs. Crop losses were calculated based on "Guideline for Chinese Environmental and Economic Accounting," an official guide to evaluating the environmental loss. Estimates based on the assumption that 40 percent of SO_2 and NO_x are discharged by coal-fired power plants.

13. Morgan Stanley Asian Research, "China's Air Pollution," August 15, 2013.

14. China 12th Five Year Plan, 2011-2015 binding targets.

15. Id. Morgan Stanley, "China's Air Pollution."

16. Based on GE analysis derived from IHS-CERA, IEA, Barclays, and the BP Statistical report.

17. Daniel Yergin, "Ensuring Energy Security," *Foreign Affairs*. Volume 85 No. 2. April 2006. This statement was made to support the shift from coal to oil in the Royal Navy.

18. A rich literature has emerged in recent years concerning the concept of resilience. See, for example: Louise K. Comfort, et al, eds, "Designing Resilience: Preparing for Extreme Events," University of Pittsburgh Press, Pittsburgh, 2010; Fikret Berkes, "Understanding Uncertainty and Reducing Vulnerability: Lessons from Resilience Thinking," *Natural Hazards,* Vol. 41, 2007, pp. 283-295; and, Rolf Pendall, et. al, "Resilience and Regions: Building Understanding of the Metaphor," *Cambridge Journal of Regions, Economy and Society,* Vol. 3, 2010, pp. 71-84.

19. Hernandez, Vittorio, *All Headline News,* (2008-02-01). "Three-Week Massive Snow Storm Costs Chinese Economy $7.5 Billion" January 2, 2008. Jian, Yang & Chen, Lydia, *The Shanghai Daily,* "Crisis in Chenzhou – No power or water," January 31, 2008.

20. For the Age of Gas outlook, economic growth in China, in real 2005 U.S. dollars on purchasing power parity basis, remains in the 7 to 9 percent range over the forecast period to 2025. Electricity intensity of GDP is assumed to fall by about 1.8 percent per year.

21. In the latest energy development five-year plan for 2011-2015, government expects to decrease the energy consumption per unit of GDP by 16 percent. Current plans are to increase natural gas to 7.5

percent of primary energy by 2015. New government primary energy targets for gas to 2020 are expected to be in the range of 10 percent. The Age of Gas outlook only reaches 6 percent by 2015 and 7.5 percent by 2020 reflecting the challenge of reaching those targets so quickly, but also the potential for faster growth if government policies align toward gas development.

22. GE's Age of Gas outlook is part of a global integrated energy outlook and is benchmarked to energy balance statistics from the International Energy Agency (IEA), the US Energy Information Administration (EIA), the BP annual statistical report, along with data from the China statistical yearbook. The differences in data combined from various sources may result in minor differences from official China government statistics.

23. Based on the change in estimated total primary energy supply in million tons oil equivalent divided by GDP in real 2005 PPP dollars between 2012 and 2025.

24. Based on data in the BP Statistical Report 2013.

25. Spegele, B. and Scheck, J. "Energy-Hungry China Struggles to Join Shale-Gas Revolution," *The Wall Street Journal*, Sept. 5, 2013.