This draft includes preliminary research, analysis and recommendations. It is being distributed now to stimulate discussion and feedback. Please send your comments and ideas directly to me at sforbes@wri.org.

The United States and China: Moving toward Responsible Shale Gas Development

Sarah M. Forbes

September 2013

Introduction

Both the United States and China have significant natural gas resources, including large unconventional reserves trapped in shale formations. Although the American shale gas industry is mature compared to China's embryonic counterpart, the two countries share strong interests in developing these enormous energy resources. Moreover, it is in each country's interest to collaborate to address shale development challenges in China for three key reasons: environmentally smart development, energy security, and economic development opportunities (see details in the "3Es" text box). Whether shale gas is developed in China will influence global energy dynamics, and how it is developed will impact the global environment. Responsible shale gas development includes protecting the local environment as well as decreasing emissions that contribute to climate change.

This paper aims to inform future bilateral collaboration on shale gas within the context of expected actions in Chinese shale gas development that are reflected in existing plans and targets, even as uncertainties persist. The context for the US shale gas revolution is summarized, while the similarities and differences between the two countries' shale development are described. The paper also reviews existing collaboration between the United States and China on shale gas, concluding with several recommendations on how bilateral collaboration might be expanded to better address both countries' needs. Some of the areas for furthering cooperation include enhancing environmental safeguards, overcoming data sensitivities, improving business-to-business collaboration, and supporting joint research.

China is estimated to hold 230 trillion cubic feet (Tcf) to 1,275 Tcf of shale gas reserves, with the International Energy Agency (IEA) calling it the largest in the world.[1] [2] Even if the higher end volumes are exaggerated, it is indisputable that China has significant quantities of shale reserves. Therefore, its development is an attractive proposition for a country that has long dealt with resource scarcity, from oil to water to iron ore. For reasons ranging from strengthening domestic energy security to diversifying away from coal, about 70% of the total energy mix, gas is favorably viewed as a "bridge fuel" to cleaner types of energy.

The Chinese government has already introduced a flurry of incentives and targets to boost gas production, particularly unconventionals such as shale and coalbed methane. Broadly speaking, China aims to double the share of natural gas in its energy mix by 2015, which incorporates a specific production target for shale gas.[3] But China's shale development is only in the nascent

---

[1] IEA, 2012. "World Energy Outlook" http://www.worldenergyoutlook.org/publications/weo-2012/

[2] James A. Baker III Institute for Public Policy Rice University, 2011. "Shale Gas and U.S. National Security" http://www.bakerinstitute.org/publications/EF-pub-DOEShaleGas-07192011.pdf

[3] For descriptions of the announced targets and plans, see Reuters 2011. China sets ambitious shale gas output targets-paper. Available at http://af.reuters.com/article/energyOilNews/idAFL3E7LC0DM20111012 (accessed May 2012); Bloomberg. 2011. "China to Set Shale-Gas Output Targets, Securities Journal Says." http://www.bloomberg.com/news/2011-10-11/china-to-set-shale-gas-output-targets-securities-journal-says.html (accessed May 2012); and Delegation of the European Union in China. 2011. "China's Twelfth Five Year Plan (2011-2015) - the Full English Version".

exploratory stages—and estimates of potential recoverable resources remain uncertain. This is why China hopes to be able to learn from US success in this realm--where shale production has increased nearly 10-fold since 2005--and determine whether and how it might be replicated. In fact, bilateral collaboration between the two countries on shale gas is already taking place, providing a good foundation to influence responsible shale gas development in China.

Three "Es" on why the United States and China should collaborate on shale gas

Environmentally smart development

China and the United States are the world's largest emitters of greenhouse gases (GHGs), but they also have massive unconventional natural gas resources that, with technological advances, are being unlocked. If this shale gas provides a significant substitute for coal, it could result in a net reduction of GHG emissions. However, this requires serious attention to managing fugitive methane emissions. It will also be necessary to effectively address other risks, including competition for water resources, along with other significant air quality problems[1] and water pollution threats. Bilateral collaboration offers one promising avenue for achieving the environmental benefits while meeting China's growing energy demand, in part by sharing information and building on the US experience with regulating production.

Energy security

The proper incentives and policies for bilateral cooperation can help accelerate shale gas development in China, boosting the country's energy security. From a global geopolitical perspective, increased domestic energy security in China decreases dependence on energy imports from unstable regions. While it is uncertain what effect Chinese shale gas production would have on potential US gas exports, expected rising gas demand in China could still provide opportunities for exports at some point if domestic production is insufficient.

Economic development

US-China collaboration on shale gas can also create opportunities for US companies who are looking for new market opportunities overseas (providing oilfield services, for example) and benefit Chinese companies who are looking to enter a new market, either at home or abroad. While there can be beneficial spill-over effects to economic development associated with energy development, the external costs to society and the environment must be mitigated through sound environmental policy.

Available at http://cbi.typepad.com/china_direct/2011/05/chinas-twelfth-five-new-plan-the-full-english-version.html (accessed May 2012).

Shale gas in the United States: success and lessons learned

By now, the US shale gas revolution is a well-known phenomenon in which independent, private natural gas producers pioneered production of gas from shales, a resource that was previously classed as "unrecoverable." These small companies thrive on a high-risk, high-reward business model. They buy into specific shale gas reserves—plays that the major oil companies deem unprofitable—and apply innovative production approaches to prove that extraction is possible and profitable. By relying on the combination of two existing and commercially available technologies, horizontal drilling[4] and hydraulic fracturing (or "fracking"),[5] operators could unlock the gas trapped in shale formations over large areas and produce at scale.

Although the shale revolution seemed like an overnight success, it could have only been realized based on decades of US federal government support. A raft of federal-level measures facilitated shale gas development, including spending on research and development (R&D) and tax credits (see Table 1). It is worth emphasizing, however, that some of this R&D was conducted through public-private partnerships, with industry providing matching funds to match government dollars. This funding structure leveraged industry experience, and in many cases, industry operators implemented the research. Meanwhile, universities and other researchers, funded through smaller Department of Energy grant programs, conducted complementary research and brought their expertise to bear.[6] Finally, beginning in the 1930s, the United States built a highly integrated natural gas pipeline infrastructure that operates based on "common carriage"[7] to ensure that producers have access to existing pipelines.[8]

Table 1: US government R&D and financial support for shale gas development

Mechanism	Description	Level of Support	Timeframe
R&D Public-private partnership	Eastern Gas Shales Project by DOE. Fundamental science and engineering research including geological characterization and development of drilling methods.[9]	$172.4 MM ($137.4 MM Federal and $35 MM Industry cost-share) [1999 dollars][10]	1976-1992[11]

[4]The directional deviation of a wellbore from vertical to horizontal so that the borehole penetrates a productive shale formation in a manner parallel to the formation (adapted from OSHA 2012). WRI's definition of the vertical and horizontal drilling attributable process includes disposal of mud—that is, liquid that circulates in the wellbore during drilling—and placement and cementing of the well casing.

[5] A stimulation treatment in which specially engineered fluids are pumped at high pressure and rate into the reservoir interval to be treated, causing vertical fractures to open. Proppant, such as grains of sand of a particular size, is mixed with the treatment fluid to keep the fractures open once the treatment is complete (adapted from SOG 2012). WRI's definition of the hydraulic fracturing attributable process includes staged perforation of the well casing, flowback of treatment fluid, and wastewater treatment

[6] http://www.sbir.gov and http://www.grants.gov/search/search.do?mode=VIEW&oppId=128973; Small Business Innovation Research-SBIR and Historically Black Colleges and Universities-HBCU programs

[7] Common carriage refers to a pipeline system used by many entities that must be accessible upon reasonable request.

[8] Energy Institute, 2012. "Fact-based Regulation for Environmental Protection in Shale Gas Development" A Report for the Energy Institute, The University of Texas at Austin, http://www.energy.utexas.edu/images/ei_shale_gas_regulation120215.pdf.

[9] http://www.fischer-tropsch.org/DOE/_conf_proc/MISC/Conf-89_6103/doe_metc-89_6103-2A.pdf

[10] Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000 http://www.nap.edu/catalog/10165.html

[11] NETL, DOE's unconventional gas research programs 1976-1995.

R&D Public-private partnership	Natural Gas R&D by DOE	Annual natural gas budget of $12-117 MM[12]	1997-2007
R&D led /funded by an industry consortium	Gas Research Institute. In addition to the funds from industry (surcharge/donation), the consortium also received government research dollars.	By surcharge(approved by FERC): 0.12 cents to 1.5 cents per Mcf[13 14]	1976-1998
		By donation[15]: Annual total budget of $50-100 MM	1998-2005
Incentive pricing	Natural Gas Policy Act Section 107	Deregulated the wellhead sales price for shale gas	1978-present
Tax credit	Crude Oil Windfall Profits Tax Act Section 29	$0.50-1.00 per Mcf	1980-2002

Source: This table is based on research and analysis conducted by WRI.

Regulatory support also played a significant role in the emergence of the shale gas industry. The Natural Gas Policy Act of 1978 encouraged the exploration and development of unconventional gas,[16] in large part by deregulating wellhead prices from "Devonian-age gas shales, coal seams and geo-pressured brines."[17] Beginning in 1980, Section 29 of the Windfall Profits Tax Act provided a production tax credit of $0.50 per thousand cubic feet (Mcf) of natural gas produced from shales and $1.00 per Mcf for coalbed methane (CBM). The tax credit provided immense support for the pre-commercial shale gas industry until it expired in 2002, just as commercial production was first achieved at the Barnett shale in Texas. These economic incentives proved effective in driving the industry forward.

The US shale experience has not been entirely positive, however. Hydraulic fracturing has become highly controversial, with numerous public concerns about environmental and community impacts. At the local level, there is significant public opposition to shale gas development because of potential ground and surface water contamination and induced seismicity, as well as the noise, traffic, and land use impacts associated with shale gas production. There is also growing concern about greenhouse gas emissions from shale production, including methane emissions that contribute to climate change. This concern is amplified as a result of certain environmental regulatory compliance exemptions for the oil and gas industry (see Table 2).

These exemptions for hydraulic fracturing are currently being evaluated by the Environmental Protection Agency (EPA), as the agency works to improve regulatory clarity and protect against known risks. In the meantime, Colorado, Wyoming, Pennsylvania, New York, among others, are

[12] US GAO, "Department of energy: Oil and natural gas research and development activities," 2007 http://www.gao.gov/products/GAO-08-190R
[13] only a portion of this went to unconventional gas research
[14] Linden, Henry R, 1996. "The evolution of an energy contrarian." Annual review of Energy and the Environment 21.1 (1996): 31-67.
[15] In 1998 GRI's funding mechanism radically changed, leading to a phase out of the mandatory surcharge and a shift towards voluntary funding by industry and government.
[16] Unconventional gas in this context includes shale gas, as well as coal bed methane.
[17] Vello A. Kuuskra and Hugh D. Guthrie, Guthrie, 2001. "Translating Lessons from Unconventional Gas R&D To Geologic Sequestration Technology," http://seca.doe.gov/publications/proceedings/01/carbon_seq/1a3.pdf

adopting improved state regulations.[18] For example, Pennsylvania—which has seen substantial development in the Marcellus shale formation—now enacts rules for hazardous wastes to flowback water[19] from hydraulic fracturing.[20] Other states such as New York have addressed concerns by adopting temporary bans on hydraulic fracturing. At the federal level, improvements in emissions standards and reporting have recently been adopted.

Table 2 US federal regulatory exemptions, improvements, and their consequences

Regulation	Description	Consequence
Energy Policy Act of 2005	excluded hydraulic fracturing from regulation under the Safe Drinking Water Act's	operators need not obtain an SDWA Underground injection Control Program permit for hydraulic fracturing--the so-called 'Cheney-Halliburton Loophole'[21,22]
Subtitle C of the Resource Conservation and Recovery Act	exempted exploration and production waste from fracturing and drilling from the hazardous waste disposal restrictions	waste from shale gas development (including flowback) water are subject only to local and state regulations, lacking Federal oversight
Emergency Planning and Community Right-to-Know Act, Toxic Release Inventory	exempted oil and gas extraction industry from reporting in this inventory	information about the chemicals used in hydraulic fracturing and shale gas development is not disclosed, unless a local or state regulation requires it
Greenhouse Gas Reporting Program, Section 114 of the Clean Air Act	requires reporting of emissions data from petroleum and natural gas facilities that emit more than 25,000 tons of carbon dioxide equivalent per year,	total emissions from oil and gas facilities are reported and the oil and gas sector are estimated at the Federal level based on this

[18] GAO, 2012. "Unconventional Oil and Gas Development: Key Environmental and Public Health Requirements" http://www.gao.gov/products/GAO-12-874

[19] Flowback water is used treatment fluid that returns to the surface upon release of pressure on the wellbore in the hydraulic fracturing attributable process.

[20] Energy Institute, 2012. "Fact-based Regulation for Environmental Protection in Shale Gas Development" A Report for the Energy Institute, The University of Texas at Austin, http://www.energy.utexas.edu/images/ei_shale_gas_regulation120215.pdf.

[21] Stevens, Paul, 2012. "The 'Shale Gas Revolution': Developments and Changes." Chathamhouse briefing paper: EERG BP 2012/04. http://www.chathamhouse.org/sites/default/files/public/Research/Energy,%20Environment%20and%20Development/bp0812_stevens.pdf

[22] Energy Institute, 2012. "Fact-based Regulation for Environmental Protection in Shale Gas Development." A Report for the Energy Institute, The University of Texas at Austin, http://www.energy.utexas.edu/images/ei_shale_gas_regulation120215.pdf.

	with facilities defined as all wells owned or operated by a single entity within a specific hydrocarbon basin.	facility-level reporting.
Section 112(n)(4) of the Clean Air Act	prevents the EPA from aggregating oil and gas infrastructure into one "source" for regulatory purposes.	hazardous air pollutants from wells, gathering lines, storage tanks, and other small sources that may add up to significant emissions are unregulated.
New Source Performance Standards for Volatile Organic Compounds (VOC) as well as the National Air Emissions Standards for Hazardous Air Pollutants	Updated national standards to reduce VOC emissions from well completions by 95 percent	New wells will be "green completions", without venting of methane emissions. But, WRI analysis shows that there are additional cost-effective methods that could further reduce emissions from shale gas production. [23]

Source: This table is based, in part, on information from the Federal Policy Landscape section of WRI Report: Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems. The full report is available online at http://pdf.wri.org/clearing_the_air_full_version.pdf

What is it about the US market that enabled a revolution?

Yes, US industry invested in the development of a shale gas market. Yes, the US government invested in R&D and gave various financial incentives. These incentives offset the relatively high costs associated with unconventional gas production. But the structure of the US market itself also enabled the rapid increase in shale gas development starting in the late 2000s. The small operators thrive on the high risk, high reward plays. The market environment made such high risk plays profitable. Where necessary, developers share the risks by forming joint ventures. The natural gas pipelines are most often built by private pipeline transport companies, based on long-term contracts with a collection of end-users, which served the development of the shale gas industry well by reducing the risks associated with not being able to bring the gas to market. The leases for shale gas exploration and production rights are long term, which gave developers time to drill wells, gather data, and learn about how to produce gas from a play. The US gas market also does not work without access to capital. In fact, in some cases, Chinese investment has enabled development of certain shale gas plays in the United States,[1] particularly in a low natural gas price, post-economic crisis context.

Shale gas in China: at the starting line

Chinese natural gas consumption has outpaced production in recent years, leading China to become a net importer of gas by 2007. But boosting gas consumption is precisely what the Chinese government is encouraging as part of the rebalancing of its energy profile to reduce acute reliance on coal. Consequently, the 12th Five-Year Plan (FYP)[24] set a target to double natural gas in primary energy consumption to 8.3 percent by 2015, up from the roughly 4 percent today.[25] More specifically, shale gas production targets are ambitious: 6.5 billion cubic meters (bcm) per year (0.23 Tcf) and 990 horizontal wells drilled by 2015 (80 bcm or 2.8 Tcf by 2020).[26,27] While ambitious, the targets could be within the realm of feasibility considering the US precedent, where production increased from 21 to 136 bcm (0.74 to 4.80 Tcf), or more than 600 percent, between 2005 and 2010. But the conditions in China are not the same as those in the United States so that such a comparison may have limited utility.

The Ministry of Land and Resources (MLR) in 2012 approved shale gas as an independent mining resource, which means that private Chinese companies, rather than just state-owned enterprises (SOEs), can also develop the resource. MLR has held two auctions for shale gas exploration rights in 2012, where the first was open only to SOEs while the second was open to private entities, as well. Although priority for concession rights was given to existing oil and gas rights owners, the auctions generated interest, especially among coal-based power generators and mining companies who are looking to diversify and enter new market segments. Of the 19 blocks put up for auction in the second round, two private firms—Huaying Shanxi Energy, a subsidiary of Wintime Energy, and Beijing Taitantongyuan Natural Gas—won exploration rights, with the remaining 17 going to central and local SOEs.[28] Since many of the winners are not traditional oil and gas companies, their lack of experience will likely influence how the development process unfolds. It remains to be seen how many of the new entrants can successfully transform themselves into legitimate shale gas developers.

To further support shale production, the Chinese government has introduced economic incentives, in the form of both local subsidies and gas pricing reforms. Natural gas prices in China are currently set by the government. The gas price structure is rather complicated but basically follows a "cost-plus" model, in which the price is based on three elements: the wellhead price, which is set by the developer and then approved/adjusted by the government; the pipeline tariff, which is set by the government and is specific to the pipeline and location; and the end user price, also set by the government. Beijing determines different prices for

[24] The five year plans are established by the central government, but then the ministries and enterprises react to the FYP and incorporate the targets as part of their official plans.
[25] International Energy Agency. 2011. "World Energy Outlook Special Report: The Golden Age of Gas" http://www.worldenergyoutlook.org/goldenageofgas/
[26] Reuters. 2011. "China sets ambitious shale gas output targets-paper". Available at http://af.reuters.com/article/energyOilNews/idAFL3E7LC0DM20111012 (accessed May 2012).
[27] Bloomberg.,2011. "China to Set Shale-Gas Output Targets, Securities Journal Says". Available at http://www.bloomberg.com/news/2011-10-11/china-to-set-shale-gas-output-targets-securities-journal-says.html (accessed May 2012).
[28] WRI, 2013. "China moves forward with shale gas by holding second auction" http://www.chinafaqs.org/blog-posts/china-moves-forward-shale-gas-holding-second-auction (accessed April 2013)

residential, commercial, and industrial end users.[29] This has led to differentials in domestic prices versus imported prices—for example, domestic gas in 2011 delivered by pipeline was at about $8/million British thermal units (MBtu), while spot LNG prices were as high as $18/MBtu.[30]

Price controls are a legacy of the planned economy, but may be no longer suitable for today's China, especially given its priority to spur domestic gas production. As such, the government has embarked on gas price reforms. Pilot reform schemes have been under way for more than a year in Guangdong and Guangxi provinces, where wellhead prices have been liberalized and essentially linked to oil product prices imported via Shanghai.[31] The pilot reforms are meant to introduce more market pricing for natural gas, which will help to stimulate domestic shale gas development, in part by allowing producers to recoup the considerable capital costs associated with development and production.[32] Indeed, the ongoing pricing reforms will be important to catalyzing domestic production, as the International Energy Agency in 2012[33] highlighted distorted gas pricing as among the most important barriers to meeting China's goal of increasing natural gas consumption.

Challenges abound

Despite the Chinese government's support of shale development, its progress may be constrained by the scarcity of water resources. Competition for water between fracking and other end uses was vividly illustrated in northern Shaanxi province when officials temporarily cut off a city's water supply during a shale drilling test.[34] Reaching the 6.5 bcm production target would require 13.8 million cubic meters (485 million cubic feet) of water. For comparison, the entire Chinese industrial sector uses 35 bcm of water a year (1.24 trillion cubic feet).[35] Although water use for hydraulic fracturing is modest when compared to total industrial water usage, the incremental increase in water consumption can be locally significant in areas where water is scarce. It is also worth noting that about 90 percent of the water used for hydraulic fracturing stays underground and is not recoverable for use in other fracking operations or for other purposes. In addition to water resource limitations, there exist technical and practical challenges associated with the steep and varied terrain in some of the regions in China where shale resources are expected to be the richest.

China may also face regulatory hurdles in its shale development, since administrative responsibility for the natural gas industry remains fragmented. Provincial governments, too, play an important role in project approvals. Although MLR has the authority to grant exploration rights, environmental regulations and standards are still pending at the Ministry of

---

[29] IEA, 2012. "Gas Pricing and Regulation: China's Challenges and IEA Experience" https://www.iea.org/publications/freepublications/publication/ChinaGasReport_Final_WEB.pdf

[30] Ibid.

[31] Ibid.

[32] Reuters, 2011. "Update 2-China reforms shale gas price pilots, pilots new scheme". http://www.reuters.com/article/2011/12/27/china-gas-pricing-idUSL3E7NR3UR20111227

[33] IEA, 2012. "Gas Pricing and Regulation: China's Challenges and IEA Experience" https://www.iea.org/publications/freepublications/publication/ChinaGasReport_Final_WEB.pdf

[34] China Dialogue, 2013. "Chinese fracking plans prompt "water grabbing" fears" http://www.chinadialogue.net/article/show/single/en/5789-Chinese-fracking-plans-prompt-water-grabbing-fears

[35] Caixin, 2013. "Environmental Frets as Frackers Move In" http://english.caixin.com/2012-11-20/100462881_1.html

Environmental Protection (MEP) and are not expected until after successful demonstration of shale gas production. There will likely need to be more coordination among many ministries, including MLR, the Ministry of Water Resources, MEP, and the National Energy Administration.

Because shale gas development is likely to proceed in areas that are densely populated, it is important to ensure that demonstrations, as well as future developments, abide by regulations, standards, and best practices. Although existing standards for oil and gas development can be applied, they are unlikely to address the full range of risks. Some analysts anticipate that future shale gas policies in China may follow the example of CBM, which was ultimately supported by a suite of policy incentives.[36] For example, CBM development in China was supported by various tax incentives, including resource tax exemption, preferential corporate income tax, and value-added tax reimbursement, production subsidies, government-funded R&D, and specific policies for environmental protection. However, it remains to be seen whether the CBM incentives can spur meaningful production and whether China's shale incentives will be modeled after them. Finally, China can learn from federal- and state-level experiences in the United States, which contain both instructive models and cautionary tales (see below).[37]

Technical and resource challenges, combined with an imperfect policy regime, make shale gas development's future rather murky in China. Translating the country's vast potential into reality will require time and effort to build the necessary infrastructure, institutions, and regulations and standards. More discussion across various ministries, including with the National Development Reform Commission (NDRC), about the future of China's shale gas industry are needed.

Despite the near-term uncertainty, what is certain is that China's energy needs will grow in the coming decades, and domestically produced gas will certainly be an important part of that future.

Can collaboration reduce uncertainty in China's shale future?

Many parallels exist in the US and Chinese energy profiles. Both are continent-sized countries with geographically dispersed energy resources and with energy demand centers (cities) that are often far from energy supplies. Both countries currently rely heavily on fossil fuels to power their economies, primarily drawing on coal, natural gas, and imported oil (the US and China have similar levels of crude import dependence). Both countries seek to increase energy independence by diversifying the energy mix and ramping up domestic energy production, particularly unconventional fossil fuels such as shale gas.

Yet these similarities belie the challenges unique to China in the context of shale gas development. If China were to simply replicate the US R&D programs and incentives for shale gas development, it would likely be unsuccessful in addressing the specific key barriers and questions central to the sector's successful development. And if China were to replicate the regulatory exemptions for the industry seen in the US, it would likely result in costly

[36] CSIS, 2012. "Prospects for Shale Gas Development in Asia: Examining Potentials and Challenges in China and India" http://csis.org/files/publication/120824_Nakano_ProspectsShaleGas_Web.pdf

[37] GAO, 2012. "Unconventional Oil and Gas Development: Key Environmental and Public Health Requirements" http://www.gao.gov/products/GAO-12-874

environmental degradation that affects people, ecosystems, and the economy. However, despite the unique context of shale gas in China, US experience with technological development and policy design can contribute to responsible development of shale gas in China and foster opportunities for US researchers, academics, and industry interested in cooperating on shale gas development in China.

The uncertainty in China's shale gas future results from complex factors. For the industry to succeed, a number of critical gaps must be addressed, including issues around geology, technology, policy, players, and price. The section below describes each of these gaps, building on the complementarities and differences between shale gas development in the United States and China.

Geology

Relative to the oil and gas reservoirs in the United States, fewer wells have been drilled in China and therefore, less is known about the geology generally and shale gas resources specifically. Reducing the uncertainty in the actual volume and scale of recoverable shale resources in China will require drilling more wells to collect information and gaining experience via production.[38] The geological shale structures in China are more complex, containing more faults and fractures compared with those in the United States, thus making the underground resources more difficult to characterize and develop. Some of China's most promising shale gas lies under very rugged mountains, a stark geological contrast to the plains of west Texas where Barnett shale was first produced and to the Appalachian foothills that sit above the Marcellus shale. The logistical challenges associated with producing gas in some of China's reserves will likely take more time and cost more money.

Technology

China has experience in horizontal drilling and hydraulic fracturing, but practice in applying these techniques to China's shale gas reservoirs is just starting. Successful application of these technologies in a new geology is not enough—operators also need to have the know-how to manage the operations to maximize production. This experience will only be accumulated from practice. An ability to adapt to site-specific conditions will be needed in China.[39] Options for waterless hydraulic fracturing (such as carbon dioxide, nitrogen or liquefied petroleum gas) are also of particular interest to China's oil and gas operators, who see the challenges associated with producing shale gas in water-scarce areas.

Policy

Because shale gas production costs more than conventional gas production, it is unlikely to happen on its own in China as long as lower-cost gas reservoirs can still be tapped. The US experience in shale gas, which included a package of economic incentives and public-private partnerships, serves as one potential model for encouraging shale gas

[38] GAO, 2012. "Oil and Gas: Information on Shale Resources, Development, and Environmental and Public Health Risks" GAO-12-732. http://www.gao.gov/assets/650/647791.pdf

[39] Rassenfoss, Stephen, 2012. "China's Shale Gas Potential Looks Bright, But Development Raises Questions" Journal of Petroleum Technology. http://www.mydigitalpublication.com/display_article.php?id=1104804

development. However, incentives alone are not enough. The US experience provides both positive and negative lessons for avoiding environmental impacts associated with shale gas development in China.[40] It is essential for China, or any country that aims to replicate this knowledge at the beginning of its own shale gas development, to protect the air, water, and climate, as well as people and ecosystems affected by shale gas production and use. The opposition to hydraulic fracturing seen in the United States and globally underscores the importance of public engagement, particularly in areas that are water scarce.

Players

The Chinese gas market is dominated by the three national oil companies (NOCs), all of which are very large compared to the independent companies who led shale development in the United States.[41] Although a more diversified group of companies won shale gas exploration rights in the MLR's auctions, it is unclear how these non-oil and gas companies will develop the capacity for shale gas exploration or on what timeline. At this point, the NOCs may be more interested to produce lower-cost gas first, before moving more substantially into shale development. This implies that producing shale gas at scale could well extend into the medium or even long term. For the smaller, private Chinese companies that won blocks in the second auction, they may face the challenge of direct access to the pipeline network, which are primarily controlled by the NOCs. Although shale gas resource rights are clearly delineated from other resources, some uncertainty remains over how shale gas exploration rights could overlap with held oil and gas development leases currently held by the NOCs.[42]

Price

The innovations that led to the US shale gas revolution were driven in part by high natural gas prices and by Federal government incentives that rewarded those willing to take the initial risks of exploration. Yet in China, the current cost-plus pricing model for natural gas is unlikely to support development of unconventional gas or incentivize strong risk-taking ventures. Pricing reforms may be the single most important step China can take towards facilitating shale gas development.

Ongoing US-China collaboration

Bilateral collaboration on shale gas is already underway. While this type of cooperation is positive, it is insufficient. The following provides a brief overview of the scope of existing collaboration and concludes with recommendations for filling the gaps in cooperation going forward.

---

[40] For example, see http://www.epa.gov/region8/superfund/wy/pavillion/index.html and http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_coalbedmethanestudy.cfm

[41] The oil and gas majors were largely absent from the initial US shale gas market. In the early phases (pre 2000), the independent natural gas companies (such as Mitchell Energy) drove development forward. Then, during the rapid expansion after 2005, it was small independent operators who drove shale gas development forward, with the oil and gas majors entering the market late by comparison.

[42] WRI, 2013. "China moves forward with shale gas by holding second auction" http://www.chinafaqs.org/blog-posts/china-moves-forward-shale-gas-holding-second-auction (accessed April 2013)

Business-to-Business

Chinese companies currently possess the ability to drill wells horizontally and have some experience with hydraulic fracturing but are in the nascent stages of acquiring experience and applying these techniques to shale gas extraction. Operators and service providers in the United States currently have substantial experience with drilling and fracking shales, having mastered these techniques effectively to maximize output. Given this level of technical and experiential asymmetry, China has welcomed US entities to strike up partnerships with Chinese companies, primarily the NOCs. But China has prohibited foreign companies from fully entering the onshore energy production sector on its own, forcing them to tie up with Chinese entities. As a result, several foreign companies have already begun participating in shale plays in China, such as joint ventures (JVs) between PetroChina-Shell and CNOOC-BP.[43] Leading US service providers like Schlumberger, Baker Hughes, and Halliburton also have well-established offices and/or research institutes in Beijing and provide services to Chinese companies, including the NOCs and other smaller new entrants.

China has also invested in shale gas development in the United States, with some SOEs establishing JVs with US companies. These generally take the form of acquiring stakes in company assets—investments in specific shale gas plays—not investments in the US companies themselves. It is a model that the global oil and gas industry have long used to sustain growth and hedge against financial risk. The rationale for these Chinese investments varies. In some cases, Chinese petroleum engineers are able to spend time onsite learning about shale gas development first hand. However, limits on "access to technology" remain an oft-cited constraint on China's future shale gas developments. What is meant by "access to technology" may be best described as "know how." That is, the technology for horizontal drilling or fracking may not be the key barrier for China *per se*—instead, it is the lack of experience in applying these tools to different geological formations to maximize the flow of the gas.

Government-to-Government

In 2009, President Barack Obama and then-President Hu Jintao announced the launch of the US-China Shale Gas Resource Initiative, with the goal of sharing information about shale gas exploration and technology to reduce greenhouse gas emissions, promote energy security, and create commercial opportunities. Activities conducted under the initiative include forums, workshops, and a Chinese delegation's visit to a US shale gas development operation. The governments' collaboration includes the following activities, led by key agencies:

- The US Geological Survey and DoE have worked with Chinese counterparts to develop estimates for China's shale gas resource. Although the collaboration resulted in sharing information on methodology, Chinese geological data is considered a state secret and cannot be shared with foreigners.
- DoE manages the US-China oil and gas industry forum, which sponsors an annual meeting designed to bring industry players together to share information via technical presentations.[44] In September 2012, the forum sponsored a meeting focused on shale

[43] Forbes, Sarah, 2012. "China's Prospects for Shale Gas and Implications for the United States" Congressional Testimony. http://pdf.wri.org/testimony/forbes_testimony_china_shale_gas_2012-01-26.pdf
[44] http://www.uschinaogf.org/

gas. DoE also has relevant work underway that focuses on issues under Annex III of the bilateral Fossil Energy Protocol.[45]

- In April 2013, the US Trade and Development Administration partnered with the NEA on a training program. The program included four short courses led by the Gas Technologies Institute and targeted attendees from the Chinese government and industry.[46]
- EPA[47] has collaborated with China on sharing information on safe well drilling and completion.[48]
- The US State Department also recently solicited proposals for collaboration on environmental aspects of shale gas development as part of the Unconventional Gas Technical Engagement Program.[49]

This ongoing engagement is almost singularly focused on the geological and technological gaps (see Figure 2). However, growing interest among academics and think tanks, is pointing towards collaboration focused on the policy gap.

Figure 2. Mapping the ongoing Business to Business (B2B) and Government to Government (G2G) collaboration to the described gaps

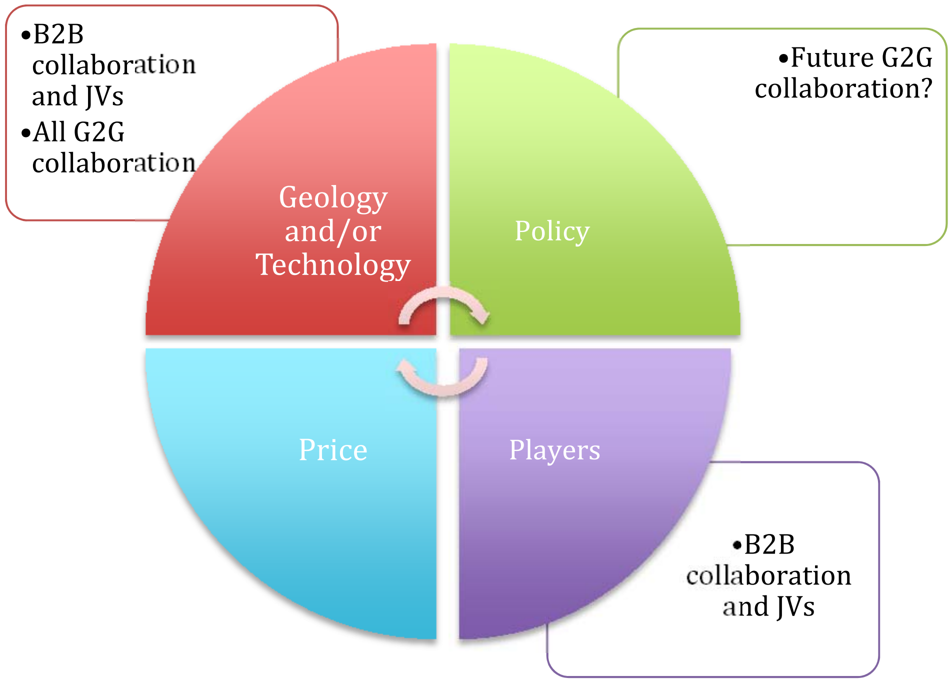
[45] http://www.fossil.energy.gov/international/International_Partners/China.html

[46] http://www.rpsea.org/attachments/calendarevents/452/US-China%20Shale%20Gas%20Resource%20Characterization%20and%20Assessment%20Workshop-%20US%20V%204_3_2013)USE.pdf

[47] Personal communication.

[48] Completion is a generic term used to describe some of the events and equipment necessary to bring a wellbore into production once drilling operations have been concluded, including but not limited to the assembly of equipment required to enable safe and efficient production from a gas well (adapted from SOG 2012).

[49] http://www.state.gov/s/ciea/ugtep/index.htm



At the July 2013 Strategic and Economic Dialogue between the US and China, the following reaffirmation was made of a continued desire to collaborate on shale gas. This commitment to work together on the legal and regulatory framework for unconventional oil and gas in China is significant, as he anticipated framework responds to many of the challenges outlined in this paper including coordination among multiple governmental agencies, incentives for building out an infrastructure, natural gas pricing reforms, regulating the fugitive methane emissions, and enabling cooperation between domestic and foreign companies.

> *"Legal and Regulatory Framework for Unconventional Oil and Gas: Welcome China's intent to accelerate the development of the legal and regulatory framework covering unconventional oil and natural gas. The framework is expected to: (1) include better coordination among the relevant agencies; (2) include regulatory incentives to build natural gas infrastructure (e.g., treatment facilities and pipelines); (3) include measures to move toward market-based natural gas pricing to promote domestic production; (4) include stronger regulation over fugitive methane emissions during production and distribution of natural gas and water usage during production; and (5) welcome foreign companies to participate in China's unconventional oil and gas industry following commercial principles. In order to speed China's progress toward cleaner fuels and reduce emissions in power generation, the United States and China decided to actively promote technical and environmental protection cooperation in unconventional energy resources such as shale gas, including through a series of shale gas development technical workshops in China…"*[50]

[50] http://www.state.gov/r/pa/prs/ps/2013/07/211861.htm

Responsible shale gas development?

There would be global environmental implications of a shale gas revolution in China. These implications could be positive:

- If policies are put in place that minimize methane leakage throughout the natural gas system,[1] there will be climate benefits.
- If environmental regulations and standards are put in place to:
  - reduce hazardous air pollutants and VOCs associated with shale gas development and to protect local air quality;
  - protect ground and surface waters. These standards must address issues of water quantity/availability and water quality and quantity;
  - span the full development process to ensure proper construction of wells and disposal of wastes generated during the hydraulic fracturing process.
- If the land use impacts associated with shale gas development are minimized.
- If the risks associated with development are assessed and managed throughout the process. Such risks include contamination of air and water, degradation of habitat, and possible induced seismicity associated with developments.

The bottom line is that the environmental impacts associated with shale gas must be understood and minimized throughout the development process. Good, comprehensive environmental standards and regulations are needed to guide this. Replicating the US environmental regulatory exemptions for industry would be a mistake.

Recommendations for moving forward

The efforts described in the previous section include cooperation between many agencies in both governments, but do not include sufficient engagement over the need for China to develop the policies and environmental regulations necessary for safe and responsible shale gas development. Future collaboration should move beyond technical aspects of cooperation and be tailored to better focus on closing the gaps. To that end, the July 2013 announcements provide a path for such collaboration. Here are three simple approaches that could ensure that the collaboration on yields a legal and regulatory framework for shale gas in China that promotes responsible development:

1. Substantive work on environmental regulations for air, water, and climate impacts

Comprehensive, life cycle environmental concerns regarding shale gas development should be addressed as part of future collaboration. The US experience with shale gas development has generated an increased understanding of the environmental impacts associated with development and how to avoid them—thorough regulatory actions as well as adoption of best practices. This new area of collaboration should not be relegated to engagement among environmental regulators in both countries but should also include cooperation between academics and think tanks as well as ministries and cabinets such as the NDRC and DoE and State Department in the US. This collaboration should involve both technical and policy aspects of environmentally sound shale production. One way to accomplish this would be to initiate a platform for multi-agency/ministry dialogue between the countries that is focused specifically on environmental policies needed for safe shale gas deployment in China. Such a platform could be a part of the already existing shale gas initiative and might consider involving industry, NGOs, academia, and government entities.

2. Small companies involvement, personnel training, and more transparency

Business-to-business collaboration will continue to be important, but there are barriers that must be addressed for it to be effective. They include inadequate involvement of smaller companies on both sides, insufficiently trained Chinese engineers to drill wells, difficulty in investing in shale assets in both countries, and sensitivities surrounding information and technology sharing.

To remedy these issues, both governments could initiate an industry forum—perhaps as an offshoot of the oil and gas industry forum—focused on the interests and needs of the small(er) shale gas companies. A new workforce training program could provide opportunities for young professionals from both countries to have an extended stay in the respective shale gas industry. This would help to cultivate a group of trained reservoir engineers, ready to support shale gas development anywhere in the world. Leaders in both governments should jointly discuss the barriers to data and finance, and could begin by commissioning a joint report from industry, government, and academic stakeholders in both countries.

3. Facilitate opportunities for joint R&D

While existing technical collaboration is important, it should evolve into deeper efforts that include exchanges of researchers and dialogues aimed at solving the unique challenges of shale production in China. Both governments should fund researchers in academia and industry to partner bilaterally and co-develop novel approaches for conserving water use (e.g. waterless fracking) and to develop new approaches for reducing air emissions and other environmental impacts associated with shale gas development.

Taking this recommendation seriously means prioritizing extended exchange programs over short workshops and meetings. It also means expanding beyond the questions around geology and technology and including joint research on the economic and policy aspects of shale gas development. A collaborative research and demonstration program, similar to what has been established under the Clean Energy Research Center program would be one way to encourage joint technology development and demonstration.

Acknowledgements

Thanks to my many colleagues who reviewed and commented on early drafts of this paper, including Hua Wen, Tien Shao, Liu Hongpeng, Hu Tao, James Bradbury, Amanda Stevens, Victoria Pursell, and Alex Doukas. Enormous thanks to Kevin Kennedy and Ranping Song for their reviews as well as guidance and leadership throughout the writing and review process. Thanks to David Victor for a particularly thoughtful review, and to Damien Ma and Kevin Foley for their edits and help in shaping this piece. I'd like to thank Liu Xu, Wang Wen, Amanda Stevens, and Evan Branosky for our collaborative work—much of which informed this draft. Conversations with many have helped inform and shape my understanding of the shale gas context in China, and my understanding of how US-China work can be improved. Thanks to Li Zheng, Deborah Seligsohn, Peng Suping, Julio Friedmann, Scott Smouse, Tim Carr, Ming Sung, Jerry Fletcher and Qingyun Sun for taking the time to discuss these issues from time to time. Finally, thanks to Brookings for inviting me to write this paper and to Kenneth Lieberthal for his expert guidance and reviews.