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China's Elusive Shale Gas Boom

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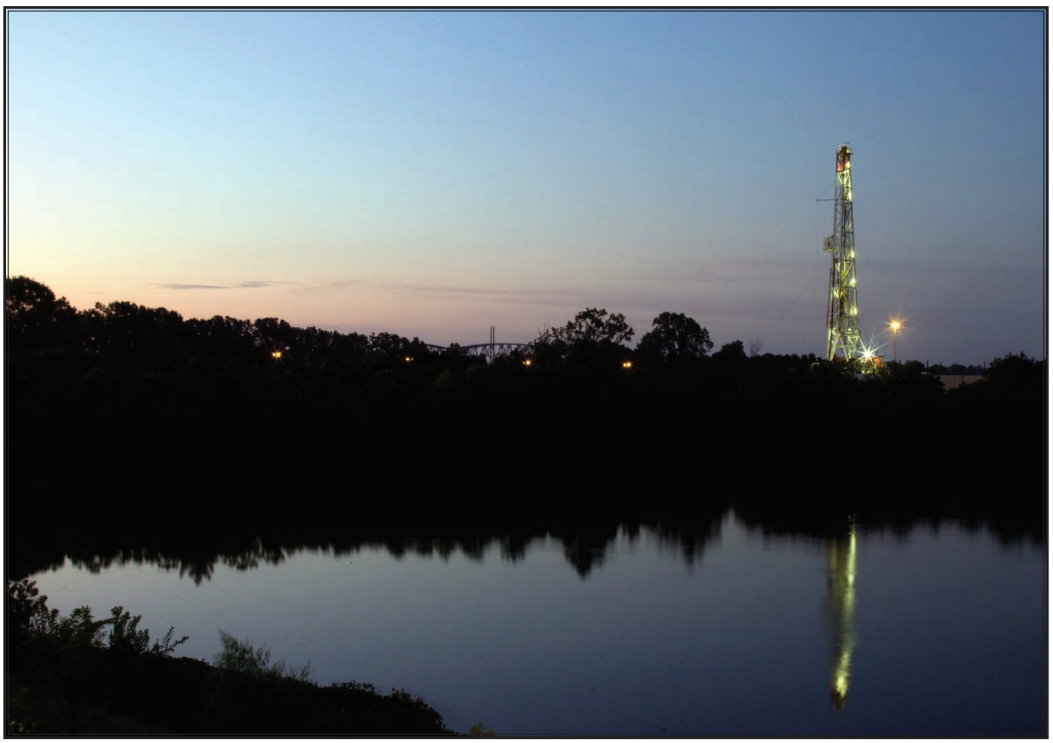

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Zhongmin Wang is a Fellow at Resources for the Future (RFF). His research focuses primarily on energy economics and policy in the United States and China. His recent work has studied the history, market structure, and impact of the shale gas industry in the United States and compared the shale gas situation in China with the US experience. Other recent work on China covers areas such as green growth, carbon cap and trade, housing, and transportation. His work has appeared in the *Journal of Political Economy*. Prior to joining to RFF in September 2012, he was assistant professor of economics at Northeastern University, Boston and Monash University, Melbourne, Australia, and a lecturer at China University of Petroleum, Beijing. He holds a PhD in economics from Georgetown University and a BS and MA in management from China University of Petroleum.

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Introduction

China's natural gas market is expected to see robust growth over the next decade. This is a function of several factors. First, as part of the country's effort to effect an energy transition to cleaner fuels, natural gas is viewed as a viable bridge fuel. Second, China's natural gas consumption is significantly below the global average, implying a potential for tremendous growth. Finally, several economic drivers seem to favor increasing consumption of gas, not least of which is China's emphasis on urbanization in supporting future growth.

A centerpiece of China's natural gas strategy is to develop its ample shale gas reserves, a topic of much discussion both inside and outside China. With the largest technically recoverable shale reserves in the world, China desires to replicate the US shale gas boom. This desire is reflected in Beijing's plan, unveiled in March 2012, for the country to achieve a highly ambitious shale gas production target of 60-100 billion cubic meters (bcm) by 2020.

Consequently, Beijing has adopted a number of policies to promote and support shale gas development. By late 2014, however, the State Council had already cut China's 2020 shale gas production goal to just "over 30 bcm." The dramatic reduction of the official target reflects an acknowledgement that China faces great obstacles in exploiting its shale gas resources.

At the same time, debate persists over whether it is even in China's best interest to prioritize shale gas over the development of conventional and other types of unconventional gas. China's conventional natural gas production is still growing, and the country has large reserves of tight gas and coal-bed methane (CBM).[1] Moreover, China's national oil companies (NOCs) have mature technologies for getting these types of unconventional gas out of the ground. Even the China National Petroleum Corporation (CNPC), the country's largest onshore oil and gas producer, has publicly argued that it makes more sense to emphasize tight gas and CBM over shale.[2]

While acknowledging the debate, this paper focuses specifically on China's shale gas development and the prospects ahead should China decide to proceed toward its stated targets. It discusses China's fundamental challenge in developing shale resources, summarizes the policies that the Chinese government has taken in this effort, and concludes with thoughts on how China might be able to overcome its challenges.

The Fundamental Challenge

Conceptually, it is useful to separate shale gas development into two stages. The first, or the innovation stage, is the development of cost-effective extraction technologies, which can only be achieved through "learning by doing" and technology innovation. Once technologies are proven cost-effective, shale gas development enters the second, scaling-up stage, which involves significantly ramping up output. Continued technology improvements in the second stage help improve profitability and expand development into new plays.

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The first stage is much more challenging than the second. Once drilling in a shale gas play has proven profitable, further capital investment in exploration and development in it or similar plays is easy to attract, particularly if shale gas drilling activity remains open to profit-seeking investors.

China, however, is still in the first stage, in which the fundamental challenge is to lower the cost of extraction through innovation so that firms may find it profitable to drill shale gas wells. That is because, at this point, drilling shale gas wells is simply not a profitable enterprise in China.

To illustrate, take the case of China's two largest shale gas players, China Petrochemical Corporation (Sinopec) and CNPC. By late 2013, Sinopec had reportedly invested a total of $370 million in shale gas development, while CNPC had invested a total of $640 million, or over $1 billion combined.[3] However, that same year Sinopec had produced a total of only 2.58 billion cubic feet (bcf) of commercial shale gas and CNPC a total of 2.47 bcf.[4]

Since the wellhead natural gas price is about $9.06/thousand cubic feet (mcf) in Sichuan[5]—where the majority of shale wells are being drilled—and the Chinese government's subsidy for shale gas is $1.81/mcf, a generous estimate of the two NOCs' total revenue from shale gas production puts it at just $54.4 million. This implies that the two companies' short-term losses by late 2013 were close to $1 billion.

Why is it not profitable at present to drill shale gas wells in China? The simple reason is high production costs. By definition, profit is the difference between revenue and cost, and revenue equals price multiplied by quantity. Even if shale gas could command a price of $15/mcf, the two NOCs' revenue would be merely $75.7 million, so their losses would still be close to $1 billion. Various reports suggest that the cost of drilling a shale gas well in the Sichuan Basin is about three to four times the $3 million it costs to drill a similar well in the United States.[6]

Tough Earth

So why does it cost so much to drill a shale gas well in China? The two primary reasons are the lack of learning by doing and economies of scale and more complex geologies.

For one, only a small number of shale gas wells have been drilled in China—about sixty as of the end of 2013, all of which were done by CNPC and Sinopec. This small number of wells affects the cost of development in several ways.

First, it implies that the two NOCs have not had enough experience to learn how to improve technology and lower drilling and hydraulic fracturing cost. Second, the large fixed costs required for drilling (e.g., the cost to assess the resource base and to understand the geology of the targeted reservoir, and the cost to build infrastructure such as roads and pipelines) are not spread over a huge number of wells, which means cost per well is higher than it otherwise would be. Third, drilling and fracturing machinery may not be fully utilized.

Another reason for the high cost in China is the difficult geology. The geology of shale gas resources in China, according to engineers inside and outside China, is considerably less favorable than it is in North America.[7] According to the Energy Information Administration (EIA), "most Chinese shale basins are tectonically complex with numerous faults—some seismically active—which is not conducive to shale development."[8]

The geology of shale gas resources in China, according to engineers inside and outside China, is considerably less favorable than it is in North America.

The EIA report further notes that the southwestern quadrant of the Sichuan Basin—accounting for just over 50 percent of China's shale gas reserves—is the most promising shale play in China due to its relatively favorable geology, water resources, existing pipelines, and access to major urban markets. However, its "considerable structural complexity, with extensive folding and faulting, appears to be a significant risk for shale development," according to PetroChina engineers

quoted in the report. In another report, the same authors reinforced the point that the Sichuan Basin has "significant geological challenges, such as numerous faults (some active), often steep dips, high tectonic stress, slow drilling in hard formations, and high H2S and CO2 in places."[9]

The difficult geology renders the existing technologies more costly, even if using some of the best available technologies. CNPC and Sinopec may not have the world's leading technology, but they are capable of horizontal drilling and hydraulic fracturing since they have been successfully drilling tight gas wells for many years. Even for Shell, which has a production-sharing contract with CNPC and presumably has access to the best technologies in the world, several years of drilling wells in the Sichuan Basin has not yielded much success.

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This suggests the complex geology appears to be a major hindrance. While Shell's drilling and testing indicated good resource potential, there are "significant fault-related problems, such as frequent drilling out of zone and resulting doglegs that complicated well completion."[10]

In addition to geology, water scarcity may make the cost of drilling prohibitive in certain areas where potential shale gas plays exist. Current hydraulic fracturing technologies require large amounts of water, so it isn't a coincidence that China has initially focused on the Sichuan Basin where water resources are more abundant. However, the Tarim Basin in Xinjiang province, where China's second-largest shale gas play is located, faces severe water scarcity.

"Over 95 percent of the Tarim play is subject to extremely high baseline water stress or arid conditions, including areas with extremely high groundwater stress and seasonal variability. Collectively, these conditions will pose major challenges for companies to access water," according to the World Resources Institute.[11]

If the geology (and depth) of the shale gas resources in the Sichuan Basin were very similar to that of the major shale gas plays in the United States, there would be little doubt that firms would have great incentives to drill wells in that area. As noted above, firms can receive $11/mcf for shale gas in the Sichuan area, after the government subsidy is taken into

account. In comparison, US natural gas prices have hovered around $4/mcf recently, but firms are still profitable drilling shale gas wells in the United States.

To be sure, China's lack of infrastructure, the rough terrain, and the need to transfer technology from the United States are all factors that can lead to incremental increases in production cost. But those costs can be calculated quite precisely and can surely be lowered to below $7/mcf fairly quickly.

Nonetheless, the tougher geology and other suboptimal conditions mean that China will continue to face difficulties in lowering costs in the near term. Leveraging economies of scale (by drilling thousands of wells) and continued innovations can lower costs. But they require large initial capital costs and sustained investment in innovation. Given the considerable uncertainty over whether and when firms would be profitable in drilling their shale plays, firms are likely to remain hesitant to invest generously in drilling wells.

Current Shale Gas Policies in China

These uncertainties, however, have not prevented the Chinese government from taking an active role in planning and supporting the development of shale gas. In March 2012, four government agencies jointly issued the "12th Five-Year Plan for Shale Gas Development." In October 2013, the National Energy Administration (NEA) introduced a shale gas industrial policy document that declared shale gas development to be a new national strategic industry.

The broad policy package included fiscal and research and development (R&D) funding support to promote shale gas development, opening up the sector to new entrants, and reforming natural gas pricing and pipeline transport. Each of these baskets is briefly discussed below.

Opening shale gas development to new entrants will be important if China is to galvanize more competition.

Allowing New Entrants

First, some context is needed, which merits a brief summary of China's oil and gas industry. Three vertically integrated NOCs—CNPC, Sinopec, and China National Offshore Oil Corporation (CNOOC)—essentially control the production, service, and transportation sectors of China's oil and gas industry. The three NOCs are majority-owned by the Chinese state and their top executives are directly appointed by the central government. These executives wear dual hats and respond to both commercial and political incentives.

The Chinese state, represented by the central government, owns oil and gas mineral rights. Land rights are separate from mineral rights and belong to the state in the case of urban areas but are collectively owned in the case of rural and suburban areas. Chinese policies on oil and gas mineral rights require the NOCs to register their blocks of oil/gas resources with the Ministry of Land and Natural Resources (MLR) and cede their control if they do not make investments in a timely matter. However, this latter requirement has not been enforced.

Nearly 80 percent of the prospective shale gas reserves with the highest potential overlap with conventional oil and gas reserves, and the exploration rights to the overlapping areas have been granted to the NOCs. The control of these production blocks in the hands of the NOCs means the sector naturally keeps out new entrants, making the sector much less

competitive than it is in the United States, where shale development originated with wildcat entrepreneurs willing to take on risks.

Even CNOOC, the smallest of the three and historically focused on offshore production, has a hard time competing with CNPC and Sinopec in shale plays. Therefore, opening shale gas development to new entrants will be important if China is to galvanize more competition. In fact, the effort to do so has been one of the most visible policy initiatives from Beijing. As a first step in implementing this policy, MLR tendered its first round of shale gas block auctions in June 2011. Six firms—the three NOCs, a provincial oil company, and two state-owned CBM firms—were invited to submit bids on four shale gas blocks. In the end, Sinopec and one of the CBM firms each won a block.

The second step was the State Council's approval of shale gas as a new type of mineral in December 2011. On the one hand, this step allows the NOCs to keep their control over conventional oil and gas resources; on the other, it allows MLR to open shale gas development to new entrants, including privately owned firms.

The third major step was a second round of auctions that MLR conducted in September 2012. That round included a total of 20 shale blocks that do not overlap with conventional oil and gas resources. While it is widely acknowledged that most of the acreage that was being auctioned have worse geology and infrastructure than those already belonging to the NOCs, that round of auctions was open to essentially all domestic firms (and international firms that are majority-controlled by domestic firms) with a registered capital of at least 300 million yuan ($50 million). In early December, MLR announced that a total of 16 firms, out of 83 firms that submitted bids, won 19 of the 20 blocks.

The bidding results were somewhat peculiar, however. First, the NOCs did not win any of the blocks, and none of the auction winners had any experience in oil and gas exploration and development. Some of the winning firms are in the business of power generation, some are energy investment firms, and some were established just a few months before the auction. Second, the winning firms' promised investment amount is, on average, 670 million yuan ($110 million) per block, which is far above the minimum requirement of 90 million yuan ($15 million) per block.[12]

Fiscal Incentives

In November 2012, China's Ministry of Finance (MoF) and NEA jointly announced a fiscal subsidy of $1.81/mcf for shale gas production, effective from 2013 to 2015. The definition for shale gas in the subsidy notice

appears to be narrow. According to an MLR official, only 5 to 7 trillion cubic meters (tcm) of the 25 tcm of shale gas reserves MLR estimated for China satisfies the shale gas definition.[13] The duration of the subsidy period is short, but the notice mentioned that the government may extend the subsidy beyond 2015, depending on the status of development.

Additional fiscal support was contained in the NEA's shale gas industrial policy document. First, two types of mineral resource fees are to be reduced or exempt for shale gas development. Second, tariffs are to be waived for importing equipment that cannot be domestically produced. Third, further tax incentives are to be studied.

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However, there appears to be inter-agency disagreement over the extent of fiscal support for shale gas. The finance ministry reportedly holds the opinion that the existing fiscal policies already satisfy the need for shale gas development in China, and that it will not offer more favorable fiscal policies.[14]

R&D

The five-year shale gas plan touches on broad R&D policies but fails to include concrete details. It states that the government aims to increase the funding for investigating and evaluating shale gas resources in China and that a research program on critical shale gas technologies is to be established as a major national science and technology project. It further states that the government aims to strengthen the development of the national shale gas R&D center and other major shale gas laboratories and to establish shale gas demonstration areas. The shale gas R&D center was established in 2010 and is part of the Research Institute of Petroleum Exploration and Development, which is a research arm of CNPC.

Some of these are not entirely new. The Chinese government had already supported several large shale gas R&D projects through its "National Basic Research Program (973 Program)" and other major science and technology funding schemes. In fact, much of the language on R&D appeared in NEA's "National Energy Technology 12th Five-Year Plan" issued in December 2011.

The lack of details likely reflects the fact that most of the R&D will come from the NOCs, since they essentially monopolize oil/gas exploration and production. It also suggests R&D spending will be primarily shouldered within these firms rather than explicitly from central coffers. The bottom line is that Beijing is pushing the firms to adopt the most advanced technologies.

Gas Pricing

The Chinese government has long set the price of conventional natural gas and tight gas at levels below the equilibrium market price. The domestic natural gas price is also lower than its imported price. As a result, natural gas shortages often occur. In light of these problems, China has started to reform its natural gas pricing policies. Under the new pricing system that the National Development and Reform Commission (NDRC) announced in June 2013, province-specific city-gate price caps are linked to the import price of two types of substitute fuels (fuel oil and liquefied petroleum gas)—essentially moving to an oil-linked pricing system for natural gas.

However, this pricing scheme applies only to incremental volume consumption (as opposed to existing volume consumption) and for non-residential users only. This interim pricing scheme is still quite far from the ultimate goal of establishing a system in which the market determines all natural gas wellhead prices and only the price of pipeline transportation is regulated by the government.

Still, this represents a step forward, as the wellhead price of shale gas has been deregulated, even as city-gate gas price may still be subject to a price cap, depending on how the gas is sold and transported.

Pipelines

Inadequate natural gas pipeline infrastructure and the lack of an open access policy to existing pipelines are often cited as a hindrance to shale gas development. This is in part because the NOCs own and operate virtually all of China's major pipelines.

In February 2014, NDRC issued a new policy on the development and operations of natural gas infrastructure that requires pipeline operators to maintain independent accounting and to provide unused pipeline capacity to new customers on a fair and nondiscriminatory basis. This is a limited open access policy—new customers only have open access to those capacities that are currently not being used by existing customers and pipeline operators.

Whither China's Shale Boom?

Putting aside the debate over whether it is economically justified to prioritize China's shale gas over conventional natural gas and tight gas, we conclude with a brief assessment of whether Beijing's policies can spur the shale boom that it intends to achieve. The assessment presumes that *it is* justified to emphasize the development of shale gas resources.

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Some of the policies described above—subsidy, pricing incentives, and R&D policies—aim to make shale gas production a more attractive proposition to firms by helping to boost their revenue or enhance existing technology. Other policies—reforming natural gas pricing and opening access to pipelines—aim to boost the natural gas market in general. These policies reinforce each other in principle and appear justified on economic grounds.

For instance, fiscal subsidies and R&D support can be justified on the grounds that shale gas development has social and economic benefits (by replacing the use of coal). Market pricing reforms and open access to pipelines can reduce distortions and improve efficiencies. It is worth noting that the US federal government used these very policies from the late 1970s to the early 1990s to promote its own natural gas sector.

Opening shale gas development to new entrants is a major policy initiative. It is a policy intended to break the oligopolistic nature of the NOCs and introduce more competition into shale gas development. This policy is certainly consistent with the Chinese government's goal of letting the market play a decisive role in resource allocation.

It allows new entrants to start to acquire oil and gas exploration and development experience and expertise, which will benefit the potential scaling up of China's shale gas industry down the road. Any investment in exploration by these firms will also help China better assess its shale gas resources.

However, this is an initial step, and one that cannot contribute much to overcoming the fundamental challenge on its own—lowering costs through learning by doing and innovation.

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Despite winning the second round of auctions, the new entrants have little incentive to make the investments they promised, simply because they cannot avoid the fate of incurring hefty losses in the near term.

The new entrants have no experience in oil and gas drilling, and the shale gas blocks they won have less favorable geology and infrastructure than the blocks awarded to CNPC and Sinopec. It is unrealistic to expect firms without any prior experience in even conventional oil and gas drilling to dive into developing shale gas reservoirs with unfavorable geology.

Indeed, by the end of September 2013, reportedly only 14.2 percent of the planned two-dimensional seismic survey on the blocks awarded during the second round had been finished, and drilling essentially had not yet started.[15] Because of the slow progress made by the auction winners, the third round of auctions has been delayed.

The US Experience

It is useful to compare these new entrants to a pioneering US firm, Mitchell Energy & Development (hereafter "Mitchell Energy"), a medium-sized firm that is usually credited with making initial investments in shale gas drilling and playing a critical role in creating the industry in the United States.

Unlike the new Chinese entrants, Mitchell Energy had the long-term need to seek a new source of natural gas to fulfill its contractual obligations, and it enjoyed many advantages that allowed it to minimize financial losses and to eventually obtain high returns on its early investments.

For one, Mitchell Energy had an excellent team of geologists and engineers and state-of-the-art expertise in fracturing tight gas. The company began drilling in an area with favorable shale geology and with multiple layers of natural gas reservoirs so that it had the option of completing the well to conventional natural gas reservoirs if the shale reservoir turned out to be unproductive.

The company also had access to a mechanism through which it could eventually obtain large returns from its investment. It leased large tracts of land and the associated mineral rights at low prices early on and later sold the land and the firm itself at a much higher price. This mechanism—made possible by the private land and mineral rights ownership system in the United States—helped to overcome the difficulty of monetizing technology innovations in the oil and gas industry.

Different Incentives and Vested Interests

Even if the Chinese government decides to auction off some of the shale gas blocks with the most

favorable geology, it is doubtful that the new entrants would make large investments in drilling shale gas wells in the short run.

Unlike the shale gas blocks auctioned in the second round, most of the shale blocks with favorable geology overlap with conventional oil and gas reservoirs. If the new entrants win such blocks, they should be allowed to drill into the overlapping conventional oil and gas reservoir. It is economically inefficient to prohibit new entrants from drilling into the conventional oil and gas reservoir, and it is difficult to enforce a policy that does not allow new entrants to drill into conventional oil and gas reservoirs.

It appears that China's best hope for overcoming the fundamental challenge in shale gas development lies with its NOCs.

The irony is that after winning such shale gas blocks, the new entrants would be more incentivized to first develop conventional oil and gas resources and delay drilling into shale gas reservoirs. It is much more profitable and less risky to develop conventional oil and gas reservoirs than shale because the available technologies are cost effective for developing the former but not yet for the latter. This implies that the development of China's conventional oil and gas resources (including tight gas) would accelerate if Beijing allows new entrants to develop them and lets oil and gas prices be determined by the market.

However, it is difficult for the Chinese government to open the development of conventional oil and gas resources to new entrants on a large scale. Such a policy would greatly affect the interests and operations of the NOCs, who are expected to lobby strongly against such a policy. For example, they may argue that the below-market natural gas prices discouraged them from making more investments in developing conventional natural gas and tight gas. They may also point out that they assume many social responsibilities (e.g., keeping redundant workers) that make them appear inefficient.

Encouraging Private Firms

It is even more politically difficult for China to implement policies that can encourage new entrants, especially privately owned firms, to undertake large and risky investments in shale gas. Private firms will expect reasonably high returns for their investments, but that may prove quite challenging in the Chinese context.

Take the US experience again as an example. Suppose one of the new entrants succeeded in improving technology and lowering cost after making a large initial investment in shale gas drilling. How does it then monetize its innovations?

In the United States, independent oil and gas firms, such as Mitchell Energy, did not monetize their innovations by selling their new technologies because few such technologies are patentable and it is difficult to keep them secret (since operators and service firms work together).

Instead, these US firms largely obtained returns for their risky bets via leasing land and the associated mineral rights at low prices: investing in drilling and innovations would subsequently make the land appreciate in value. The financial reward from selling land as a valuable asset was incentive enough to encourage independent oil and gas firms in the United States to take big risks.

In China, there is little to no chance that the government will allow private ownership of land and mineral rights.

In China, however, there is little to no chance that the government will allow private ownership of land and mineral rights. Therefore, a plausible way for a private firm to obtain returns from its investment is for the government to allow this firm to have control over a large amount of land and mineral rights. However, it is politically very difficult for China to auction off large amounts of oil and gas resources to private firms so that their owners, rather than the state, can have the chance to realize greater financial returns.

NOCs To The Rescue?

Given these considerations, then, it appears that China's best hope for overcoming the fundamental challenge in shale gas development lies with its NOCs. They enjoy huge advantages over the new entrants in terms of technology, experience, financial resources, and policy.

CNPC and Sinopec have significant experience in developing tight gas, which allowed them to acquire certain advanced technologies in horizontal drilling and hydraulic fracturing. An important but rarely noticed fact is that the production of tight gas in the United States experienced significant increases before the shale gas boom occurred. Given that China's NOCs already have the experience and technologies to develop the abundant reserves of tight gas, it seems a natural and promising area for Beijing to focus on.

Meanwhile, the "Big Two" have already invested billions of dollars in acquiring shale gas assets in North America, even though it is not clear the extent to which these acquisitions have ultimately helped them obtain the best technologies.

What's more, these two NOCs have been drilling in shale gas blocks with the most favorable geology and

infrastructure in China, and they have established national demonstration areas. (CNPC has two demonstration projects and has been cooperating with Shell on another. Sinopec has one demonstration area where it announced in March 2014 that it had made major breakthroughs.)

Under the assumption that it is justified to prioritize and support the development of shale gas, the key question remains how best to motivate the NOCs to invest in shale gas drilling. One potential way to incentivize the NOCs may involve incorporating shale gas investment into the important evaluation criterion of the top NOC executives. Competition between government officials and the associated cadre evaluation system are considered by many scholars as a major driver behind China's rapid economic development.[16]

By increasing such political incentives, the NOCs could be motivated to make riskier investments in shale gas drilling while paying less attention to the economics of such investments. Yet trumpeting political incentives with no regard to economics is unlikely to be good policy either, since it will likely require more subsidies from the government to cover NOC losses.

The smothering smog in many Chinese cities is a daily reminder to policymakers in Beijing that there is an urgent need to replace the use of coal with natural gas. Unfortunately, it does not seem that a shale gas boom would materialize soon in China. Technologies must become more cost effective, a process that requires strong incentives and considerable time.

Endnotes

[1] China's risked, technically recoverable tight gas reserve is 8 to 11 trillion cubic meters (tcm), and its proven tight gas reserve is 3.3 tcm, about 39 percent of China's overall proven natural gas reserve. See Li, J., B. Guo, M. Zhen, and T. Yang. 2012. "Main Types, Geological Features and Resource Potential of Tight Sandstone Gas in China," *Natural Gas Geoscience* 23(4): 607–15.

[2] In his speech at the 25th World Gas Conference in Malaysia on June 7, 2012, Chairman of CNPC Zhou Jiping stated, "In the near term, CNPC will still prioritize conventional gas exploration and development," but that "we are actively exploring and developing tight gas, CBM and shale gas in different stages. As for tight gas, we have found a large reserve base and owned mature development technologies, and we are now achieving a rapid increase of production. Regarding CBM, the resource distribution is already known and the technologies are basically mature, so we are well positioned to realize sizable increase of output." See Zhou, J., 2012. "The Rapidly Growing World and Chinese Natural Gas Markets," speech at the 25th World Gas Conference, Kuala Lumpur, Malaysia, June 7, 2012, accessed from http://www.cnpc.com.cn/en/press/speeches/The_Rapidly_Growing_World_and_Chinese_Natural_Gas_Markets.shtml?COLLCC=515792860&.

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[8] Ibid.

[9] Stevens, S., Moodhe, K., and Kuuskraa, V., 2013. "China Shale Gas and Shale Oil Resource Evaluation and Technical Challenges," Society of Petroleum Engineers (SPE) report 165832.

[10] Ibid.

[11] Reig, P., T. Lou, and J. Proctor. 2014, "Global Shale Gas Development: Water Availability & Business Risks," Washington, DC: World Resources Institute, accessed from http://www.wri.org/publication/global-shale-gas-development-water-availability-business-risks.

[12] Tian, T., B. Li., "Development Status of the Winning Firms in the Second Round of Shale Gas Auction," *China5e*, July 17, 2013, accessed from http://www.china5e.com/news/news-840453-1.html.

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About The Paulson Institute

The Paulson Institute, an independent center located at the University of Chicago, is a non-partisan institution that promotes sustainable economic growth and a cleaner environment around the world. Established in 2011 by Henry M. Paulson, Jr., former US Secretary of the Treasury and chairman and chief executive of Goldman Sachs, the Institute is committed to the principle that today's most pressing economic and environmental challenges can be solved only if leading countries work in complementary ways.

For this reason, the Institute's initial focus is the United States and China—the world's largest economies, energy consumers, and carbon emitters. Major economic and environmental challenges can be dealt with more efficiently and effectively if the United States and China work in tandem.

Our Objectives

Specifically, The Paulson Institute fosters international engagement to achieve three objectives:

- To increase economic activity—including Chinese investment in the United States—that leads to the creation of jobs.
- To support urban growth, including the promotion of better environmental policies.
- To encourage responsible executive leadership and best business practices on issues of international concern.

Our Programs

The Institute's programs foster engagement among government policymakers, corporate executives, and leading international experts on economics, business, energy, and the environment. We are both a think and "do" tank that facilitates the sharing of real-world experiences and the implementation of practical solutions.

Institute programs and initiatives are focused in five areas: sustainable urbanization, cross-border investment, climate change and air quality, conservation, and economic policy research and outreach. The Institute also provides fellowships for students at the University of Chicago and works with the university to provide a platform for distinguished thinkers from around the world to convey their ideas.

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