Water and Shale Gas Development
Leveraging the US experience in new shale developments
Global development of shale gas resources has the potential to expand significantly outside the United States. However, there continue to be environmental concerns, particularly with respect to water use. As operators outside the United States explore shale gas, there are many lessons that can be taken from the United States' experience. This paper highlights areas that operators of new shale developments should consider. It also includes an analysis of considerations for Argentina, China, Poland and South Africa focusing on water regulation, water use and management, and water movements during shale gas development.
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Natural gas production in the United States has grown significantly in recent years as improvements in horizontal drilling and hydraulic fracturing technologies have made it commercially viable to recover gas trapped in tight formations, such as shale and coal. The United States is now the number one natural gas producer in the world and, together with Canada, accounts for more than 25 percent of global natural gas production.¹ Shale gas will play an ever-increasing role in this resource base and is projected to increase to 49 percent of total US gas production by 2035, up from 23 percent in 2010, highlighting the significance of shale gas in the US energy mix in the future. Lower and less volatile prices for natural gas in the past two years reflect these new realities, with benefits for American consumers and the nation’s competitive and strategic interests, including the revitalization of several domestic industries.²
In its “2012 Annual Energy Outlook,” the U.S. Energy Information Administration (EIA) referred to the “enormous potential” of shale gas, and according to the Institute for Energy Research, the United States has enough natural gas to meet domestic electricity demand for 575 years at current fuel demand for generation levels—enough natural gas to fuel homes heated by natural gas in the United States for 857 years and more natural gas than Russia, Iran, Qatar, Saudi Arabia and Turkmenistan combined.

As Figure 1 illustrates, US shale gas reserves are vast and broadly dispersed; the EIA estimates that the lower 48 states have a total of 482 trillion cubic feet of technically recoverable shale gas resources with the largest portions in the Northeast (63 percent), Gulf Coast (13 percent), and Southwest regions (10 percent), respectively. The largest shale gas plays are the Marcellus (141 trillion cubic feet), Haynesville (74.7 trillion cubic feet), and Barnett (43.4 trillion cubic feet). Activity in new plays has increased shale gas production in the United States from 11 billion cubic meters (bcm) in 2000 to 140 bcm in 2010. Such production potential has the ability to change the nature of the North American energy mix and according to the National Petroleum Council 2011 study, “Prudent Development: Realizing the Potential of North America’s Abundant Natural Gas and Oil Resources,” the natural gas resource base could support supply for five or more decades at current or greatly expanded levels of use.

Water regulation

This rapid expansion in shale gas production has given rise to concerns around the impact of operations in areas such as water, road, air quality, seismic and greenhouse gas emissions (GHG). The process of hydraulic fracturing (fracking) in a shale gas well requires significant volumes of water and causes additional greenhouse gas emissions compared to conventional gas wells. There is already significant resistance to shale gas development due to these water and emission concerns in many parts of the United States and Western Europe, with France and Bulgaria imposing nationwide moratoriums on shale gas production through fracking. The regulation of shale gas is an evolving landscape as the industry has developed so rapidly that it has often outpaced the availability of information for regulators to develop specific guidance.

Figure 1. US lower 48 states shale gas plays.

At present, the US shale gas industry is regulated by a patchwork of existing oil and gas regulations on drilling and well site activities, combined with environmental regulations on water and air management. This loose regulatory landscape is beginning to change with growing state and federal attention. In 2010, the U.S. Environmental Protection Agency (EPA) launched a four-year field study on the impact of shale gas hydraulic fracturing and, in 2011, the U.S. Department of Energy received a report by the Secretary of Energy Advisory Board (SEAB) for shale gas providing recommendations on how to reduce the environmental impact and improve the safety of shale gas production. In addition to these reports, numerous smaller studies continue to provide information to support improvements in regulation and leading practice.

In 2010, New York issued a temporary moratorium on additional shale gas development to allow the state’s Department of Environmental Conservation (DEC) to finish its Supplemental Generic Environmental Impact Statement (SGEIS) on issues surrounding natural gas drilling. New York published a Revised Draft SGEIS on September 28, 2011, which was open for public comment until January 2012. There has been no further movement from the DEC on the moratorium. In June 2011, Maryland Governor Martin O’Malley issued an order calling for a three-year study of the economic and environmental effects of drilling the Marcellus Shale before permits to drill can be issued. And in August 2011, New Jersey Governor Chris Christie placed a one-year moratorium on hydraulic fracturing so that the Department of Environmental Protection “can further evaluate the potential environmental impacts of this practice in New Jersey, as well as evaluate the findings of ongoing federal studies.” (Note, however, that no hydraulic fracturing operations were taking place in New Jersey when the moratorium was issued.) Several other states, however—including Wyoming, Pennsylvania, Arkansas, Colorado, Louisiana and Texas—have passed new legislation or regulations in response to the increased activity associated with natural gas development.

Water use and management

One of the most contentious and widely publicized issues in shale gas production is water management. Shale gas production is a highly water-intensive process, with a typical well requiring around 5 million gallons of water to drill and fracture, depending on the basin and geological formation. The vast majority of this water is used during the fracturing process, with large volumes of water pumped into the well with sand and chemicals to facilitate the extraction of the gas; the remainder is used in the drilling stage, with water being the major component of the drilling fluids. Relatively small amounts of water are also used for dust suppression on site, and for the cleaning and flushing of drilling equipment. Although increasing volumes of water are being recycled and reused, freshwater is still required in high quantities for the drilling operations as brackish water is more likely to damage the equipment and result in formation damage that reduces the chance of a successful well. The need for freshwater is a growing issue, especially in water-scarce regions and in areas with high cumulative demand for water, leading to pressure on sources and competition for water withdrawal permits. The pressure to increase efficiencies is high as industry demand for water grows with the development of more wells.

Water contamination is another aspect of shale gas production that has generated significant resistance to current shale production processes. According to the Massachusetts Institute of Technology (MIT) 2011 Gas report, which reviewed three studies of publically reported incidents related to gas well drilling, there were only 43 “widely reported” water contamination incidents related to gas well drilling in the past decade (to 2010) during which time, there were about 20,000 shale gas wells drilled with almost all of them being hydraulically fractured. Of these, 48 percent of the incidents involved groundwater contamination by natural gas or drilling fluids; 33 percent involved on-site surface spills; 10 percent involved water withdrawal and air quality issues, and blowouts; and, the remaining 9 percent involved off-site disposal issues (see Figure 2).

Regarding contamination incidents, the MIT report stated that “with over 20,000 shale wells drilled in the last 10 years, the environmental record of shale gas development has for the most part been a good one—but it is important to recognize the inherent risks and the damage that can be caused by just one poor operation.... In the studies surveyed, no incidents are reported which conclusively demonstrate contamination of shallow water zones with fracture fluids.”

In areas with deep unconventional formations, such as the Marcellus areas in Appalachia, the shale gas under development is separated from freshwater aquifers by thousands of feet and multiple confining layers. To reach these deep formations where the fracturing of rock occurs, drilling goes through the shallower areas, with the drilling equipment and production pipe sealed off using casing and cementing techniques. A new voluntary chemical registry (FracFocus) for disclosing fracturing fluid additives was launched in the spring of 2011 by the Ground Water Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission (IOGCC). Texas operators are required by law to use FracFocus. The IOGCC, comprised of 30 member states in the United States, reported in 2009 that there have been no cases where hydraulic fracturing has been verified to have contaminated water. A key objective of the EPA’s ongoing study is to better understand the full life-cycle relationship between hydraulic fracturing and drinking water and groundwater resources.

The movement and disposal of produced water from fractured wells is also a part of the debate on the environmental impact of shale gas production. After fracturing, each well returns a percentage of the injected fracture fluid volume over its lifetime; this water is heavily polluted, creating a risk of groundwater contamination upon its return to the surface if not correctly contained and treated. Concerns around such risks have led to the moratorium on shale gas development in New York’s Marcellus Shale. In addition to the nature of the produced water, the growing volumes of wastewater are increasing demand for efficiencies in water treatment technologies to improve water reuse and
recycling. Innovative water management solutions are required to address the long-term sustainability of water use in shale gas production.

**Water movements**

The volume of equipment, materials and water required to support shale gas operations presents a significant logistics challenge. Given the remote nature of most locations and the frequent operations movements across highly dispersed and numerous well site locations, flexibility is required in the transport model making road transport the logistics model of choice for most environments. While pipeline and rail movements can be effective for long-distance or point-to-point movements, the final distribution to and from the well pad is almost exclusively managed via road transport. Road transport volumes and types vary significantly depending on the operational phase of the project, with the majority of demand during the fracking and completion phases, which can account for 60–85 percent of total transport volumes. Some large operations are required to source, plan and manage up to 300 truck movements per day within a single basin, which is the equivalent of a pan-regional transport operation in many other sectors. This concentration creates significant challenges, with on-site congestion causing issues to the operations teams and local residents, and leading to significant cost exposure to an already marginal cost operation.

The high volume and intensity of road transport associated with shale gas production present some unique challenges for operators. A shortage of transport operators with sufficient knowledge, difficulties in tracking and optimizing delivery schedules, reducing burden on strained road infrastructure, and a lack of standardized reporting and regulatory data can all lead to high costs, Health Safety Security Environment (HSSE) exposure, and regulatory compliance issues. With up to 30 percent of completion costs related to transportation, operators are exploring different options to reduce transport activity, with a key focus on water hauling, which can represent up to 80 percent of logistics activity. Research into water-free fracking, on-site treatment and disposal and assessment of alternative modes of transport are all being pursued, but are currently unable to generate significant impact. Within the boundaries of current capabilities, the adoption and integration of logistics leading practice provide the most straightforward, technology-ready approach to reducing transport cost and regulatory and HSSE exposure.

Improvements in water movements also have an impact on other aspects of shale operations, specifically HSSE exposure, operational performance and compliance.

**HSSE exposure**

Improved transport planning processes and systems can reduce the number of truck moves, while telematics systems can provide real-time visibility of truck movements and driver performance, supporting reduction in wait times, less congestion and better driver HSSE compliance.

**Operational performance**

Better monitoring and planning capabilities will reduce bottlenecks and smooth delivery into a site (e.g., managed slot windows, dynamic re-routing to avoid congestion). Availability of accurate operational data can allow operators to identify issues and enable continuous improvement in both drilling and transportation. Logistics costs can be reduced through efficiency gains (e.g., reduction of waiting time) and automated processes can reduce administrative costs. Past implementations have shown that consistent adoption of logistics leading practices can deliver up to 45 percent reduction in transport costs.

**Compliance**

The use of a water inventory monitoring tool can support water management regulatory compliance through visibility of water draw, usage and movements. Automated end-to-end processes and systems enable accurate and rapid data capture, storage and reporting. A cross-operator, basin-wide solution would also confirm consistent basin-wide reporting standards across multiple sites and operators.

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**Figure 2. Chart of water contamination incidents related to gas well drilling.**

<table>
<thead>
<tr>
<th>Incident Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater contamination</td>
<td>48%</td>
</tr>
<tr>
<td>On-site surface spills</td>
<td>33%</td>
</tr>
<tr>
<td>Water withdrawal and air quality issues, and blowouts</td>
<td>10%</td>
</tr>
<tr>
<td>Off-site disposal issues</td>
<td>9%</td>
</tr>
</tbody>
</table>

Source: Massachusetts Institute of Technology 2011 Gas Report.
Overview of shale gas life cycle activities

Civil/site prep
Forest clearing, excavation, building of access routes, constructing and installing wells pads and preparing site for drilling activities.

Drilling
Natural gas will not readily flow to vertical wells because of the low permeability of shales. This can be overcome by drilling horizontal wells where the drill bit is steered from its downward trajectory to follow a horizontal trajectory for one to two kilometers, thereby exposing the wellbore to as much of the reservoir as possible.

Completion/fracking
As drilling is completed, multiple layers of metal casing and cement are placed around the wellbore. After the well is completed, a fluid composed of water, sand and chemicals is injected under high pressure to crack the shale, increasing the permeability of the rock and easing the flow of natural gas.

Flowback
A portion of the fracturing fluid will return through the well to the surface due to the subsurface pressures. The volume of fluid will steadily reduce and be replaced by natural gas production.

Production
The fissures created in the fracking process are held open by the sand particles so that natural gas from within the shale can flow up through the well. Once released through the well, the natural gas is captured, stored and transported away for processing.

Figure 3. Shale gas lifecycle.

<table>
<thead>
<tr>
<th>Civil/site prep</th>
<th>Drilling</th>
<th>Completion/fracking</th>
<th>Flowback</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build access roads, construct and install well pads, prepare site for drilling</td>
<td>Drill vertical and horizontal wells</td>
<td>Complete wells with steel and cement casings Release gas through hydro-fracking</td>
<td>Capture, store and treat returned fracturing fluids</td>
<td>Capture, store and transport gas</td>
</tr>
</tbody>
</table>

Typical timelines
60 days | 15–60 days | 15–30 days | 20 days | 5–40 years

Source: Accenture 2012.
1.1 Shale resources outside the United States

Although estimates are likely to change over time as additional information becomes available, the international shale gas resource base is currently considered to be significant. The initial estimate of technically recoverable shale gas resources in the 32 countries examined in the EIA’s “World Shale Gas Resources” study is 5,760 trillion cubic feet (see Figure 4). Adding the US estimate of the shale gas technically recoverable resources of 862 trillion cubic feet results in a total shale resource base estimate of 6,622 trillion cubic feet for the United States and the other 32 countries assessed. To put this shale gas resource estimate in context, the world’s technically recoverable gas resources are roughly 16,000 trillion cubic feet, largely excluding shale gas. Thus, adding the identified shale gas resources to other gas resources increases total world technically recoverable gas resources by more than 40 percent to 22,600 trillion cubic feet.

The estimates of technically recoverable shale gas resources for the 32 countries outside the United States represent a moderately conservative “risked” resource for the basins reviewed. Given the relatively sparse data currently available and the differences in approaches employed to determine the resources, these estimates are quite uncertain. At the current time, there are efforts under way to develop more detailed shale gas resource assessments by the countries themselves, with many of these assessments being assisted by a number of US federal agencies under the auspices of the Global Shale Gas Initiative (GSGI) that was launched in April 2010.

At a country level, there are two country groupings that emerge where shale gas development appears most attractive. The first group consists of countries that are currently highly dependent upon natural gas imports, have at least some gas production infrastructure, and their estimated shale gas resources are substantial relative to their current gas consumption. For these countries, shale gas development could significantly alter their future gas balance, which may motivate development. Examples of countries in this group include Chile, France, Morocco, Poland, South Africa, Turkey and Ukraine. In addition,

Figure 4. Map of 48 major shale gas basins in 32 countries.

Legend
- Assessed Basins with Resource Estimate
- Assessed Basins without Resource Estimate
- Countries within Scope of EIA Report
- Countries outside Scope of EIA Report

South Africa’s shale gas resource endowment is interesting as it may be attractive to use this natural gas as a feedstock to its existing gas-to-liquids (GTL), coal-to-liquids (CTL) plants and combined cycle gas turbine (CCGT) currently running on diesel.

The second group consists of those countries where the shale gas resource estimate is large (e.g., above 200 trillion cubic feet) and there already exists a significant natural gas production infrastructure for internal use or for export. In addition to the United States, notable examples of this group include Algeria, Argentina, Australia, Brazil, Canada, China, Libya and Mexico. Existing infrastructure would aid in the timely conversion of the resource into production, but could also lead to competition with other natural gas supply sources. For an individual country, the situation could be more complex.

Outside the United States there are certain shale plays that could change the energy security of the countries in which they are located. These include the following:

Argentina – The Neuquén Basin

According to the EIA, Argentina has 774 trillion cubic feet of technically recoverable shale gas, making it the world’s third-largest player in the shale game behind the United States and China. Located on Argentina’s border with Chile, the 137,000 km² Neuquén Basin is the South American nation’s largest source of hydrocarbons, holding 35 percent of the country’s oil reserves and 47 percent of its gas reserves. Within the basin, the Vaca Muerta Shale formation may hold as much as 240 trillion cubic feet of exploitable gas. ExxonMobil has recently entered into an agreement with Americas Petrogas for the Exploration and Production (E&P) farm-out of 163,500 gross acres of its Neuquén-based Los Toldos blocks. This area is also being explored and developed by Shell, Apache, EOG, Total and Wintershall, among others. Argentina’s biggest energy company, YPF, has found unconventional shale oil and natural gas in Mendoza province, confirming the extension of the massive Vaca Muerta area. YPF said exploration at the Payun Oeste and Valle del Rio Grande blocks pointed to an estimated one billion barrels of oil equivalent (boe) in unconventional oil and gas in Mendoza. Energy resources and reserves in the province, which border the Andes mountain range in western Argentina, currently stand at 685 million boe.

Canada – Horn River Shale Basin

British Columbia’s Horn River Shale Formation is the largest shale gas field in Canada and part of Canadian deposits that amount to as much as 250 trillion cubic feet of natural gas. Since 2008, a total of nine companies has ventured into the Horn River market, including ExxonMobil, Apache, Devon Energy and Encana. While large-scale commercial production of shale gas has not yet been achieved in Canada, many companies are now exploring for and developing shale gas resources in Alberta, British Columbia, Quebec and New Brunswick. Development of shale gas, and other unconventional resources, will help confirm supplies of natural gas are available to the growing North American natural gas market for many decades. Encana, Canada’s largest natural gas producer and one of the biggest in North America, is looking for a single partner for a package of assets that could include positions in the Collingwood Shale, the Tuscaloosa Marine Shale, the Mississippi Lime and the Eaglebine Shale in the United States. All have natural gas liquids or oil potential and are in the early stages of exploration and development.

China – Sichuan and Tarim Basin

In 2011, the EIA estimated that China had 1,275 trillion cubic feet of technically recoverable shale gas. Since then a geological survey led by China Ministry of Land and Resources (MLR) confirmed a total of 882 trillion cubic feet of technically recoverable shale gas, excluding Tibet. The Sichuan Basin, located in south-central China, covers a large 211,000 km² and accounts for 40 percent of the country’s shale resources. China hopes to produce between 60 billion and 100 billion cubic meters a year by 2020—an objective that some analysts are skeptical can be achieved. Royal Dutch Shell has recently signed the first production-sharing contract to explore, develop and produce shale gas in China, a move that fits in with China’s overall strategy to bring technical and operational know-how to the development of its untapped reserves of the unconventional fuel. CNOOC Ltd., China’s biggest offshore energy producer, plans to develop new fields, acquire overseas assets and develop unconventional resources such as shale gas to meet output targets. The country is “determined” to learn shale-gas technology from its partners and deploy it in China, holder of the world’s largest deposits of the fuel, Chairman Wang Yilin has stated.

Poland – Baltic-Podlasie-Lublin Basins

The EIA has assessed that Eastern Europe may hold as much as 250 trillion cubic feet of shale gas, with Poland’s Silurian Shale plays boasting 187 trillion cubic feet of that total. The Russia Federation currently supplies 25 percent of Europe’s natural gas, and Poland’s potential shale resources could reduce Europe’s dependence on natural gas imports. Whether these reserves will be developed is still to be seen, but the 38-million-strong Slavic nation will have a strong claim to energy independence as its projected reserves equate to 300 years of domestic consumption.
Several companies including ExxonMobil and Chevron have begun to drill test wells and more than 100 companies rushed to grab a share of Poland’s gas concessions. Some of those early tests produced decent flows, but others showed quite different results from wells drilled into US shale deposits. ExxonMobil said its two test wells did not justify commercial production. ExxonMobil said in January 2012 that two exploratory wells failed to flow enough gas to make development profitable. In June 2012, ExxonMobil announced it would end its search for shale gas in Poland. Flow rates at sites drilled by 3Legs Resources Plc. and BNK Petroleum Inc. were not as high as similar wells in the United States.

South Africa – The Karoo Supergroup

Known by paleontologists as one of the world’s most fertile hunting grounds for fossil remains, the Karoo Supergroup (KSG) might also be one of the most plentiful sources of shale gas in the world. The KSG is constituted mainly of shales and sandstones and spans across 88,000 km², underlying more than two-thirds of the entire area of South Africa and containing an estimated 485 trillion cubic feet of technically recoverable gas. Shale gas could reduce the country’s dependence on coal to fuel 85 percent of its energy needs.

Other regions

India’s Oil and Natural Gas Corp (ONGC) and US oil company ConocoPhillips have signed an agreement to explore and develop shale gas assets and look for opportunities in deepwater exploration. The agreement is for sharing technical knowledge on shale gas explorations, but ONGC and ConocoPhillips could also jointly bid for shale gas assets overseas. India may still launch the first shale gas licensing round by the end of 2013 even though the government pushed back plans to unveil a policy on exploration of unconventional gas resources trapped in rocks.
A key objective of this report is to highlight the trends and lessons learned from shale development in the United States that can be applied to shale developments in other geographies. To emphasize this point, we will present four case studies in this report of four very different shale developments: Argentina, China, Poland and South Africa. The following is a detailed description of these shale developments.

Argentina
Argentina is the largest natural gas producer in South America with 1,416 billion cubic feet (bcf) annual output in 2010. Natural gas prices in Argentina were kept low by the government since the economic crisis in 2002. As a result, natural gas production dropped almost 15 percent from its peak of 1,628 bcf and natural gas tested reserves dropped 50 percent to only 13.4 trillion cubic feet in 2011 due to decreasing exploration activities in the past decade. Meanwhile, the demand for natural gas in Argentina has increased in recent years in line with economic growth, and the country has had to rely on gas imports from neighboring Bolivia and Liquefied Natural Gas (LNG) shipments. Shale gas has brought new hope for addressing energy demands. Based on an EIA estimation, Argentina has 774 trillion cubic feet of technically recoverable shale gas, which is almost 60 times that of its current tested natural gas reserves. To encourage domestic natural gas exploration and production, the Argentinian government introduced its “Gas Plus” program in 2008 to allow new discovered unconventional gas to be sold at a higher price based on cost and reasonable profit. This incentive program allows approved companies to charge up to $5/thousand cubic feet (mcf) for their natural gas production.

The Neuquén Basin covers the Neuquén province and parts of Mendoza, Rio Negro and La Pampa provinces in central-west of Argentina, holding 407 trillion cubic feet of the country’s 774 trillion cubic feet estimated resources. This basin largely overlaps with existing natural gas production regions. The Neuquén province alone currently produces almost half of the nation’s conventional gas. The geological formation of the Neuquén Basin is very similar to major US shales with the average depth of the 204 trillion cubic feet of recoverable shale gas in the Vaca Muerta formation within the Neuquén Basin at 2,400 meters. Geological features and existing local natural gas infrastructure make future development in the Neuquén Basin very promising. Other basins including the San Jorge Basin and the Austral Magallanes Basin have 95 trillion cubic feet and 172 trillion cubic feet reserves, respectively.
Many shale operators have started exploration activities in Argentina. Apache partnered with YPF, previously controlled by Repsol, but was renationalized in April 2012 by the Argentinian government, to explore unconventional resources including shale gas in the Neuquén and Austral Basins. Apache has been awarded 1.6 million gross acres (3,642 km²) in the Neuquén Basin for shale gas development and the company drilled the first horizontal multi-fracture shale gas well in South America in 2011. In May 2011, one of Apache’s horizontal wells in the Neuquén Basin tested at a rate of 7 million cubic feet (mmcf)/day. Canadian firm America Petrogas joined with ExxonMobil to explore 660 km² of blocks in the Neuquén Basin. The company drilled a test well together with ExxonMobil and the result is under evaluation. With undergoing exploration activities, EIA’s original estimation on Argentina’s shale gas potential is waiting to be confirmed with new data from the operators.

**China**

The recent success of shale gas development in the United States, as well as a domestic push to reshape the energy structure to reduce dependence on coal, has put shale gas under the spotlight in China. In December 2011, the China State Council approved shale gas as a new type of natural resource that will be managed separately from conventional gas. In March 2012, the National Development and Reform Commission (NDRC) issued its Shale Gas Development Plan (2011–2015) that sets clear targets for the industry by 2015 and 2020. However, the shale gas industry in China remains at an early stage with most activity in exploration and drilling of test wells.

Data from a recent Ministry of Land and Resources (MLR)-led geological survey shows China has 882 trillion cubic feet of technically recoverable shale gas resources, a lower figure than the EIA’s estimate. Figure 6 illustrates shale gas distribution in China. The Sichuan Basin in the Upper Yangzi region and southwest China (a region covering Sichuan, Chongqing, Yunnan, Guizhou and Guangxi provinces) has 10 trillion cubic meters (350 trillion cubic feet) of shale gas, which equates to 40 percent of total national reserves. Unlike US formations, where most shale seams are at depths of less than 3,000 meters (with the exception of the Haynesville Shale), the shale-bearing layers in many Chinese formations are between 3,000 to 5,000 meters deep. Therefore, US shale gas development models cannot be simply replicated in China and the complex geological conditions will increase the cost of drilling wells.

Figure 6. Shale gas distribution in China.
The shale gas industry has, for the first time, been put in a strategically important position in the government’s 12th five-year energy plan (2011–2015). In addition, the Shale Gas Development Plan (2011–2015) states that by 2015, the government aims to complete an investigation on shale gas reserves and their national distribution. The plan also estimates annual production reaching 6.5 billion cubic meters (230 billion cubic feet) and confirmed technically recoverable reserves reaching 600 billion cubic meters (21 trillion cubic feet) by 2015. With almost no commercial production today, reaching such targets will require significant investment at each stage of the value chain in the next couple of years, as well as technology development and collaboration between national oil companies (NOCs) and experienced shale gas operators from other countries.

NOCs and state-owned entities have been the first to be allowed to explore and develop shale gas resources in China. So far most activities are in exploration, with only very limited commercial production. The three major NOCs (CNPC, Sinopec and CNOOC), Yangchang Petroleum Group, and China United Coalbed Methane Co (China CBM) are actively involved in shale gas exploration. By the end of 2011, CNPC had drilled 11 test wells in southern Sichuan and northern Yunnan, four of which had exhibited industrial-level gas flow. Sinopec has its exploration activities mainly in Guizhou, Anhui Sichuan and Chongqing. In Chongqing, Sinopec has shale gas production in Liangping County with an estimated annual output 300–500 million cubic meters (10–18 billion cubic feet). 25 Yanchang Group is very active in its traditional territory of Shanxi province and has successfully fracked the first horizontal well in China.

China CBM has proposed to start exploring three regions in Shanxi province. 26 In the first round of national shale gas exploration rights auctions, organized by the MLR, Sinopec and Henan Coal Bed Methane Co won the bid. A second round of auctions is due to start in late 2012.

International oil majors are actively partnering with NOCs to enter China’s shale gas market. CNPC and Statoil began test drilling in China in early 2011. Sinopec has teamed with BP to explore shale gas in Guizhou in 2010, joined forces with ExxonMobil to conduct geological research in Sichuan, and is also working with Chevron in Guizhou to carry out risk assessments. Shell is the most active international oil company (IOC) in China, and has already signed the first production-sharing contract with CNPC to explore, develop and produce shale gas.

Poland

Poland has the most significant shale gas potential in Europe. Poland’s shale gas resources are located in the Baltic-Podlasie-Lublin Basins (see Figure 7), creating a strip across the country from northwest to southeast. The EIA estimates 187 trillion cubic feet of technically recoverable shale gas resources in the Baltic-Lublin-Podlasie Basins of Poland; of those, 120 trillion cubic feet are in the Baltic Basin. 27 A report released in March 2012 by the Polish Geological Institute was able to confirm 67 trillion cubic feet of technical recoverable shale gas resources in these three basins after a 16-month research project with external support from the U.S. Geological Survey. 28 The average depth of shale formations in Poland is from 2,500 to 3,800 meters, which is up to twice as deep as the average depth of 2,000 meters observed in the Marcellus Shale. 29 30 Variations have been observed among different basins, with 1,000–4,500 meters depth for the Baltic Basin, 1,000–3,500 meters depth for the Lublin Basin, and 4,000–5,000 meters depth for the Podlasie Basin (near Warsaw). These geological characteristics could likely result in higher drilling costs, linked to higher demands on water in the drilling stages.

Shale gas activities in Poland started in 2007; by September 2011, a total of 101 shale gas exploration authorizations had been granted and another 26 applications were being processed. 31 International oil majors have entered the Polish market in the form of joint ventures. 3Legs Resources formed a joint venture with ConocoPhillips to evaluate shale gas potential in the Baltic Basin and drilled the first exploration well in Poland. PKN and PGNiG are the most active Polish operators. As of August 2011, based on square kilometers covered, the top 10 concession holders in Poland were: (1) San Leon Energy with 14 licenses covering 11,520 km², (2) ExxonMobil, (3) PKN Orlen, (4) Chevron, (5) Marathon Oil & Gas, (6) BNK Petroleum, (7) 3Legs Resources, (8) Nexen, (9) ConocoPhillips and (10) Petrolivest. 32
With authorizations received, current industry activities have moved onto drilling of testing wells. 22 exploration wells were started in 2011 and 13 wells were completed by February 2012. 14 new exploration wells were planned for late 2012 and as many as 123 wells are planned by 2017. So far, state-owned PGNiG, 3Legs Resources, BNK, Talisman Energy, Marathon Oil and ExxonMobil have all completed their first batch test wells. ExxonMobil, BNK and 3Legs released rather disappointing results, stating that the gas flows in their testing wells are lower than similar prospects in US shale and commercial production cannot be justified. Despite this negative news, the Polish government strongly believes shale gas would help to reduce the nation’s energy dependency on Russia and cut greenhouse gas (GHG) emissions through transforming the coal-based electricity generation sector. A consortium formed with state-owned power utilities companies and PGNiG will co-finance and co-develop shale exploration along the Baltic coast. Utilities will finance exploration activities in exchange for future gas supplies in off-take agreements. Poland’s Treasury Minister said the country may be producing one billion cubic meters (35 billion cubic feet) of shale gas per year by 2014.

Figure 7. Map of Poland’s shale gas basin.

South Africa

South African electricity generation is currently heavily coal-based. The Department of Energy intends to have 9 percent of energy from open cycle gas turbines by 2030 and shale gas could help to reach this target.\(^{37}\) According to the EIA, South Africa has an estimated 485 trillion cubic feet of technically recoverable shale gas located in the Karoo Basin (see map, Figure 8). Of this, 298 trillion cubic feet is believed to be in the Whitehill Shale.\(^{38}\) The real volume of shale gas reserves is still waiting to be confirmed through physical exploration activities.

Unlike Poland and China, where shale gas formation are buried deeper than the United States, the average depth of shale gas in South Africa is 2,500 meters (8,000 feet),\(^{39}\) which is quite similar to the Barnett Shale.\(^{40}\) However, the Karoo Basin contains significant areas of volcanic intrusions that impact the quality of the shale gas resources, limit the use of seismic imaging and increase the risk of shale gas exploration.

A number of companies have started pursuing shale gas development in the Karoo Basin by obtaining Technical Cooperation Permits (TCPs) from the South Africa Petroleum Agency (see map, Figure 8). Shell is the biggest TCP holder with 185,000 square kilometers of land in the Karoo Basin. Falcon Oil and Gas has 30,000 square kilometers of TCPs. Sasol, Chesapeake and Statoil have formed a joint venture and together hold 88,000 square kilometers of TCPs, but in December 2011, Sasol decided to put its Karoo shale gas plan on hold.\(^{41}\) Anglo Coal and Australian Sunset Energy also have their own TCPs. According to South African regulations, TCPs allow no more than desktop research; with further applications required to obtain authorization for physical exploration activities. However, the application to convert these TCPs into physical exploration licenses was suspended over a year to allow the government to conduct policy and technical reviews before final decisions.\(^{42}\) On September 7, 2012, the South Africa government accepted the recommendations from the Department of Mineral Resources (DMR) and finally lifted the moratorium on shale gas exploration.\(^{43}\)

Figure 8. Map of operators’ TCP coverage in the Karoo Basin.

The topic of shale gas regulation is dominated by hydraulic fracturing, the key feature of shale gas that separates it from well-regulated conventional gas production. However, existing regulations to protect water resources during oil and gas development are also affected by the greater intensity of water, energy and infrastructure used in shale gas operations. This consequence is driving significant uncertainty in the US regulatory landscape, which is still adapting to the new industry.

The speed of industry growth has outpaced the availability of rigorous data on its potential impact, which has hindered the ability of government to adequately assess and regulate operations. This situation has led to a patchwork regulatory landscape and to a moratorium on shale gas development in New York State, France and Bulgaria. To resolve this issue, there has been renewed focus by the US federal government on establishing better understanding of the potential impacts of shale gas development, to most effectively regulate this critical new energy resource.
2.1 Regulatory history and the current landscape

Hydraulic fracturing of gas wells began in 1949; however, it remained largely unregulated until significant unconventional gas production began around the millennium with the commercial development of coal-bed methane. As production grew, media reports and public complaints of drinking water contamination raised concerns, leading the EPA to commission a study into the risks of hydraulic fracturing to drinking water. In 2004, this study found that hydraulic fracturing of coal-bed methane posed minimal threat to underground sources of drinking water, which was a significant finding in support of the industry. In 2005, following the EPA report, the federal Energy Policy Act granted hydraulic fracturing a specific exemption from the Safe Drinking Water Act (SDWA), which regulates all underground injection.

Since the Energy Policy Act passed in 2005, shale gas production in the United States has grown significantly, from less than one trillion cubic feet in 2005 to over three trillion cubic feet in 2009. Such rapid growth, along with continued reports of environmental effects, has led to renewed calls for change in the regulatory landscape, particularly for the federal government to provide increased regulation or guidance. This pressure led to the introduction to congress of the FRAC Act in 2009, which sought to repeal the 2005 SDWA exemption and require disclosure of components used in all fracturing fluids. The bill was sent to committee but was not passed to congress for vote. In the absence of new federal regulation, states have continued to use existing oil and gas and environmental regulations to manage shale gas development, as well as introducing individual state regulations for hydraulic fracturing.

The current regulatory landscape is comprised of an overlapping collection of federal, state and local regulations and permitting systems, implemented by oil and gas, natural resources and environmental agencies. A mapping of current federal and state regulation is shown in Figure 9. These regulations cover different aspects of the development and production of a shale gas well, with the intention that they combine to manage any potential impact on the surrounding environment and water supplies. These combinations of regulations have long served to regulate oil and gas development in numerous states; however, the new process of hydraulic fracturing is something that has not previously been managed by these regulations. Therefore, the related intensity in terms of water, emissions and site activity mean existing regulations are being reassessed for their suitability for this new production method.

Federal regulations

With its exemption from the SDWA, hydraulic fracturing is not directly regulated by federal standards. However, a number of federal laws still direct oil and gas development, including shale gas.\(^{44}\) These regulations affect water management and disposal, as well as air quality and activities on federal land. The Clean Water Act is focused on surface waters and regulates disposal of wastewater and also includes authorizing the National Pollutant Discharge Elimination System (NPDES) permit program, as well as requiring tracking of any toxic chemicals used in fracturing fluids.

Outside water use, the Hazardous Materials Transport Act and Oil Pollution Act both regulate ground pollution risks relating to spills of materials or hydrocarbons into the water table.

State regulations

Regulation of oil and gas production has traditionally occurred primarily at the state level. This level of regulation is also the case for shale gas, with most shale gas-producing states issuing more rigorous standards that take primacy over federal regulations, as well as additional regulations that control areas not covered at the federal level, such as hydraulic fracturing. Within states, regulation is carried out by a range of agencies. Energy or natural resource-focused departments generally set requirements for site permits, drilling, completion and extraction, while environmental or water departments regulate water, emissions and waste management.

The specific regulations vary considerably among states, such as different depths for well casing, levels of disclosure on drilling and fracturing fluids, or requirements for water storage. The majority of states in shale gas-producing regions now have varying hydraulic fracturing regulations on their books, specifically for disclosure of fracking fluids, proper casing of wells to prevent aquifer contamination and management of wastewater from flowback and produced water. Disposal of wastewater by underground injection has emerged as a point of concern for state regulators due to large inter-state flows of wastewater to states with suitable geology for Class II disposal wells and reports of earthquakes near some well sites. States such as Arkansas and Ohio have placed local moratoriums on disposal wells in locations where increased seismic activity has been recorded and Ohio is developing rigorous new standards for disposal wells.\(^ {45}\)
Typical timelines

<table>
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<tr>
<th>Civil/site prep</th>
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<th>Completion/ fracking</th>
<th>Flowback</th>
<th>Production</th>
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<tbody>
<tr>
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<td>Drill vertical and horizontal wells</td>
<td>Complete wells with steel and cement casings Release gas through hydro-fracking</td>
<td>Capture, store and treat returned fracking fluids</td>
<td>Capture, store and transport gas</td>
</tr>
</tbody>
</table>

Federal regulatory impact

- The National Environmental Policy Act (NEPA) requires that exploration and production on federal lands be thoroughly analyzed for environmental impacts.
- Under the Clean Air Act, National emission standards for hazardous air pollutants (NESHAP) are used to limit toxic pollutants.
- Under the Clean Air Act, Engine NESHAP rules regulate newly refurbished engines including monitoring and reporting requirements.
- The US Environmental Protection Agency (EPA) has proposed new performance standards for toxic air emissions for oil and natural gas production.
- The US EPA administers most of the federal laws.
- The U.S. Department of Interior Bureau of Land Management (BLM) is responsible for issuing fracking permits on federal lands.
- Hazardous chemicals must be recorded on material safety data sheets and reported in the event of a crisis as part of the Emergency Planning and Community Right to Know Act.
- The Clean Water Act (CWA) regulates surface discharge of produced water and storm water through the National Pollutant Discharge Elimination System (NPDES) permitting process.
- The CWA sets wastewater standards for industry, and water quality standards for contaminants in the surface water.
- The Oil Pollution Act (OPA) enforces spill prevention requirements and reporting operations.
- The EPA has proposed that drillers use “green completion” techniques to reduce emissions of volatile organic compounds from wells. Green completions are required in Colorado and Wyoming.
- Comprehensive Environmental Response, Compensation and Liability Act (CERLA) enables the federal government to respond to releases of hazardous substances that threaten human health or the environment.
- The Safe Drinking Water Act (SDWA) excludes fracking from its Underground Injection Control (UIC) program. Instead, the EPA and states implement the UIC program to protect groundwater resources. Forty states have primacy for this with the EPA implementing the program directly in New York and Pennsylvania.
- Groundwater is often protected under State Pollutant Discharge Elimination System (SPDES) permits rather than just discharges to surface water, as with the NPDES permits.
- In addition to state regulations, the Delaware River Basin Commission and Susquehanna River Basin Commission impose water quantity laws.
- States regulate hazardous wastes and implement waste management procedures that are exempt from the federal Resource Conservation and Recovery Act.

State regulatory impact

- States are able to implement federal regulations.
- All states require a permit to drill and operate a well.
- All states have regulations regarding drilling, abandonment and plugging of wells.
- States regulate the effective casing and cementing of wells.
- Transportation of water, sand and additives are regulated under state regulations.
- Disclosure of chemicals used in fracking is regulated at a state level, but regulations differ in strength. Wyoming, Texas and Arkansas require disclosure of all chemicals, Pennsylvania and Michigan only require disclosure deemed hazardous, Louisiana and Colorado are expected to implement disclosure regulations soon.
- The U.S. Department of Interior Bureau of Land Management (BLM) is responsible for issuing fracking permits on federal lands.
- The Clean Water Act (CWA) regulates surface discharge of produced water and storm water through the National Pollutant Discharge Elimination System (NPDES) permitting process.
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Other regulations

In addition to federal and state regulations, local governments and water basin management commissions also control aspects of shale gas development in some regions. In the northeast, groups such as the Susquehanna River Basin Commission and Delaware River Basin Commission manage water supply and disposal permits across state and county lines. Local counties and municipalities also play a role in local site and infrastructure permitting.

The overlapping of authorities and immaturity of the industry have led to a varied regulatory landscape for hydraulic fracturing and shale gas development. This situation creates considerable complexity for operators and other stakeholders who should maintain compliance across jurisdictions, creating a desire for standardization. The simplicity of standardization should, however, be balanced with the optimization of regulations for local conditions. There is strong consensus that maintaining regulatory primacy at the state level is preferred due to the variations in geology, water, gas composition and infrastructure in different shale gas basins, meaning a one-size-fits-all national policy is likely to be sub-optimal for all parties. Federal focus is therefore on supporting states in developing detailed shale gas regulations for their conditions, confirming they are transparent, data-backed and consistent.

2.2 Federal efforts to support regulatory consistency

Based on the preference for state primacy, the EPA has assumed the role of coordinating and supporting research into the impacts of hydraulic fracturing to provide rigorous data and guidance for state regulation development. In particular, the EPA has undertaken a major national study to understand the impacts of hydraulic fracturing on drinking water resources. The study will include a review of published literature, analysis of existing data, scenario evaluation, laboratory research and case studies. The EPA will release initial study results in a report expected at the end of 2012 and a final report at the end of 2014. The objective of this study is to provide a definitive federal position on the issue of fracking in shale gas, which will provide states with greater clarity on what regulations are required to protect water resources.

While there is broad agreement among operators and industry specialists that the risk of migration of fracking fluids from the fracking site to underground drinking supplies is extremely remote, it is expected that the EPA report will provide greater clarity on this and will also assess the risks to drinking water from current drilling and well casing procedures.

In addition to technical research into hydraulic fracturing, the Secretary of Energy sought to provide broader industry guidance by convening a subcommittee of his Advisory Board to develop a report on the immediate steps that can be taken to improve the safety and environmental performance of shale gas development. The SEAB shale gas report was requested and completed in 2011, and identified four major areas of concern that should be addressed:

- Possible pollution of drinking water from methane and chemicals used in fracturing fluids.
- Air pollution.
- Community disruption during shale gas production.
- Cumulative adverse impacts that intensive shale production can have on communities and ecosystems.

To address these concerns, the SEAB offered twenty recommendations to support safety, environment and development objectives. These broad recommendations, such as increasing communication between state regulators, included specific actions, such as providing funding to the State Review of Oil and Natural Gas Environmental Regulations (STRONGER) organization to review and compare state shale gas regulations. The recommendations can be summarized as focusing on the following key areas:

- Maintaining water quality through focus on groundwater protection and wastewater disposal.
- Managing water supply through reducing water intensity, developing better baseline data and focusing on a life-cycle, systems approach to water management.
- Standardizing fracturing fluid disclosure as the benefit of transparency outweighs Intellectual Property (IP) protection.
- Reducing use of diesel, both as a fracking fluid and as an energy source for power and transport.
- Developing a cumulative, holistic approach to managing impact on communities and ecologies.
- Supporting these recommendations by promoting regulatory comparison, and sharing and incentivizing leading practice.
- Improving air quality through data collection, life-cycle analysis and focus on fugitive emissions.
2.3 Key trends

In its final report, the SEAB assessed the level to which its recommendations have currently been implemented and concluded there was limited implementation at this time. Given the dissatisfaction of operators with the current regulatory complexity, the desire of the federal government to implement its recommendations for responsible development, and the desire of other stakeholders for increased transparency, there is likely to be significant evolution of shale gas regulation. Based on these pressures, we expect a number of key trends in regulation.

Disclosure

Many states (including Wyoming, Arkansas and Texas) have already implemented regulations requiring disclosure of the materials used in fracking fluids and the US Department of Interior has indicated an interest in requiring similar disclosure for sites on federal lands. As operators are required to disclose the materials and volumes used in certain states, the argument of IP protection in other states quickly erodes. The FracFocus website, jointly operated by the Department of Energy and the Ground Water Protection Council, is a voluntary registry for companies to report chemicals. In the future, FracFocus may become the basis for a more rigorous reporting system.

Cumulative approach

As the development of each shale gas basin continues, there is increased awareness that the cumulative impact of individually low-impact operations risks creating negative environmental consequences. The adjustment of regulations to be more focused on cumulative inputs and outputs at the basin level will require enhancements to regulatory procedures and data availability.

Water tracking

Understanding the impact of operations on the water table involves both a cumulative and also an end-to-end approach to water management. Tracking of water use, from the initial sourcing to disposal, is expected to become an increasingly rigorous requirement to allow regulators to assess the holistic impact of operations.

Focus on intensity

Cumulative regulatory impact assessments will encourage operators to reduce the intensity of shale gas production across their new and existing operations, including water, energy and emissions intensity. As the industry matures and operations become increasingly optimized, operators and regulators will focus on intensity as a way of reducing costs, allowing greater output for the same input costs, environmental footprint and disruption to local communities. Particular areas of focus will include recycling of wastewater for fracking and supporting use of efficient technologies. Innovation in operations and analytics will be critical to assessing efficiency performance.

Pressure on water treatment

Even if the current EPA study confirms that fracking itself does not pose a risk to drinking water, increased regulatory pressure will be placed both on well completions and treatment or disposal of wastewater. This will encourage more rigorous regulations on operators’ management of wastewater.

Growing standardization

As the industry matures and disclosure increases, there will be increasing standardization in terms of operational excellence and leading practice. This standardization combined with increased pressure for coordination and comparison in regulations will lead to more consistency in regulation between regions, which will reduce complexity of compliance, in contrast to the other trends in regulations, which are likely to increase complexity.
In Focus

Water regulation in Argentina, China, Poland and South Africa

Water regulation related to shale gas in Argentina, China, Poland and South Africa is in its early stages as governments start to pursue the development of their shale resources.

Argentina regulation

Onshore oil and gas resources in Argentina are governed by provincial governments in their own territory, based on the Federal Hydrocarbon Law. Therefore, exploration permits are granted by provincial states. Operators are also regulated by environmental regulations issued by the Federal Secretary of Energy and more stringent rules at the provincial level. For oil and gas operations, Environmental Impact Studies are required by Resolution 105/92 and Resolution 340/93 requires Annual Environmental Audit Studies to be prepared by consulting firms registered with the Secretary of Energy.

Water is primarily regulated by the provincial government. In the Neuquén province, the General Water Resource Office (DGRH) is responsible for applying the water code in the province. Considering the amount of water consumed by the shale gas industry, conflicts in water demand with other users could occur. Within the province, a user community has been created to resolve water demand conflicts, which has been regarded as good practice. Due to a lack of a national water law, inter-provincial water conflicts are more difficult to resolve and a River Basin Water Management model has been used by Neuquén and neighboring provinces.

The AIC River Basin Authority was introduced in 1985 to act as the water management authority for Rio Negro, Neuquén and Limay River Basin. Managing water quality is also within the scope of provincial water laws. There is growing demand in Argentina for more stringent wastewater discharge regulations to improve widespread surface water pollution. However, with the complexity of varying environmental/water regulations in different provinces, progress is relatively slow. Researchers in Argentina also raised concerns over chemicals used in the fracking process and disclosure of details in fracking fluid is not mandatory in the country.

China regulation

Due to the early stage of shale gas development, current environmental regulations in China remain focused on the conventional oil and gas industry. In March 2012, the Ministry of Environmental Protection (MEP) issued the report, "Technical Guidelines for Oil and Gas Industry Pollution Prevention." This document stressed the importance of wastewater recycling and gave guidance on fracking fluids used in the oil and gas industry. This document also requires the creation of underground water monitoring schemes to confirm current industrial practices in underground injection do not cause any water pollution. However, this document does not specifically cover shale gas and related unique water challenges. Revision of this document will not occur until late 2013.

In addition, the "Technical Guidelines for Environmental Impact Assessment—Constructional Project of Petroleum and Natural Gas Development on Land," issued by the MEP in 2007, sets clear standards for wastewater discharge and stated leading practices to prevent pollution caused by wastewater in the oil and gas industry.

Although there are no specific environmental regulations on shale gas, the NDRC shale gas development plan (2011–2015) does cover environmental issues. The plan states a series of leading practices, which includes fracking water recycling, strict rules on drilling activities and an enhanced monitoring scheme for wastewater discharge, for shale gas operators to reduce negative impacts on the local environment. These areas could be the focus for future shale gas industry-specific regulations.

Poland regulation

In Poland, government bodies regulating shale gas development include the Ministry of Environment, State Mining Authority and National Water Management Authority. In general, Poland lacks specific legal regulations that would apply directly to operations in the field of shale gas. Therefore, any business activity in this area is currently regulated by the same legislation for conventional natural gas, the Act of 4 February 1994 Geological and Mining Act, which was revised on December 11, 2001 and enacted on January 1, 2002. Poland lacks specific legal regulations focusing on shale gas exploration activities with the support from the Department of Geology and Geological Concessions (DGGC); further approval from the State Mining Authority is required for commencement of any mining activity.

Based on the current Water Act (July 2001), a separate water permit is required for utilizing surface and groundwater with a capacity over 5m³ per day and for projects such as drainage facilities and mines. Applications have to be made to the National Water Management Authority. Water permits granted also cover the discharge of wastewater. The European Union regulation 2006/1907/EC concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH),
establishing a European Chemicals Agency, is applicable to the use of chemicals in the hydraulic fracturing process. In contrast to a voluntary disclosure system in the United States, additives used in hydraulic fracturing are public information in Poland and have to be approved by the State Mining Authority.

A recent environmental impact assessment report on horizontal drilling and fracking for the first Polish well showed minimum environmental impact. The report coordinated by the Polish Geological Institute concluded that hydraulic fracturing did not generate air pollution, only caused temporary elevated noise within permissible levels, had no effect on the quality of surface and groundwater, and did not cause earthquakes. Such positive results could influence future environmental legislations in Poland.

South Africa regulation

Shale gas exploration and production is regulated by the Mineral and Petroleum Resources Development Act (MPRDA) in South Africa. The Petroleum Agency is responsible for issuing exploration permits. Based on the current system, a Technical Cooperation Permit (TCP) is issued to allow initial paper-based research and acquisition of seismic data from other sources, including the Petroleum Agency. A Reconnaissance Permit is issued to allow operations to search for mineral or petroleum by geological survey with remote sensing technologies, but not physical exploration. An Exploration Right has to be obtained for physical exploration activities and a separate Production Right is required for subsequent production activities. However, MPRDA is currently under review with the intention of streamlining the licensing process to avoid delays.

The National Water Act requires industry water users to register with the Department of Water Affairs (DWA) and obtain a permit. Wastewater discharge is also regulated by the DWA. Therefore, shale gas developers will need to obtain permits from the DWA for sourcing and discharging water. In practice, no shale gas operators have successfully reached the stage of applying for water permits, although Shell attempted to obtain Exploration Rights. Public concerns about the environmental impact of fracking led the DMR to issue a moratorium between April 2011 and September 2012, which temporarily suspended all applications for shale gas exploration. So far, there are no physical exploration activities in South Africa and more specific regulations on shale gas water sourcing and discharge may be introduced in the future before operations begin.

The following table highlights the most relevant water regulation trends the various markets given the nature of the shale development and the local regulatory context.

<table>
<thead>
<tr>
<th>Disclosure</th>
<th>Argentina</th>
<th>China</th>
<th>Poland</th>
<th>South Africa</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Disclosure of chemicals used in Poland already mandatory. Although currently not obligated, operators in South Africa are committed to voluntarily disclose the chemicals used in fracking. In the future, we also expect China and Argentina to also require some level of disclosure.</td>
</tr>
<tr>
<td>Cumulative approach</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>All four countries are developing plans to look at the environmental impact of overall shale development.</td>
</tr>
<tr>
<td>Water tracking</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Some form of water monitoring and tracking is expected in all the focus markets.</td>
</tr>
<tr>
<td>Focus on intensity</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Public concerns around the environment in all of these geographies are high. There is a wider trend to reduce water, energy and emissions.</td>
</tr>
<tr>
<td>Pressure on water treatment</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>This is an area of emphasis in all shale plans.</td>
</tr>
<tr>
<td>Growing standardization</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Regulations are at early stages and each country is assessing the local environmental impact and developing its own view. Regulations are likely to be consistent at each national level, but with significant potential variation by nation.</td>
</tr>
</tbody>
</table>
Water management

The volumes of water required to frack a well, and the volumes and characteristics of the wastewater produced from shale gas operations, make water management central to shale gas production. Operators are faced with a number of options regarding the sourcing of water and the disposal of wastewater, from disposal in underground injection wells, to reuse in further operations and recycling to clean freshwater. Local regulatory frameworks, the characteristics of the returned water in different regions, and the cost-effectiveness of different options constitute some of the drivers behind these choices. This landscape is a constantly evolving one as players explore the most effective water management options available to them.
3.1 Water use and production

Water plays a key role in each stage of the shale gas well life cycle, from well development to production (see Figure 11). The key challenges for operators are:

- Sourcing sufficient volumes of water required for drilling and fracking each well.
- Effectively managing the volumes of wastewater generated.

Sourcing sufficient volumes of water

Water used in hydraulic fracturing is sourced from surface waters (lakes and rivers), groundwater (wells, aquifers), municipal supplies, and from wastewater from previous fracking processes. Once collected, the water is hauled or piped to the site where it is stored in lined impoundments or tanks until it is used in the drilling and fracking stages.

The volumes of water required in shale gas production vary considerably from well to well. The FracFocus website, which details the water use of wells across the United States, shows the variety of volumes required across different wells. Factors influencing this total volume will include:

- The depth, length and number of horizontal segments fracked: The longer the segment, the more water is required for the fracking process.
- There is a trend for longer horizontal segments: two years ago, these would be approximately 3,000 feet long— with advances in technology, these can now cover up to 6,000 feet.
- The geological characteristics of the shale play: shale plays differ widely in their geological characteristics (depth, thickness, total porosity) resulting in different water requirements. The Haynesville Shale (3,200 to 4,110m in depth), for example, requires on average one million gallons of water during the drilling phase compared to 60,000 gallons for the Fayetteville Shale (300 to 2,100m in depth).

As an average, approximately five million gallons of water are required to drill and frack a well, the equivalent of 1,000 water truck movements. The fracking stage is the most water intensive, using up to 90 percent of the total water use, as illustrated in Figure 12. In contrast, only a small amount is necessary for the maintenance of the equipment (flushing and cleaning) following the fracking.

Despite public perceptions to the contrary, these water requirements are low when compared to other sectors (agricultural, industrial), and when set against the water intensity of other forms of energy. The 2009 "Modern Shale Gas Development in the United States: A Primer" reports that total volumes required for shale gas production in a shale basin range from 0.1 percent to 0.8 percent of total water use. Pennsylvania’s annual total water consumption is approximately 3.6 trillion gallons, of which the shale gas industry withdraws about 0.19 percent for hydraulic fracturing.

Nevertheless, access to water sources is likely to become more of a constraint for operators in arid regions facing growing depletion of water resources, and in areas where water flows and

Figure 11. Water management challenges across the shale gas lifecycle.

<table>
<thead>
<tr>
<th>Civil/site prep</th>
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<td>Capture, store and transport gas</td>
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<tr>
<td><strong>Decommission</strong></td>
<td></td>
<td>Release gas through hydro-fracking</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Typical timelines**

- 60 days
- 15-60 days
- 15-30 days
- 20 days
- 5-40 years

**Water management challenges**

- Access to water from surface, groundwater or municipal water sources
- Volumes and quality of water required for the drilling fluid (up to 99% of the fluid depending on the operator/shale)
- Volumes and quality of water required for the fracking fluid
- Managing the volumes of flowback water returned to the surface in the first few days following the fracking
- Managing the volumes of produced water returned to the surface following production
availability follow seasonal variations. In Pennsylvania, for instance, access to permits for water can be more of a challenge in the summer when minimum flow rates need to be maintained. In July 2012, the Susquehanna River Basin Commission (SRBC) suspended water withdrawals due to lower stream flow levels in the Susquehanna Basin, including a majority of shale gas operators including Chesapeake and Talisman. In dry regions of Texas, water demands for shale gas production are viewed as competing with water use for irrigation and domestic use.

The volumes of water required at source depend on a number of factors. These volumes can be reduced, for instance, by optimizing the well configuration and the number of wells per pad—and by modifying the constitution of the fracturing fluid. The composition of fracturing fluids has changed over the years, and continues to see changes. Gel-based fluids were largely used until the emergence of “slickwater fracturing”—using a low-viscosity mix of water and friction reducers—in the 1990s. Slickwater fracturing, which requires higher volumes of water, with fewer requirements on the water quality, is now widely used.

Figure 13 shows one example of the composition that may be encountered in shale gas fracturing, with 99.51 percent of water and sand (proppants), and the remainder consisting of chemicals. These chemicals fulfill varying purposes, from increasing the fluid viscosity to help the proppant transport (gelling agents), to limiting bacteria growth (biocides), the build-up of scale (scale inhibitors), the viscosity of the fluid (surfactant), or the friction between the fluid and the well (friction reducers).

The water quality requirements for the water used in the drilling fluid are higher than for the fracturing fluid due to the risk of damage to the drilling equipment (this higher quality requirement has implications for water reuse, see Section 3.2).

An emerging trend in the composition of the fracturing fluid is to use less and “cleaner” additives. These “green” fracks include the use of guars and starch-based chemicals that are biodegradable and non-bio-accumulating. Through its Green Frac™ program, Chesapeake claims to have “eliminated 25 percent of the additives used in hydraulic fracturing fluids in most of [their] shale plays.”

Still in initial stages of development, waterless fracturing fluids (including liquid propane, liquid CO2, nitrogen gas foams and gels), are being explored. These fluids, however, present their own challenges. The use of liquid propane, for instance, presents safety risks linked to using an explosive gas underground.

Figure 12. Water use in drilling and fracking across four US shales.

<table>
<thead>
<tr>
<th>Water use per well (000 gal)</th>
<th>Barnett</th>
<th>Fayetteville</th>
<th>Haynesville</th>
<th>Marcellus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Fracking</td>
<td>3,500</td>
<td>3,500</td>
<td>3,500</td>
<td>3,500</td>
</tr>
<tr>
<td>Total</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Notes:
- 69 availability follow seasonal variations.
- 70 In July 2012, the Susquehanna River Basin Commission (SRBC) suspended water withdrawals due to lower stream flow levels in the Susquehanna Basin, including a majority of shale gas operators including Chesapeake and Talisman.
- 71 Gel-based fluids were largely used until the emergence of “slickwater fracturing”—using a low-viscosity mix of water and friction reducers—in the 1990s.
- 72 Slickwater fracturing, which requires higher volumes of water, with fewer requirements on the water quality, is now widely used.
- 73 Figure 13 shows one example of the composition that may be encountered in shale gas fracturing, with 99.51 percent of water and sand (proppants), and the remainder consisting of chemicals.
- 74 These chemicals fulfill varying purposes, from increasing the fluid viscosity to help the proppant transport (gelling agents), to limiting bacteria growth (biocides), the build-up of scale (scale inhibitors), the viscosity of the fluid (surfactant), or the friction between the fluid and the well (friction reducers).
- 75 The water quality requirements for the water used in the drilling fluid are higher than for the fracturing fluid due to the risk of damage to the drilling equipment (this higher quality requirement has implications for water reuse, see Section 3.2).
- 76 An emerging trend in the composition of the fracturing fluid is to use less and “cleaner” additives. These “green” fracks include the use of guars and starch-based chemicals that are biodegradable and non-bio-accumulating.
- 77 Through its Green Frac™ program, Chesapeake claims to have “eliminated 25 percent of the additives used in hydraulic fracturing fluids in most of [their] shale plays.”
- 78 Still in initial stages of development, waterless fracturing fluids (including liquid propane, liquid CO2, nitrogen gas foams and gels), are being explored. These fluids, however, present their own challenges. The use of liquid propane, for instance, presents safety risks linked to using an explosive gas underground.
Managing the volumes of wastewater generated

Following the fracking, varying volumes of the injected fracture fluid will flow back to the surface ("flowback water"), mixed with “formation water” containing dissolved minerals from the formation. Although there is no formally agreed definition, flowback and produced water are jointly referred to as “wastewater.” The water recovery rate, that is, the amount of wastewater recovered from the volume injected as part of the fracking process, both in the short term (flowback water) and in the long term (total produced), varies by well and by shale. There are “dry” shales with lower water recovery rates (15–25 percent of the injected water returning to the surface), such as the Marcellus, and “wet” shales with high water recovery rates (up to 75 percent), such as the Barnett.

The flowback water constitutes the highest volumes of wastewater over the life cycle of a well—it can represent a million gallons of water or more over the course of weeks, with the majority captured in the first several hours to several weeks.

The challenges of managing these high initial volumes of water differ from conventional oil and gas production where the produced water gradually increases over the life cycle of the well—and therefore the solutions involved will be different (see sidebar on "Managing produced water: unconventional vs. conventional").

The flowback water contains a number of constituents, depending on the fracturing fluid and the shale formation. These include the additives from the drilling fluids (e.g., biocides, scaling inhibitors, friction reducers), in addition to salts, metals, organic compounds present in the formation, such as chemicals causing scaling and hardness (e.g., calcium, magnesium, sulphates and barium), and Naturally Occurring Radioactive Materials (NORM). NORM is brought to the surface in the drill cuttings, in solution in the produced water, or in scales or sludges. The levels found in wastewaters are significantly lower than the safe limits of exposure; however, these should be monitored carefully in case concentrations increase during waste treatment. At concentrations higher than regulatory limits, the material must be disposed of at licensed facilities.

A further characteristic of this produced water is its salinity, measured in levels of Total Dissolved Solids (TDS). These levels vary between the shales, depending on the rock strata and the geologic basin, from brackish to saline to brine. Managing these levels of TDS has wider implications for water reuse and recycling.

Following this high initial flow, the levels of wastewater generated gradually decrease as production begins. Following field development, the returned water is produced in small quantities by a multitude of different wells over longer periods of time. The logistics challenges involved in managing these small volumes of water produced by multiple sources over longer periods of time will be different to those presented during field development—and the opportunities to reuse the wastewater are also different.

Figure 13. One example of composition of a fracturing fluid.

The key difference between shale and conventional gas production is that shale plays have limited permeability, which limits hydrocarbon flow to the wellbore. To release the gas contained within the shale, effective permeability is created artificially through hydraulic fracturing, a process by which a fracturing fluid is pumped into the reservoir to cause fractures. This process has implications for the management of produced water in shale gas production—which differs from conventional oil and gas, as shown in the table below.

This comparison explains some of the key differences in water management options available to shale gas operators when compared to conventional oil and gas:

- In shale gas production, the large volumes of flowback water produced in the initial stages need to be managed from the start of the production.
- The water quality of produced water from shale gas is often characterized by high TDS levels. This poses challenges in terms of water reuse in further operations and treatment to create freshwater.

**Figure 14:** Comparison of characteristics of produced water in conventional and unconventional.

<table>
<thead>
<tr>
<th>Volumes of produced water</th>
<th>Conventional oil and gas</th>
<th>Shale gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low volume initially</td>
<td>• The water-to-oil/gas ratio increases over the life of a conventional oil or gas well, until a stage where water forms up a majority of the volumes brought to the surface&lt;sup&gt;88&lt;/sup&gt;</td>
<td>Very high initial volume of flowback water (up to one million gallons over the course of a few weeks)&lt;sup&gt;89&lt;/sup&gt;</td>
</tr>
<tr>
<td>The water-to-oil/gas ratio increases over the life of a conventional oil or gas well, until a stage where water forms up a majority of the volumes brought to the surface&lt;sup&gt;88&lt;/sup&gt;</td>
<td>• This high volume rapidly drops off to a small residue amount of produced water (~50 barrels/day)&lt;sup&gt;90&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristics of produced water</th>
<th>Conventional oil and gas</th>
<th>Shale gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainly natural water naturally present in the formation</td>
<td>• Additional water may be from enhanced water recovery or water flooding</td>
<td>The returned water is mainly water injected during the fracking process (flowback water)</td>
</tr>
<tr>
<td>The returned water is characterized by its salinity (levels of Total Dissolved Solids)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Water management options

There are a number of options available to operators to manage these water requirements and the produced wastewater. Factors considered when evaluating different water management options will include costs, the shale’s particular characteristics, the life cycle stage of the well (e.g., pre- or post-development), the local infrastructure, the local regulatory framework, the availability of local water sources, and public perception of water risks in the area (e.g., aquifer pollution, earthquakes).

Underground injection

This method of disposal of produced water is normal practice in conventional oil and gas production. Operators can inject their wastewater in underground injection wells, or Class II Wells, or pay a third-party commercial disposal company to take their water and inject it into a disposal well. In the United States, either type of well must be permitted by a state agency or the EPA through the Underground Injection Control (UIC) program. These underground formations are situated in porous rock formations, thousands of feet underground.

As the cheapest disposal option for flowback and produced water, and with approximately 200,000 underground wells in the United States, disposal in underground injection wells is one of the most widely used, and most cost-effective, wastewater management options. Produced water is either hauled to these underground disposal sites, or piped (thus reducing traffic and hauling costs). The availability of injection wells in the Barnett, Haynesville and Fayetteville Shales explains the lower volumes of water recycling and reuse in these shales compared to the Marcellus. With the lack of nearby underground injection wells in Pennsylvania, operators in the Marcellus have to haul their wastewater several hundred miles away to wells in Ohio, thereby increasing the disposal costs and encouraging higher levels of reuse.

This preferred option could come under strain should links between their use and local earthquakes (for instance in Ohio) be made, which could increase pressure on regulators to limit the disposal of wastewater in injection wells. These restrictions could affect other areas as well—in 2011, the Arkansas Oil and Gas Commission (AOGC) shut four disposal wells in the Fayetteville Shale, after an outbreak of earthquakes near the town of Guy. In the absence of underground injection wells, operators in the Marcellus have turned to water reuse.

Table 1. Produced water by US Shale Play

<table>
<thead>
<tr>
<th>Shale</th>
<th>Initial water production (first 10 days) (gallons per well)</th>
<th>Long-term water production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett</td>
<td>500,000 – 600,000</td>
<td>High</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>500,000 – 600,000</td>
<td>Moderate</td>
</tr>
<tr>
<td>Marcellus</td>
<td>500,000 – 600,000</td>
<td>Low</td>
</tr>
<tr>
<td>Haynesville</td>
<td>250,000</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

High “long term” produced water generating play: > 1,000 Gallons per MMCF
Moderate “long term” produced water generating play: 200 – 1,000 Gallons per MMCF
Low “long term” produced water generating play: < 200 Gallons per MMCF
The unit of measurement used for comparison of long-term produced water is gallons of water per million cubic feet (MMCF) of gas or hydrocarbon liquid equivalent.

Source: Data from Chesapeake Energy.
development stages, flowback water ensures continuous volumes of water are available for reuse.\(^{99}\) Later in the life of a field, these wells will start producing small amounts of water over longer periods of time—making reuse less attractive.

The quality of the returned water will shape the decision on the levels of treatment required to reuse the water (simple filtration or dilution, or further treatment) without affecting well productivity. There are wide variations in the geochemistry of flowback water used for recycling and reuse in closed-loop systems, and there is currently no universal water quality standard.\(^{100}\) In particular, the constituents of concern include:

- **Concentration of Total Dissolved Solids (TDS):** High levels of salinity can impact the effectiveness of some of the friction reducers\(^ {101}\) used in the drilling fluid, resulting in adverse precipitation. In most cases, the TDS concentration of the flowback and produced water is higher than the desired TDS range for new fracture fluids.

- **Levels of Total Suspended Solids (TSS):** The returned water should be treated to a level where suspended solids will not cause scaling in the injection train or clogging of the pore space in the formation.

- **Concentrations of scale-forming chemicals:** Levels of scale-forming chemicals (including barium, calcium, magnesium) should be limited as these can have a negative impact on equipment and infrastructure.

- **Levels of microbial constituents:** Biological growth should be controlled, as microbes can increase the likelihood of plugs being formed in the wells.

Some operators will choose a simple dilution and/or filtration of the flowback water—this will suffice to meet the requirements of the fracking fluid. However, filtration only removes large solid particles (TSS), but will not address metals, or chemical constituents in the water, including high concentrations of TDS. Although reuse of returned water without treatment for TDS is an attractive option, the quality of the water deteriorates following each reuse as the brine becomes increasingly concentrated. Large amounts of freshwater are thus required to dilute these volumes when reusing wastewater for new fluids.

Varying levels of TDS and TSS levels in different shales will impact the different options available to operators (see Table 2 below). In the Woodford and Fayetteville Shales, for example, the TDS levels of the flowback water can be lower than in other shales—this could provide an incentive for increased levels of water reuse.\(^ {102}\)

### Table 2: Salinity of the flowback water from different US shales expressed in concentrations of TDS.\(^ {104}\)

<table>
<thead>
<tr>
<th>Shale</th>
<th>Average TDS (ppm)*</th>
<th>Maximum TDS (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fayetteville</td>
<td>13,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Woodford</td>
<td>30,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Barnett</td>
<td>80,000</td>
<td>&gt;150,000</td>
</tr>
<tr>
<td>Marcellus</td>
<td>120,000</td>
<td>&gt;280,000</td>
</tr>
<tr>
<td>Haynesville</td>
<td>110,000</td>
<td>&gt;200,000</td>
</tr>
</tbody>
</table>

* Parts per million.

**Treatment to create freshwater**

Treating the water to produce clean freshwater is the most expensive management option, due to the technologies used and the pre-treatment required. Evaporation and crystallization technologies are costly and require high energy inputs (see sidebar on "Primer: Water treatment technologies"). However, these technologies present the best options for treatment of the brines, in particular for removing the high levels of TDS.

Depending on the shale’s characteristics and regulatory requirements, operators are likely to use the “lowest-cost option that is legal and sustainable."\(^ {103}\) Furthermore, these choices are constantly evolving, with the drivers likely to change in the future.
Primer: Water treatment technologies

Water treatment considerations

From the different water management options available to operators, the water management option finally selected will depend on the quality requirements set for the treated water—that is, the requirements for reusing the treated water in the fracking, or the requirement to treat the water to freshwater. A further rationale for treatment of produced water is to reduce the volume of water to reduce costs associated with transporting large volumes of water to underground injection wells (this can reach up to half of the original volume following thermal distillation, for example).

Treatment technologies can be divided into two general categories, depending on which types of pollutants are removed: salt and other inorganic materials on the one hand, and oil and grease and other organic materials on the other hand. This distinction can be summarized as desalination and conventional treatment technologies. Much of the industry’s focus in the past year or two has been on finding technology solutions for the very high TDS flowback water found in the Marcellus Shale and other shale gas plays. Most of the technologies in this niche rely on thermal distillation and evaporation.

For shale gas operators to increase water recycling without compromising gas well productivity, many different water technology suppliers provide solutions for water treatment. Based on their methods, those technologies can be classified into four main groups.

Filtration

Filtration is widely used to remove suspended solids in wastewater. Filtration methods are broad, encompassing simple filters similar to those used in household use, to more efficient and costly filters with dedicated designs. The most basic filtration techniques are situated at the lower end of the treatment technologies, for instance, cartridge filters and media absorption devices. Filtration devices used in the shale gas industry consist of a filter with pore size range from 0.04 to 3 micros, which capture total suspended solids from wastewater and produce clean water. However, the process does not reduce the TDS levels in the wastewater. After treatment, water is usually hauled to new wells and blended with freshwater, a process that dilutes remaining contaminants in filtered water, for fracturing.

Chemical precipitation

Chemical precipitation is used to remove scale-forming constituents such as calcium, magnesium, barium, strontium, iron and manganese. It is also used to remove metals. Treatment chemicals and/or pH are added to the produced water to form particles that settle. The treated water is then decanted to remove these particles and create sludge. The water produced can then be reused in further operations or for other purposes (as long as the levels of salinity are acceptable) or can be discharged in limited applications.

Thermal-based technologies

While filtration and chemical precipitation do not reduce the TDS levels, thermal-based technologies specifically address the desalination requirements of wastewater with high TDS levels. This type of technology includes thermal-distillation, evaporation and crystallization. These technologies use varied energy sources to heat up water to near boiling temperature, to produce distilled clean water and concentrated brine or crystallized salt. Distilled water is then either collected for reuse or evaporated directly to achieve zero-water discharge (ZWD). Water treatment suppliers offering thermal-based technologies include Aqua Pure, Altelia Rain, Layne, Aquatech and GE.

Evaporation and crystallization remain very expensive. In Pennsylvania, proposals to build a regional crystallizer facility to provide reasonable per treatment cost of water per gallon may address these concerns. Thermal-based technologies significantly reduce the TDS levels, usually below 500 parts per million (ppm), which meets the standard for safe disposal as required by environmental regulations. The concentrated brine only on average accounts for 20 percent of the original wastewater, which significantly reduces the transport cost for hauling water to injection wells.

Membrane filtration technologies

Membrane technologies such as Reverse Osmosis (RO) are not effective at TDS levels higher than 35,000–45,000 ppm—as such, it has limited use in shale gas production. Membrane filtration technologies involve passing the produced water through a membrane that has a minimum pore size, which blocks the suspended and dissolved particles that are larger than the membrane pore size while the water and smaller particles pass through. The pore sizes vary, from microfiltration to RO.
3.3 Key trends

As competition for access to water increases, water reuse and recycling will become more widespread—particularly if the use of underground injection wells for wastewater disposal becomes more restricted.

More competition for access to freshwater

Access to water is likely to become more of a constraint for operators, particularly in arid areas and regions with seasonal water flow variations. In the United States, regulators have started to impose seasonal limits on volumes of water withdrawals via permitting restrictions in Pennsylvania. In drier regions, the competition for access to freshwater resources in particular areas will make water reuse more attractive. Logistics practices and wider water reuse will be key in addressing these concerns. In the long term, although non-water-based fracking methods have not yet reached wide-scale use, operators are increasingly looking at alternatives to hydraulic fracturing, in addition to the use of proppants requiring less water for transport.

More restrictions on the use of underground injection wells

There are currently approximately 200,000 underground injection wells in the United States, and permits to use these are relatively easy to get. However, the use of these wells could become more restricted. In the United States, links between underground injection wells and local earthquakes could, for instance, lead to further regulation of their usage. Moreover, in countries where underground injection wells have not been used, and where there is less familiarity with these and limited availability, this might be more of a constraint. The use of alternatives such as higher levels of water reuse or treatment to clean water will increase the cost by 10–15 percent and make hauling to the treatment facility more costly.

Each well will have its own unique configuration, driving different water management options

Each well and shale will continue to drive the water management options available to operators. The volumes of reuse in the Haynesville Shale, for instance, are very low compared to other shales, due to the poor flowback volumes and produced water quality (high TDS, high solids and high scaling coupled with low volumes of flowback water produced). This situation is a stark contrast to growing volumes of reuse in the Marcellus (some operators have targets of 85–100 percent reuse of flowback water). Moreover, the quality of the water from different sources will be different—in some countries groundwater can contain higher levels of biological growth, and therefore require more treatment—thus driving up costs.

The price of natural gas will continue to drive investment in different water management options

If the price of natural gas in the United States increases, there will be more drilling for natural gas. This possible increase is likely to act as a driver for increased levels of water treatment and reuse. New technologies are looking to reduce the cost of water treatment, while limiting energy inputs, impact on local air quality, and transportation demand. At present, sophisticated forms of water treatment are also the more costly. In the future, operators are likely to come up with innovative ways of treating wastewater from shale gas operations. Some argue that a regional crystallizing facility could reach a reasonable treatment cost per gallon.

Increased emphasis on the management of waste streams from wastewater treatment

Wastewater reused multiple times in shale operations will result in large quantities of highly saturated brine. Some of the technologies used to treat this wastewater back to lower levels of TDS will result in a number of waste streams. Thermal distillation treatment, for instance, results in a brine stream, while treatment through evaporation and crystallization create dry by-products. These waste streams will need to be managed effectively as part of a “cradle-to-grave” approach—particularly in stricter regulatory environments, such as in Europe.
In Focus

Water use/management in Argentina, China, Poland and South Africa

Water management in Argentina, China, Poland and South Africa will be different depending on the water scarcity and resources in the area.

Argentina water use/management

The local climate in the Neuquén Basin of Argentina is defined as arid, semi-arid and sub-humid.113 Neuquén province has a population of 551,000 and a population density as low as 5.9/km². The basin has access to surface water including the Neuquén River, Limay River and Lake Nahuel-Huapi. Although the average water availability per person is adequate for provinces like Neuquén and Mendoza within the basin, regional water stress is still observed. Water consumption by local agriculture irrigation reaches more than 7,000 m³/ha, which is equivalent to the water demand per hectare of an urban area with a density of 6,000 inhabitants/km².114 With 5 million gallons of water consumption per well, each fracking operation roughly is equal to the irrigation water demand of 1–2 hectares of crop per year. Large-scale development of shale gas would unavoidably cause conflicts between the industry and major water users in the agriculture sector.

Underground water resources have been widely used in many regions of Argentina for the purpose of agriculture irrigation. Historically, pollution of underground aquifers due to incorrect borehole closure and surface contamination was an issue for water users and can even contribute to soil salinization.115 Flowback water from shale gas wells contains high levels of salt and, if disposed of inappropriately, would risk increasing soil and surface water contamination. Therefore, shale gas operators in the region need to carefully handle wastewater discharge and develop adequate wastewater treatment capacity.

China water use/management

China’s water resources are scarce and unevenly distributed. Renewable water resource per capita was estimated at 2,156 m³/year in 2007, only one-fourth of the world average according to a World Bank water report.116 While China as a whole is facing a serious water crisis, the problems are made even worse by the fact that water resources are unevenly distributed spatially and temporally. Regions with large shale gas reserves have significant overlap with seasonal water shortage regions. In 2010, five southwest provinces (Sichuan, Chongqing, Guizhou, Yunnan and Guangxi), which hold 40 percent of national shale gas reserve, suffered six-month severe drought disasters. Ministry of Water Resources (MWR) data shows that 23 million people and 16 million cattle in these five provinces have difficulties to access drinkable water.117 North and northeast China have 26 percent of shale gas resources, but that part of the country is lacking water in general as water resource per capita in North China is even lower than the national average, only 700 m³/year.118 Lower Yangzi-Southeast China has more water resource, but only holds 18 percent of the shale gas reserve. Although shale gas has less water consumption per unit of energy compared with coal and fuel ethanol, large-scale development of shale gas in drought provinces requires good water management practice.

Underground water injection remains the top choice for wastewater discharge in the United States. Recent incidents in Ohio, however, have triggered public concerns on the links between wastewater injection and earthquake. In 2008, a 7.9 magnitude earthquake struck Sichuan and caused 70,000 deaths. Local communities are very sensitive to development programs related to geological changes. Underground water injection may face public opposition and become a difficult option for wastewater discharge. Municipal wastewater treatment facilities in China lack the capacity to treat potential wastewater from shale gas development. The State Council released a municipal wastewater facilities development plan that shows an ability to treat 77.5 percent of municipal wastewater, and the country is aiming for an 85 percent of treatment rate by 2015.119 Despite government efforts to increase investment, the gap between existing capability and demand for wastewater treatment cannot be closed in the short term. Shale gas operators need to develop their own wastewater treatment solutions, such as on-site treatment technologies, for their operations in China.

Poland water use/management

Water consumption for fracturing is a common public concern, but shale gas operation is unlikely to have a major impact on water resources. Shale gas operators can source water from considerable aquifer and surface water resources. Simulations by the Polish Geological Institute showed that the city of Warsaw alone consumes 4 to 10 times more water annually than the potential cumulative annual water
consumption for hydraulic fracturing in the whole of Poland.\textsuperscript{120} Poland is not a dry country and the 2010 EU water exploitation index (WEI), a measurement for pressure on freshwater resource, shows less than 20 percent for Poland.\textsuperscript{121} A WEI above 20 percent implies that a water resource is under stress and values above 40 percent indicate severe water stress and clearly unsustainable use of the water resource. However, in Poland, local regulations set the maximum rate of water extraction from a given aquifer, which is more important than the cumulative amount of water extracted. In theory, this management prevents a scenario where multiple users try to access a huge amount of water from the same aquifer at the same time.

Water pollution caused by fracturing is another public concern. The fractured formation in Poland is buried at a depth of up to 4,000 meters and its aquifer layer is at 100–300 meters. Even considering the possibility of induced fractures, which may penetrate 100 meters vertically, there are still more than 3,000 meters of isolation between them. At the surface, flowback water needs to be treated to prevent pollution. However, operators may face challenges on wastewater treatment due to the lack of wastewater treatment facilities in Poland. Based on a report prepared for the European Commission on environmental investment priorities in Poland, 190 million m\textsuperscript{3} per year of wastewater are emitted without treatment, and more than 75 percent of this is from municipal sewage systems.\textsuperscript{122} Sewer systems are largely missing in rural areas and current municipal sewage systems will not be able to cope with the additional volume of wastewater generated by the shale gas industry. Operators will have to invest in on-site water treatment technologies to cope with a large amount of wastewater once production starts.

Wastewater from shales in other parts of the world sometimes contain NORM, but the Upper Ordovician and Lower Silurian Shales in Poland do not contain elevated concentrations of natural radioactive elements, meaning this issue is not critical.

Figure 15. Regional population distribution that has difficulties accessing drinkable water in China in 2010.

In 2010, 33 million people had difficulties accessing drinkable water in five provinces, Southwest China.


South Africa water use/management

The water situation in South Africa is characterized by low average rainfall and high evaporation. The country has 500 millimeters (mm) of average annual rainfall, about half the world’s average of 860 mm. Within South Africa, rainfall is not evenly distributed; 21 percent of the country receives less than 200 mm of rainfall a year.\textsuperscript{123} The Karoo, where the shale gas formations are located, is a semi-desert arid area of South Africa and its name comes from a Khoisan word meaning “thirsty land.” The annual average rainfall in some parts of the Karoo can be less than 200 mm.
The climate of the Karoo is likely to cause problems for water sourcing, but it might also offer some opportunities for water treatment. The high evaporation rate will make thermal-based evaporation technology more efficient in the Karoo. This type of technology uses various energy sources to separate pure water from wastewater via the evaporation process. The concentrated brine or even crystallized waste can be transported with much less traffic volume. With limited water resources in Karoo, operators are also considering seawater and acid mine drainage water for fracking operations. Advanced water treatment technologies can help to explore these possibilities. Due to public opposition and the government’s decision to suspend the application process for exploration permits, operators are keen to show their commitment to being environmentally sustainable developers. Shell has promised not to compete with the local people of the Karoo for their water. As part of this effort, Shell has committed to identify, assess and manage groundwater issues related to the Karoo gas exploration project. A consortium of hydro geologists, led by SRK Consulting, has initiated an investigation in three exploration precincts for which Shell has applied to obtain exploration licenses. Shell has also committed to focus on disclosing details of fracking fluid composition at each drilling location on the Shell South Africa website. Other operators are likely to follow Shell’s practice in the future.

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Specific water regulation relating to shale water use and management is not available in all markets. The following table provides an overview of the trends that will be most relevant to the various markets.

<table>
<thead>
<tr>
<th>More competition for access to freshwater</th>
<th>Argentina</th>
<th>China</th>
<th>Poland</th>
<th>South Africa</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>More restrictions on the use of underground injection wells</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>Poland is not a dry country and shale gas is not expected to have a major impact on water resources.</td>
</tr>
<tr>
<td>Each well will have its own unique configuration, driving different water management options</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>To be seen – this depends on a number of factors, including public opinion, local risk of earthquakes and local regulatory requirements.</td>
</tr>
<tr>
<td>The price of natural gas will continue to drive investment in different water management options</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased emphasis on the management of waste streams from wastewater treatment</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>Although not specifically mentioned, we expect this to be an area of emphasis given public sentiment in all markets. In China, the government plans to build more wastewater discharge monitoring stations by 2015, to monitor water quality after treatment, and in Argentina, the local agriculture sector may demand more stringent rules on wastewater TDS level.</td>
</tr>
</tbody>
</table>

Figure 16: Relevance of water use and management trends to focus markets.
Water plays an important role on both the input and output ends of shale gas development projects. Water is needed to make up frack fluids. Following completion of a frack job, much of the water used in the frack fluids returns to the surface initially as flowback water and later as produced water (collectively referred to as "wastewater" here). Management of the wastewater streams presents challenges and potentially significant costs to the oil and gas operators.

**Underground injection**

In selecting a water management option, oil and gas companies consider costs, regulatory requirements, and whether or not an option can physically be used at a site. The most commonly selected option in the US shale gas industry is underground injection into disposal wells. Underground injection is typically among the lowest-cost options when it is available locally. The state oil and gas and environmental protection agencies are generally comfortable with the low risks posed by injection. Operators are likely to use injection unless there is a strong reason not to do so.

But there are some situations in which injection is not the first-choice option. If a suitable injection formation is not available near the well site, like in the Pennsylvania portion of the Marcellus Shale, operators are forced to look at alternative options. When regional freshwater supplies are limited, approaches that treat the wastewater to a level that allows reuse can help in providing sufficient water to sustain ongoing drilling and fracturing programs.

**What alternatives can be used when injection is not available?**

In the United States and Canada, injection is widely used and is well accepted by the government regulatory agencies. However, in my experience, injection is viewed with somewhat less enthusiasm in many other parts of the world. Neither regulators nor the public have a high degree of familiarity and comfort with injecting wastewater deep into the ground, and as a result they view injection with skepticism.

If injection is not available because of regulatory or policy barriers or an inability to find a good injection formation, the operators should consider other wastewater management options until one or more options are found that better addresses the company’s needs.

A variety of water management options have been employed at different locations and times in the US shale gas sector. Water management choices have evolved steadily over time and will most likely continue to evolve. Some of these are likely to be the options selected for use when shale gas is produced in other parts of the world.

Operators should manage the flowback and produced water in a cost-effective manner that complies with regulatory requirements. When injection is not available at a location, operators should look to other options. Most of the flowback and produced water from US shale gas wells that is not injected is managed in one of the following ways—these are applicable elsewhere in the world, too. The options are shown from lowest to highest amount of treatment:

- **Treat onsite and reuse.**
  
  Born out of necessity, several companies operating in the Marcellus Shale experimented with capturing the initial volume of flowback water, filtering it to remove suspended solids, then blending it with new freshwater to make up frack fluids for new wells. The early tests were positive, and soon nearly all Marcellus flowback was managed in this way. This type of process works well on the large volumes of one-time flowback that are generated by each well. They are less effective for managing the low volumes of produced water that continue to flow for months from each active shale gas well. Much of the ongoing produced water is trucked offsite for treatment or disposal. Treatment with simple processes (like a sock or bag filter) followed by reuse for future frack fluids is an attractive option that is being evaluated in other US shale regions, too. This method holds promise for use in other countries. However, each shale play should be evaluated separately to see whether the flowback quality is amenable to reuse after simple filtration.
Treatment to create clean brine
Flowback and produced water contain high levels of total dissolved solids (TDS), plus other constituents, like metals. In some locations, treatment to remove TDS is not necessary. As long as the metals are removed, the salty wastewater can be discharged or reused.
One of the most common approaches used to remove metals from produced water is to raise the pH, add a coagulant or flocculent chemical to promote solids formation, and then use clarification to remove the resulting metals solids. In some instances, this is the only form of treatment used, while in other instances it serves as a pre-treatment step before moving to a more advanced form of treatment. The chemical supply companies are actively working to develop new formulations that can function well at high salinity levels.

Treatment to create clean freshwater
Because of the high levels of TDS in flowback and produced water (TDS levels are initially high and quickly become even higher over the course of the first few days and weeks of the flowback process), these wastewaters are particularly challenging to treat to make freshwater. When TDS concentrations are lower than approximately 40,000 mg/L, RO-type membrane desalination processes can be used following pre-treatment. However, when the wastewater has TDS levels higher than 40,000 mg/L, RO technology becomes uneconomical to use. The only technology that is able to treat high-TDS wastewater is thermal distillation. Many companies offer their own versions of thermal distillation using several different mechanical processes. The basic principle of thermal distillation is to heat the wastewater to form water vapor. The water vapor is condensed or distilled creating a clean water stream and a concentrated brine stream. The technology works well, but requires a large amount of energy input to heat the water. If companies use this type of treatment, they should consider the cost of managing the resulting brine stream, too.

Evaporation or crystallization
In some arid locations, a few commercial disposal companies use large ponds to evaporate flowback and produced water passively. In crystallizer systems the entire volume of flowback and produced water is evaporated to a dry by-product in a mechanical heating device. However, in the absence of a free or inexpensive source of heat or energy, crystallizer systems become very expensive. The advantage they offer is that there are no liquid by-product streams.

As a final thought, in wastewater management, like in many other fields, one size does not fit all. Although some options are often favored, they are not suitable for use everywhere. Alternative options have a role depending on the site-specific situation. As shale gas operations move into other countries that have their own regulatory requirements, different climates and availability of infrastructure, the operators should evaluate each field individually. The cost of natural gas also plays a role in the types of water management options that are selected. Currently, gas prices are very low. Operators are unlikely to pay incrementally higher costs to use advanced water treatment technologies unless there are no other options available.
Water movements

The intensity and volume of water movements combined with the onshore and remote nature of many unconventional plays have resulted in an unprecedented focus on logistics as a key requirement for shale gas operations. Flexible and efficient logistics operations are required to support effective management of HSSE compliance; confirming on-time service delivery to dynamic operations and retaining control over water and water transportation costs, which are a significant portion of shale gas operations. Moreover, the growing concern around water resource usage and the call for greater water management oversight means that there is the opportunity for logistics to play a critical role in sustainable water management.
4.1 Shale gas development life cycle: logistics requirements

Logistics support is required across the shale gas asset life cycle, from transportation of materials to prepare the well site, through to ongoing produced water collections across the life of the completed well (see Figure 17). In advance of any drilling operation, access roads, well site and impoundments have to be constructed and prepared. At this stage, access road networks, impoundment locations and well pad layout should be carefully designed to take into consideration the large scale of truck movements that will be needed in the future. During the drilling phase, the majority of the logistics requirements are still related to movements of materials supply, with only small quantities of water required as an input for forming drilling fluids. As the well transitions into the fracking phase, logistics activity reaches a peak with large quantities of fracture fluid being used to stimulate the well. As mentioned previously, large volumes of water need to be sourced for the drilling and fracking phases. Freshwater is typically sourced from local water supplies and hauled directly to the point of use at the well pad. Alternatively, operators may haul to an intermediate area such as an impoundment for storage until it is needed to form fracturing fluids. This phase of the operation is highly volatile and prone to changes in plan, requiring a flexible and responsive logistics support model.

At completion of the fracking process, a portion (depending on the particular well and the play) of the injected fracking fluid will flow back to the surface. This flowback water can be transported away, either to an injection well for disposal or to a water treatment facility for further treatment; alternatively, in the case of multiple wells being drilled on the same pad, it can be filtered and/or treated on site for reuse in other wells. At the same time, the preparation of the well site for production would also begin. Rigs and other supporting equipment will be disassembled and transported away to the next drilling location. Once the flowback process is completed, the well will continue to produce water in the form of produced water that will require transportation, treatment and disposal over the life of the well.

The remote location of many of the shale gas plays and the dynamic nature of the operations make road transport the most commonly used mode of transportation, due to its flexibility. Increasing use of pipelines and rail, supported by inventory holding locations, is evolving in some of the more mature plays or where materials and equipment are heavy bulk and not available locally (e.g., proppants) but even in these operations road transport is still the de facto mode for the “last mile” movements to the remote and ever-changing drill sites. An overview of the type of material moves and volumes, broken down by phase, can be seen in Figure 18 and a breakdown of a typical logistics network to support shale gas operations is provided in Figure 19.

![Figure 17. Water movement challenges across the shale gas lifecycle.](image_url)

<table>
<thead>
<tr>
<th>Civil/site prep</th>
<th>Drilling</th>
<th>Completion/fracking</th>
<th>Flowback</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build access roads, construct and install well pads, prepare site for drilling</td>
<td>Drill vertical and horizontal wells</td>
<td>Complete wells with steel and cement casings</td>
<td>Capture, store and return fracking fluids</td>
<td>Capture, store and transport gas</td>
</tr>
<tr>
<td>Decommission</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Typical timelines:
- Civil/site prep: 60 days
- Drilling: 15-60 days
- Completion/fracking: 15-30 days
- Flowback: 20 days
- Production: 5-40 years

Water movement challenges:
- Diverse transportation needs to support the well pad preparation and infrastructure construction effort. Water movement requirement is minimal at this stage.
- Intensive and time-sensitive nature of water usage in drilling operation requires flexible and efficient logistics support.
- Intensive and time-sensitive nature of water usage in completion/fracking operation requires flexible and efficient logistics support.
- High volume of flowback water requires effective logistics management to minimize congestions, pollution and other social impacts.
- Transportation planning and effective cost management become increasingly important as demand for water movement stabilizes.
Figure 18. Logistics requirements overview.

<table>
<thead>
<tr>
<th></th>
<th>Civil site prep/Projects</th>
<th>Drilling</th>
<th>Completion/ Fracking</th>
<th>Flowback</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (approx.)</td>
<td>60 days</td>
<td>15-60 days</td>
<td>15-30 days</td>
<td>20 days</td>
<td>5–40 years</td>
</tr>
<tr>
<td>~ percent of daily road volume required*</td>
<td>5-15 percent</td>
<td>5-15 percent</td>
<td>60-80 percent</td>
<td>2-5 percent</td>
<td>&lt;2 percent</td>
</tr>
<tr>
<td>Activities requiring road transport</td>
<td>• Road construction</td>
<td>• Mobilization of drilling equipment and rigs</td>
<td>• Mobilization of fracking equipment and tanks</td>
<td>• Mobilization of frac tanks</td>
<td>• Water tanks • Wastewater</td>
</tr>
<tr>
<td></td>
<td>• Site preparation</td>
<td>• Waste (fluid and solid)</td>
<td>• Freshwater</td>
<td>• Wastewater</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Drill pad construction</td>
<td></td>
<td>• Waste (fluid)</td>
<td>• Removal of rig and drilling equipment in preparation</td>
<td></td>
</tr>
<tr>
<td>Examples of materials/resources transported</td>
<td>• Aggregate</td>
<td>• Casing / cement</td>
<td>• Water</td>
<td>• Water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cement</td>
<td>• Drilling chemicals</td>
<td>• Proppant</td>
<td>• Drilling equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Pipeline</td>
<td>• Water</td>
<td>• Fracking chemicals</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 19. Typical shale gas logistics network.

Source: Accenture Logistics Study Marcellus Field, August 2011.
4.2 Significance of water transportation

With 5 million\textsuperscript{126} gallons of water per well being used in the completion and fracking process, the transportation of water accounts for between 60–80 percent\textsuperscript{127} of total logistics requirements in the shale gas development cycle. As a result, the water supply chain has come under close scrutiny as operators look to set up and stabilize large-scale shale gas operations.

The industry response adopted by most operators has been to “unbundle” water from drilling and fracking contractors, with the operators taking direct control and responsibility for management of the water supply chain. This responsibility has represented a significant challenge for a number of operators, many of whom have not previously managed large-scale onshore supply chain operations.

4.3 Rising to the water transportation challenge

The volume and intensity of water transportation required for shale gas development present operators with a number of logistics challenges that are not seen in conventional gas. The following section highlights some of these key challenges facing shale gas operators.

1. Regulatory compliance

The growing public concern over the environmental impact of shale gas has led to an increased focus on the way resources, particularly water, are being used, monitored and controlled. For example, many US states require operators to report on the source, volume and disposal destination of any water used. Today, this task is typically handled manually by truck drivers and back-office staff, resulting in a costly and often inaccurate end-to-end process. As regulatory requirements and the scale of operations continue to grow, shale gas operators need to verify that they have the capability to comply with the new regulations efficiently and cost-effectively.

2. Road transport health and safety exposure

The level of transport activity associated with the movement of water and other modes of transport, places operators under considerable exposure to health and safety risk. Driving-related accidents are the single largest cause of fatalities in exploration and production-related operations. The exposure within shale gas operations is even greater, with remote locations often suffering from poorly maintained road networks and limited availability of skilled drivers. As the scale of operations continues to grow, the challenge of confirming health and safety compliance to global operator standards will become even greater.

3. Local community impact

The sharp influx of logistics activities during the drilling and fracking phases can have significant impact on the local community. Increased traffic congestions, damage to local roads, noise and air pollution are among the most commonly cited concerns relating to logistics activities. Local governments have to tackle these concerns by restricting shale operation traffic from entering residential areas; implementing weight limits on certain access roads and levying maintenance fees for heavy usage of public roads. Such measures can reduce operational flexibility and increase cost. In addition, failure to properly address local community concerns can impact public relations, and potentially results in more intrusive restrictions on operations.

4. Delivery assurance for dynamic, volatile operations

Given operational techniques associated with fracking are still maturing, there is high volatility in daily activity plans, resulting in considerable challenges in planning water transportation to support the operation. In some operations, the changes to planned water movements on day of execution are averaging approximately 60 percent.\textsuperscript{128} This is set against a backdrop of limited operational visibility, with metrics and data relating to the operations often difficult to ascertain. Providing delivery assurance for the operations is critical, but over-supply will result in severe congestion of vehicles at the well pad and on surrounding roads, resulting in HSSE exposure, operational challenges in managing congestion and high lifting cost. Conversely, a shortage of water can stop the operation, causing considerable cost wastage to an already cost marginal operation. Given this, logistics teams face a daily challenge in providing the delivery assurance of water critical to the success of the overall operations.
5. Commercial viability

Water transportation in some operations can account for as much as 40 percent of total fracking cost and 20 percent of total well completion cost, making it a significant contributor to the total cost of operations. This is compounded by rising transport and commodity costs in many of the locations as the scale of operations across the basin increases. Given that many shale gas operations are cost-marginal, effective management of the cost of transportation within these operations, if achieved, can be a source of strategic competitive advantage.

6. Talent and organization

The concentration of operators working within a shale gas basin and the often remote nature of the locations away from traditional oil and gas recruitment areas is resulting in an acute “war for talent,” as operators seek to recruit skilled road transport personnel in both execution and management roles. This situation is compounded by the lack of depth of experience in road transport within many operators and the need for a flexible workforce as the operations increase and contract over time. Moreover, with a large local workforce, union relationships need be handled delicately to reduce risk of disruption to operations.

This combination of the above factors has resulted in many shale gas operators looking for alternative ways of fulfilling their growing logistics talent needs.

4.4 Key trends

As a result of the numerous challenges, many shale gas operators are now exploring alternative ways to reduce road transport exposure.

Demand-side solution – reducing water demand

On-site water treatment and disposal

The development of on-site wastewater treatment and disposal technology is helping to reduce the demand for and cost of transporting water in shale gas operations (see Section 3, Water Management). Mobile water treatment units are however not available for all water treatment technologies and the use of reinjection wells is not applicable to all geologies.

Alternatives to water

Shale gas operators are looking at alternative technologies to reduce the amount of water used during the fracking process. Gas fracking, the use of propane-based gel instead of water, can reduce the required truck trips by up to 75 percent by reducing the need for water transport as well as the need for wastewater treatment. But these alternatives are in very early stages of development and not widely available today.

Improve water withdrawal

The amount of water an operator is able to draw from local sources is typically controlled by the local river basin commissions, with a maximum daily draw rate set as part of the water permitting process. In plays where water usage is constrained, an operator may elect to always withdraw the maximum daily amount in order to verify that sufficient water is available. In contrast, in plays where there is no such constraint, operators should consider optimizing on its water draw based on actual expected demand to reduce redundant transport requirements.

Supply-side solution – reducing road transport

Alternative to road transport

The use of rail car and overland pipeline is increasingly used in the more mature basins as an alternative to road transport. However, pipeline in particular can be expensive and not all locations are well connected into the national and local rail networks. The use of pipeline and rail as a transport mode allows water to be moved to central coordination points such as large impoundments. The final movement to the well site, however, will still require road transport.

Adoption of leading-practice logistics management models

Operators are increasingly looking externally to other industries for leading logistics management practices. Learning from industries where logistics have historically been critical to the business, shale operators are looking to adapt these leading logistics practices to the shale environment to help achieve reduction in road transport use. Streamlined efficient processes, targeted use of specialist software systems, deployment of skilled logisticians, and better commercial management of the operators are helping leading operators achieve significant reduction in truck miles and providing improved delivery assurance to the operations. In view of some of the internal challenges discussed above, it is possible that these improvement initiatives may be delivered through a logistics outsourcing model to leverage the logistics market resources and knowledge.
In Focus

Water movements in Argentina, China, Poland and South Africa

As the shale development is at early stages in Argentina, China, Poland and South Africa, water movements is not yet an issue. But these markets have an opportunity to facilitate more efficient logistics operations.

Argentina water movements

Argentina’s Neuquén shale gas basin largely overlaps with existing hydrocarbon production in the region, meaning the area has a well-established infrastructure including roads and the natural gas pipeline network. Despite closely accessible surface water bodies, shale gas operators face competition from traditional water users in the region and still need road transportation to haul water to well sites. The first small-scale shale gas production operation in the Neuquén Basin required 16 water pumping trucks operating simultaneously at full capacity. With the anticipated production growth, large traffic volumes for hauling water can be expected, and there is a strong case for leading-practice logistics management models.

The Neuquén Basin stretches to the subsoil of four provinces: Neuquén, Mendoza, La Pampa and Río Negro. Surface water bodies like the Colorado River and Limay River are provincial borders between Neuquén and neighboring Mendoza and Río Negro provinces. Due to the province-based governance structure of water-related affairs, including cross-provincial water sourcing and movements, actively engaging multi-stakeholders in different provinces has to be considered when developing logistic solutions.

A key solution to reduce logistics requirement for wastewater discharge is to develop on-site water treatment capacity. The treated water can be either reused by the shale gas industry or by local agriculture for irrigation. In the city of Mendoza, wastewater treated by municipal waste plant is used for irrigation and part of the cost can possibly be covered by farmers. Similar practices can be adopted by shale gas operators in other areas of the Neuquén Basin.

China water movements

Most shale gas activities are at an exploration stage, where logistics requirements remain low; although some operators currently use trucks to haul water to and from sites in Sichuan. There are also uncertainties around potential volumes of produced water in China due to the variations in geological conditions and shale bed depths compared to the United States. Operators are gaining knowledge on the amount of produced water in test wells, which will help determine logistics strategies for future large-scale development. Poor surface conditions and dense populations in shale gas-rich regions will increase the costs for operators to build infrastructures like roads and pipelines and will result in significant HSSE exposure for any road transport-related activity. The Sichuan Basin, for example, is one of the most densely populated regions in China and most of the landscape in Chongqing and Guizhou provinces is highly mountainous. Shale gas development plans should tackle rough surface condition and poor infrastructure in many parts of the country.

Poland water movements

In northern and eastern Poland, where the most promising shale gas basin is located, the population density is relatively low (20–60 people per km) and land use is mostly agricultural. Although this leads to less public pressure regarding potential increased traffic and noise, operators will face higher fuel costs per mile in Europe compared to the US market. Adoption of leading in-class logistics management practices will be required to reduce cost associated with road transportation.

The amount of freshwater required and wastewater produced in the shale gas industry has created additional logistical issues. US operators supply water to drilling locations with tank trucks and pipelines. If similar approaches are adopted in Poland, there would be two key challenges. First, sourcing water from aquifers, operators are limited by existing regulations in Poland on the maximum rate of water extraction from a given aquifer. Diversified water sources may be required for certain regions, which would result in additional logistics costs. Second, the capacity and technical capability of municipal infrastructure for wastewater treatment are less well developed in Poland. Hauling wastewater to nearby municipal treatment facilities may not be a feasible option. The situation is unlikely to be improved in the short term due to high demand for investment in many other infrastructure projects, such as gas storage facilities and pipelines. Operators therefore need to prepare for additional logistics costs to transport water to distant treatment facilities.
South Africa water movements

The Karoo region has a mixed ethnic population of 300,000. Many of the region’s residents live in settlements with limited water and sanitation. Local residents have various concerns on shale gas; farmers fear the industry will pollute and deplete already scarce water resources, while poor people are vulnerable to any water shortage but still hope shale gas development could bring local jobs. With all these concerns, shale gas operators have to carefully manage already tense relations with locals, trying to reduce the impact of increased traffic on local communities. Operators are considering sourcing saline water from deep formations in wells near drilling sites.

An annual report published by the Department of Water Affairs on wastewater treatment plants (WWTP) in South Africa shows a total 6,614 million liters/day\(^{133}\) of designed capacity and a current usage of 5,258 million liters/day. These figures indicate that there is approximately 20 percent extra capacity at WWTP in the whole country. However, the report also suggests that a significant portion of this surplus capacity might not be ready due to inadequate maintenance. Even if extra capacity does exist and is technically suitable to process wastewater from the shale gas industry, municipal WWTPs are several hundred kilometers away from the shale gas-rich Karoo Basin. Given a higher fuel price and relatively poor road infrastructure, operators will need to consider their approach for water management, assessing transport of water to WWTPs or development of on-site wastewater treatment technology.

Figure 20. Relevance of water movement trends to focus markets.

<table>
<thead>
<tr>
<th>On-site water treatment and disposal</th>
<th>Argentina</th>
<th>China</th>
<th>Poland</th>
<th>South Africa</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative to water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve water withdrawal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative to road transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adoption of leading-practice logistics management models</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Mentioned in China and Poland due to lack of water treatment capacity. Could also be interesting for South Africa and Argentina given local conditions.</td>
</tr>
</tbody>
</table>
Given the growth in North American shale gas development, we expect other geographies with shale resources to consider their development. We expect to see acceleration in the scale of investment in shale gas projects in emerging locations such as Argentina, China, Poland and South Africa. In many of these locations, we have already seen that the local infrastructure, suppliers’ market and regulatory regime for supporting shale gas development are still at the infancy stage. Operators looking to enter these locations should expect to face operational challenges similar to that of North America, with the added complexity of having to build the supply chain foundations and infrastructure that are absent in these locations.

Many shale gas basins feature a number of operators working in close proximity and under the same state regulatory environment. There are a number of potential collaboration opportunities that are available.

**Basin-wide collaboration opportunities**

1. **Cross-basin infrastructure development**

   Where there are basin-wide infrastructure challenges such as a lack of heavy vehicle suitable roads and limited central water storage locations, operators should consider developing these local infrastructure resources in a collaborative way. Such an approach will provide a holistic view of the resource development need across the basin and in so doing enable operators to design their supply chain network in a way that improves assets and equipment performance. This approach has the additional benefits of preventing duplication in infrastructure network, thereby reducing investment cost and logistics impact on the environment and local community.

2. **Coordinated development of suppliers**

   In new shale plays where the local market is relatively immature, operators will often need to develop the local suppliers to ensure that they perform to an operational level that is in line with industry standards. Given the external challenge such as “Talent and Organization” discussed earlier, it would be beneficial for the operators to collaborate and coordinate the development of local suppliers. This would be especially beneficial in highly constrained markets where there are limited capacity and likelihood of over-competition. Operators should focus on collaborating on indirect services such as water hauling and camp services to help reduce the local supplier development effort, while allowing operators to maintain control and competitive advantage in their core areas of operations. In such case, a coordinated approach to developing local suppliers can help accelerate suppliers’ development, provide greater level of stability to the market, while minimizing risk and reducing cost to the local operations.

3. **Sharing excess carriers’ capacity**

   The concept of carrier capacity sharing works by creating a market for excess transportation capacity that is accessible by operators working in the same basin. This approach is best suited to shale plays where there exists a pool of mature shale operators working in a volatile operating environment. To benefit from such practice, the shale operators and carrier should have good visibility of their supply and demand, underpinned by an agile logistics operations and effective communications. Sharing of excess capacity can help reduce operating cost through improvement in asset efficiency and help reduce operating risk through more flexible operations.

4. **Common logistics management platform**

   At the more advanced end of the collaboration spectrum, operators should develop basin-wide logistics management platforms to reduce the battle for resources and ensure standardized regulatory reporting. The key to this development would be a shared common software backbone, underpinned by a transport management system (TMS) and include other leading-class technologies such as Global Positioning Systems (GPS) and water inventory management tools. Running this platform across multiple transport modes and operators will help optimize operations, delivering benefits to the operators, regulators and the wider public.

**Common logistics management platform**

The retail, consumer goods and automotive sectors have long been focused on the use of "transport control towers" to reduce costs and improve service through their road transport operations. Indeed, within the oil and gas sector increasingly progressive techniques have brought these benefits to the downstream distribution networks of oil tankers in recent years. It is recognized that the logistics needs of an upstream shale gas operator are much broader than traditional freight transport operations, but customized models are being designed and implemented to target the unique challenges associated with the operating environment.

Unlike other industries, the pre-planning activity adds little value to upstream shale gas operations, given the frequent changes to plan experienced on the day of execution. However, significant benefits are being realized through targeted use of technology to provide live, real-time information on water inventory levels and vehicle locations. This information allows the control tower team of skilled logisticians to effectively manage the wait times and inventory levels of water across the basin, helping to reduce HSSE exposure, eliminate congestion, provide delivery assurance and reduce costs. The detailed metrics generated through the improved data also allow the control tower team to drive targeted continuous improvement initiatives, measure carrier performance
and confirm freight payment compliance, all of which help to further improve operations. While still in the early stages of development, these models are already delivering significant HSSE, cost and delivery assurance benefits to leading-class operators.

The targeted use of technology to provide real-time information on water levels and truck movements can have an impact on improved safety, operational performance, regulatory compliance and cost improvement.

1. Manage HSSE exposure
The adoption of advanced transport planning processes can lead to efficiency savings that are equivalent to 25 percent reduction in time spent on road. The use of GPS and in-Vehicle Monitoring System can provide real-time visibility of truck movements and drivers’ performance. This can, in turn, support reductions in wait times, allow for provision of advanced congestion alerts and confirm better driver HSSE compliance. The use of a water inventory monitoring tool can help to support water management compliance through visibility of water draw, disposal and movement. When scaled up to a basin-wide level, this is a significant reduction in HSSE exposure.

2. Drive improved operational performance
Real-time information on vehicle locations can reduce delivery windows and the application of dynamic re-routing can help avoid congestion. The use of basic technologies such as automated Short Message Service (SMS) notification can also help improve connectivity with carriers, especially for those operating in remote locations. Finally, the availability of accurate operational data and logistics diagnostic tools can be used to help identify issues and evaluate continuous improvement initiatives for both drilling and logistics operations. Basic traffic information similar to the smart infrastructure and sensors being deployed in cities around the world to ease congestion could be applied at the basin level and benefit all operators looking to optimize their logistics operations.

3. Assurance of regulatory compliance
The use of automated processes and systems can help confirm accurate and rapid data capture and reporting. The potential to apply this on a cross-operator, basin-wide basis would further confirm consistent reporting standards across multiple sites and operators.

4. Capture financial benefits
The adoption of a central logistics management system in combination with leading logistics practices can help reduce logistics cost through improved efficiency. Industry benchmarks suggest in some operations, a net reduction of up to 20 percent of logistics cost is achievable in water transportation, through reducing wait times, reducing truck miles and confirming compliance in carrier payments. Further benefits could be generated through cross-operator synergies if a basin-wide solution were developed.

5. Reduce battle for resources
With operators experiencing challenges in recruiting logisticians and facing increasing cost as demand for carriers increases, a streamlined basin-wide solution would help reduce the risks in this area.

Clearly, the rapid development of shale gas operations is presenting unique challenges to operators, which can be expected to grow as the investment in shale gas continues to gather pace across the globe. As operations mature, industry-wide collaboration represents a significant opportunity for operators to achieve their common objectives of reduced HSSE risk, regulatory compliance, reduced cost and enhanced service delivery, all of which can contribute to confirming a stable and prosperous future for shale gas operations.

Figure 21. Vision of a logistics management system for shale gas.
Lessons learned for new shale developments

Shale gas reserves outside the United States are in the very early stages of development, but there are many lessons learned from the US experience that can be leveraged. In this section, we highlight six key lessons learned.
Lesson 1
Data collection and management is critical and needs to be planned early

In the United States, operators have expressed a desire for simplification and standardization of reporting across states to reduce compliance costs. At the same time, regulators are seeking increasingly more data and disclosure from operators on their water use to support life-cycle and cumulative assessments of the impact of shale gas operations. Implementing a more data-driven, yet simplified reporting framework in an already maturing industry is likely to bring about its own challenges for operators and regulators in the United States.

A key challenge for US regulators has been the availability of data upon which to base regulations. Although regulations in emerging locations may not align with those being established in the United States, regulators in emerging markets should understand that they can leverage a large volume of operating and environmental data from the United States as they develop their regulations on hydraulic fracturing, water use and wastewater disposal.

Gathering rigorous local data on environmental impacts should also be seen as a priority, given the variations in water supply, consumption and returns observed within US basins. Gathering such information early will limit the risk of the challenges and delays experienced in US regulatory development due to insufficient data.

Regulators should also take a lesson from the United States and take the opportunity to be proactive in regulating water resources from the early stages of basin development, particularly implementing cumulative water monitoring and tracking approaches early to confirm the leading practice is ingrained. To achieve this, regulators and operators should verify that appropriate data collection and management systems are in place.

Lesson 2
There needs to be a balance between standard national legislation and regulation optimized for local characteristics of the shale

In the United States, individual regulations vary considerably between states, with different requirements for well casing, disclosure for drilling fluids and management of wastewater. Although more localized regulations allow better optimization to specific environmental and geological conditions, there is also value to regulation of certain areas at the federal level. In the United States, this balance is accentuated by the traditional balance of state versus federal primacy in regulation setting. The emerging shale gas locations will be regulated by national regulatory bodies, but these regulators should consider how flexible they make regulations within their nations to allow optimal balance of regulatory simplicity and optimization.

Coordination across regulatory agencies within a region is also important. Natural resources, environmental and water agencies all have roles in the regulatory landscape. This can lead to excess compliance costs for operators and regulators if regulation setting is not coordinated. For example, in China, the Ministry of Environment Protection is responsible for environment impact assessments for activities in the oil and gas industry. For specific wastewater discharge standards, the General Administration of Quality Supervision, Inspection and Quarantine is also in the regulatory committee.

Lesson 3
In this constantly evolving landscape, water management options can change. Proactive engagement with operators in developing regulation will help the implementation of effective solutions and reduce the cost of compliance

To establish an efficient, effective regulatory environment, regulators should engage operators early to set clear directions for development.

When operators first started operating in the Marcellus from the Barnett and Woodford Shales, the assumption was that underground injection wells would be used for storing wastewater from their operations. However, this option was quickly ruled out due to the geological constraints of the Marcellus (the lack of underground injection wells). Although one operator started to build an injection well in the proximity of its operations, the volumes of produced water were too large to be contained within it. Since then, the preferred option for disposal of long-term produced water in the Marcellus has been trucking to Ohio. Today, with the discovery of the Utica Shale underneath the Marcellus, Ohio regulators might decide to limit the number of operators who can use the underground injection wells to operators based in Ohio, for instance, by imposing extra costs or restrictions on operators in Pennsylvania. In addition to this, if links are shown between injection wells and local earthquakes in Ohio, the regulators could be swift to limit the use of these injection wells. In this constantly evolving landscape, it is important for operators to engage with local regulators to help implement feasible regulations and reduce the cost of compliance.
Another example of the importance of engagement with regulators is in the area of access to water. In the United States, there are various mechanisms and water rights laws (different in each state) determining water ownership and how it is distributed to competing users through permitting. In China, the water supply is managed by the Ministry of Water Resources, and groundwater falls within the realm of the Ministry of Land and Resources. Water permits are issued by the Department of Water Administration at the provincial level and county level for sourcing water from surface water (for example, a river or lake) and aquifers. Major shale gas operators in China are NOCs in partnership with IOCs. Due to their government roots, NOCs in general have a good relationship with regulatory authorities. Because water permits are granted at the provincial or county levels, engaging local government bodies at an early stage of the shale development plan is likely to help the water permitting process and environmental impact assessment in general.

Finally, operators should engage with each other in creating long-term wastewater treatment options for off-site disposal. While a growing number of operators are entering partnerships with water treatment companies to treat their water on site, there are opportunities to shape the landscape of water disposal off site, for example, through regional disposal facilities. Wastewater plants have opened operations where they are serving as third-party commercial waste companies. This approach is underpinned by engagement with local authorities.

Lesson 4

Geographies will have different issues/solutions depending on the geology of the shale and the particular regional characteristics—regional solutions should be sought to share knowledge among operators

Local characteristics are key to framing the water management options available to operators. Regional factors to consider include the local regulatory landscape, the geology of the shale and its water management characteristics, the local infrastructure and finally, the regional water availability. The geology of particular shales will frame the conditions for managing volumes of water required in shale production. The type of shale (dry or wet) will impact the volume and quality of produced water, so the challenge of managing these will be different. The depth of the shale will have an impact on the water requirements, with deeper shales requiring on average more volumes of water for drilling. Local geographical characteristics, including the availability of underground injection wells and local wastewater treatment plants will also drive the options. Finally, levels of water availability in particular regions are likely to play an increasing role in driving more water reuse and recycling. Indeed, in a heavily scrutinized industry, operating in areas of water scarcity will add pressure to increase levels of reuse.

As the challenges faced by operators in a particular area will be similar, there is an opportunity to seek regional solutions to manage the increased volumes of wastewater generated, and the high demands on freshwater. In Pennsylvania, for instance, a regional crystallization facility is being investigated that would reduce the cost of water treatment for operators and provide all operators in the area with the option to increase their levels of water recycling.

Lesson 5

Investing in creative water management options, particularly water treatment solutions, today is worthwhile. This investment will provide a competitive advantage in the long term, in a stricter regulatory climate or in the case of water shortages—but water treatment providers need to increase efficiencies

Some operators have been creative and moved very early on to increased levels of water reuse and recycling. Range Resources, for example, was one of the first operators to test fracking with reused water. The realization that this had no impact on the fracking has led to higher volumes of reuse water in the industry. Another example is Devon Energy. Although operating in the Barnett Shale, with more than 50,000 injection wells available in East Texas, and the cost and the infrastructure to allow injection to proceed very easily, Devon Energy has run a long-term trial program with Fountain Quail distillation systems to create distilled water and concentrated brine from its wastewater. This cost the company 20–30 percent more than if it bought it locally and brought it to local injection wells. Nevertheless, this approach has given it familiarity with a waste treatment company, and critical experience in wastewater management. Efforts to invest early in water treatment are likely to give these operators a competitive advantage in the long term.

Nevertheless, the real driver behind water management practices is the price of natural gas, which will continue to determine the level of operators’ commitment to and interest in developing sophisticated water management solutions.
treatment technologies. With a high gas price, operators are likely to have more capital to spend on water treatment. Furthermore, with higher gas prices, there is an incentive to drill more wells in one location, thereby providing more opportunity for shared water management options. In high gas price markets outside the United States, this could provide the shift toward wider and more sophisticated water management options in the industry.

On the other hand, water treatment providers need to increase efficiencies. So far, the buy-in has been limited by operators in the United States, where natural gas prices have been prohibitively low to justify the underpinning investment in water treatment. In the long term, there is an opportunity— if water treatment suppliers can supply their technologies at a lower cost.

Lesson 6

The logistics operating model will impact congestion, efficiency and reporting of water movements. New markets have the opportunity to design for the basin

A number of the emerging plays in these new locations are in the exploration and appraisal phase where drilling and fracking operations are relatively small in scale. Consequently, the level of logistics activities, including the demand for water and waste transport, are also relatively modest at present. At the early stages of development many operators have opted to bundle their water management and related activities with their drilling and fracking contractors under full-service contracts. However, as development accelerates and becomes more mature in these regions, there is a greater case for operators to unbundle some of the supply chain activities such as water supply and self-perform these as a single integrated supply chain. As the North American experience has demonstrated, to do so can bring greater control, better visibility and helps manage development cost. However, operators considering the feasibility of adopting this approach will need to consider a number of factors including the scale of operation, the in-house logistics capability and the logistical constraints facing the operation.

Many of the emerging shale plays are found in regions with limited oil and gas development history. In addition, a number of the large plays are also found in remote locations and emerging economies where logistics infrastructure and local transportation supply markets are relatively immature. Many of the emerging economies are growing rapidly with competing industries with similar demands for local logistics infrastructure, equipment and local resources. Combine the above factors with the significant growth expected in the shale gas sector, we expect this environment landscape scenario will lead to a battle for resources in the local logistics markets. Operators looking to enter countries or shale plays with these characteristics should proactively mitigate this risk by growing the local supplier base; adopt leading transportation management practices to reduce logistics resources use; and look at adopting basinwide operating models to alleviate the pressure on the local logistics market.

Some shale plays are located near large bodies of surface waters or municipal sources (for instance, the Marcellus and Fayetteville Shales) that are available to operators for use in shale production. As development moves into new regions where water scarcity is an issue, water may need to be drawn from multiple sources and from surfaces located further away, thereby increasing the complexity of the logistics challenges. The Sichuan Basin, for example, the largest shale gas basin in China, which holds 40 percent of the national shale reserve, straddles populous provinces such as Sichuan and Chongqing. These regions are also centers of major economic growth and as a result of water usage competition, frequently experience seasonal water shortages. For operators developing these areas, careful planning that takes into account the balancing demand of water usage, water network and the transportation network will be required to verify that the shale gas is developed in a sustainable and cost-effective manner.
As discussed throughout the report, the nature of the shale resource and the surrounding water and infrastructure environment will result in different implications. The following table compares the characteristics relevant to developing the shale gas resources in each country.

All these markets have an opportunity to develop their shale gas resources. Whether this happens will depend on whether the shale gas can be developed economically given the environmental considerations that need to be managed. Water treatment and increased regulation will drive up costs, but without public support, economic development of shale gas resources is unlikely. Of course, natural gas prices and the importance of energy security will also play a role.

Argentina hopes shale gas development will be able help to meet the nation’s increasing energy demand and reduce natural gas imports. Fortunately, its shale gas reserve is found in existing hydrocarbon production regions where infrastructures are well established. Carefully managing the relationship with the local agriculture sector on water sourcing and wastewater discharge are key challenges. Developing a sustainable model for recycling water from drilling sites to municipal wastewater treatment facilities and finally used for irrigation would be beneficial for all parties.

China has set ambitious targets for its shale gas development. The NDRC plan highlights leading practices but does not mandate specific practices. The use of underground injection wells is still being considered, but tighter regulation around fracturing water recycling, drilling activity and monitoring of wastewater discharge is expected. Logistics will be a key challenge, and planning for this early to develop the local supply markets and create infrastructure and operating models that aim to reduce congestion and improve movements will be very important.

Poland is in the European Union, where the tightest regulation around the development of shale gas resources is expected. It is already mandatory to disclose chemicals used in fracking, and an emphasis on water treatment over using underground injection wells is expected. Although water availability is less of an issue and there may be fewer infrastructure challenges, operating costs in Europe will be higher and the cost of fuel is high.

It is very early stages in South Africa. Water availability is a challenge as is the lack of infrastructure; however, the depth of shale is an advantage. The current TCP scheme allows very limited activities and operators are waiting to convert their TCPs to Exploration Rights. Since April 2011, the government imposed a moratorium to suspend potential shale gas exploration due to public concerns around the environmental impact of the fracking method. However, a recent decision by the South Africa government to lift the ban on shale gas exploration could take previously suspended projects a step forward.
<table>
<thead>
<tr>
<th></th>
<th>Argentina</th>
<th>China</th>
<th>Poland</th>
<th>South Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIA estimated recoverable reserves</td>
<td>774 tcf</td>
<td>1,275 tcf</td>
<td>187 tcf</td>
<td>485 tcf</td>
</tr>
<tr>
<td>Local revisions</td>
<td>n/a</td>
<td>882 tcf</td>
<td>67 tcf</td>
<td>n/a</td>
</tr>
<tr>
<td>Depth of shale gas bearing layer (ref: US is 2,000–3,000 meters)</td>
<td>2,400 meters</td>
<td>3,000–5,000 meters</td>
<td>2,500–3,800 meters</td>
<td>2,500 meters</td>
</tr>
<tr>
<td>Availability of water sources</td>
<td>Adequate water per person, but regional water stress is observed due to large consumption by agriculture irrigation</td>
<td>Regions with large shale gas reserve have significant overlap with seasonal water shortage regions</td>
<td>Not a dry country and water resources are not under stress</td>
<td>Low average rainfall and high evaporation</td>
</tr>
<tr>
<td>Availability of water treatment</td>
<td>Lack of water treatment, local agriculture is sensitive to salinization</td>
<td>Lack of municipal wastewater facilities in short term, situation is expected to be improved in longer term</td>
<td>Lack of wastewater facilities</td>
<td>Lack of water treatment but high evaporation rate may make thermal-based evaporation more efficient</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Shale gas basin overlaps with existing oil and gas production region; Good roads and pipeline network</td>
<td>Poor surface condition and dense population, and some areas mountainous</td>
<td>Population density is relatively low and land use is mostly agricultural. Higher fuel cost. Potential higher sourcing costs due to competition for water resources as population centers are close; Capacity and technical capability for wastewater treatment not well developed</td>
<td>Higher fuel price and relatively poor road infrastructure</td>
</tr>
<tr>
<td>Stage</td>
<td>Exploration and test wells drilled by a number of companies</td>
<td>Exploration: test wells with gas flow and limited commercial production</td>
<td>Exploration wells: completed test wells; 13 exploration wells completed by Feb 2012; 14 more planned in 2012</td>
<td>Technical cooperation permits; No physical exploration activity by June 2012</td>
</tr>
</tbody>
</table>

Notes: tcf = trillion cubic feet
n/a = not available
Implications for operators

The trends toward disclosure, holistic impact assessments, resource intensity and water management described in this study will have significant implications for operators. Not only will changes be required to maintain compliance, but also the requirements will create opportunities for competitive advantage in operations, particularly for larger operators. This study highlights five main areas in which operators should aim to develop their capabilities to succeed in the current operating landscape.
Data management and compliance

The increased requirement for data on the flows of all materials throughout the life cycle of shale gas operations, particularly water, make it vital for operators to upscale their data management capabilities. Capturing, storing and reporting this data will require a new level of data management for operators and also for regulators to effectively use the data to support cumulative environmental impact assessments. In addition to better internal data management, operators will have to manage interaction with suppliers and contractors to ensure handovers of data are efficient and support compliance. Larger operators can benefit from clear economies of scale in the development and deployment of such data management systems, particularly if there is consistency within and across basins.

Wastewater disposal

Historically, the common methods for produced water management from oil and gas operations has been disposal by injection into the producing reservoir to maintain pressure or enhanced oil recovery (EOR), or via underground injection into EPA approved Class II Salt Water Disposal (SWD) wells. Water conservation measures and lack of disposal capacity in new areas have focused more attention and research on recycling and reuse of produced water, especially on-site treatment and re-use. Although reusing flowback water without much pre-treatment for fracking is a solution in the short term, operators will need to consider more closely the long-term implications of producing large volumes of highly saturated brine. A plethora of treatment technologies have been developed to treat wastewater from shale gas production (both for reuse and recycling), and are available to operators in different permutations, (e.g., with or without pre-treatment, from simple filtration to high-end crystallization)—albeit at a higher cost than traditional disposal options.

There are opportunities to use partnerships with treatment suppliers to best leverage these technologies. In addition to offering processes to manage wastewater across their entire operations (e.g., by using mobile solutions), these partnerships can provide operators with solutions best adapted to their needs (e.g., volumes and quality of water required for the specific fracture fluid and the particular play in which they operate). Ultimately, these collaborations provide continuous improvement opportunities to recycle higher volumes of water, at a lower cost, while increasing efficiencies (e.g., waste streams, energy inputs required).

Water and emission intensity reduction

With pressures on global freshwater sources, and increased public scrutiny and reporting of water use in shale gas, the focus on reducing the water intensity of production processes will grow. In the first instance, this reduction will be achieved by delivering efficiencies in operations, including optimizing the well configurations and the number of wells per pad, and by maximizing opportunities for end-to-end reuse of wastewater. Ultimately, the current focus on developing proppants with smaller water requirements and alternatives to hydraulic fracturing could pave the way for reducing the water intensity of shale gas production.

Given the prominence of GHG emissions reductions in the case for increased use of shale gas in place of coal and oil, operator targets, and continued public and government pressure will encourage reductions in emissions intensity of shale gas production as a license to operate. An example of this can already be seen in the move to make green completions, which minimize venting or flaring of methane during well completion, the standard in all US shale gas development. With greater data, tracking of emissions from energy use in operations, such as fracturing and water transportation will also be a target for emissions intensity improvements.

Logistics and operating models

Given the intensity and scale of the water movement requirements for shale gas, shale operators should consider the following factors when assessing existing or new shale gas development opportunities:

Make logistics a key part of the development strategy: We have already seen the important role that logistics plays in shale development, ranging from water supplying to support fracking operations to wastewater transfer reporting to support compliance requirements. Given the criticality of this role, a shale-specific logistics strategy needs to be developed and play a central role in the overall shale development strategy. Early development and adoption of such strategy will also help confirm that any step changes in logistics practices and collaboration opportunities can be identified and pursued in a timely manner.

Adopt leading logistics practices and operating models: The demand and intensity of road transportation required for shale development, especially for water movement, means that there is a need to improve upon the logistics practices that are traditionally designed for onshore conventional development. Operators can obtain more control by unbundling the water supply chain from drilling services in order to optimize water throughout the life cycle. Adopting leading logistics practices, systems and tools that are commonly used in other industries, such as a transport control tower as discussed in earlier sections, can help manage EHS exposure, improve operational performance and drive cost effectiveness. These practices have already been adopted successfully by some industry-leading operators in North America with a view for wider implementation globally.
Actively pursue cross-basin collaboration opportunities in new locations: When entering new and emerging shale plays, operators often find that there are insufficient infrastructure and logistics resources to meet the demand of a large scale shale operation. Many shale gas basins also feature a number of operators working in close proximity and under the same state regulatory environment. Coupled with the battle for resources and the cost of developing the supply chain foundation, we see considerable synergy in operators working collaboratively. Operators should actively explore collaboration opportunities such as cross-basin infrastructure development, coordinated local supplier development, shared excess capacity or make use of a common logistics management platform as mentioned previously. This approach is especially attractive in countries where the shale development infrastructure is the least mature.

Collaboration

One option to overcome the challenges of increased regulation can be found in working with regulators and other operators to reduce the intensity of the basin (e.g., shared logistics, sharing excess capacity, sharing infrastructure) and to enable water treatment (e.g., shared regional facility). By sharing exposure in these key regulatory areas, operators can reduce their individual environmental footprint while leveraging leading practices from the industry and regulatory bodies in support of the ultimate goal—sustainable and regulatory-compliant production.
Overview of the challenges in the shale gas lifecycle

The following chart summarizes the key considerations we have presented in this report in each stage of development.

<table>
<thead>
<tr>
<th>Civil/site prep</th>
<th>Drilling</th>
<th>Completion/ fracking</th>
<th>Flowback</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build access roads, construct and install well pads, prepare site for drilling</td>
<td>Drill vertical and horizontal wells</td>
<td>Complete wells with steel and cement casings</td>
<td>Release gas through hydro-fracking</td>
<td>Capture, store and transport gas</td>
</tr>
<tr>
<td><strong>Typical timelines</strong></td>
<td><strong>60 days</strong></td>
<td><strong>15-60 days</strong></td>
<td><strong>15-30 days</strong></td>
<td><strong>20 days</strong></td>
</tr>
</tbody>
</table>

**Water regulatory challenges**
- Managing permitting across all sites to assess cumulative environmental impact on region
- Implementing suitable well and casing requirements to protect groundwater
- Managing water supply permits and disclosure of fracking fluid components
- Ensuring responsible collection of water, treatment, and disposal
- Long-term tracking of water flows and limiting gas venting during completions

**Water usage challenges**
- Access to water from surface, groundwater or municipal water sources
- Volumes and quality of water required for the drilling fluid (up to 99% of the fluid depending on the operator/shale)
- Volumes and quality of water required for the fracking fluid
- Managing the volumes of flowback water returned to the surface in the first few days following the fracking
- Managing the volumes of produced water returned to the surface following production

**Water movement challenges**
- Diverse transportation needs to support the well pad preparation and infrastructure construction effort. Water movement requirement is minimum at this stage
- Intensive and time-sensitive nature of water usage in drilling operation requires flexible and efficient logistics support
- Intensive and time-sensitive nature of water usage in completion/fracking operation requires flexible and efficient logistics support
- High volume of flowback water requires effective logistics management to minimize congestions, pollution and other social impacts
- Transportation planning and effective cost management become increasingly important as demand for water movement stabilizes

**Decommission**
- Water regulatory challenges
- Water usage challenges
- Water movement challenges
Acronyms

AOGC  Arkansas Oil and Gas Commission (US)
bcf   billion cubic feet
bcm   billion cubic meters
BLM   Bureau of Land Management (of the U.S. Department of Interior)
boe   barrels of oil equivalent
CCGT  combined cycle gas turbine
CERLA Comprehensive Environmental Response, Compensation and Liability Act (US)
CTL   coal-to-liquids
CWA   Clean Water Act (US)
DEC   Department of Environmental Conservation (New York state)
DGGC  Department of Geology and Geological Concessions (Poland)
DMR   Department of Mineral Resources (South Africa)
DWA   Department of Water Affairs (South Africa)
EIA   U.S. Energy Information Administration
E&P   exploration and production
EOR   Enhanced Oil Recovery
EPA   U.S. Environmental Protection Agency
GHG   greenhouse gas
GPS   Global Positioning Systems
GSGI  Global Shale Gas Initiative
GTL   gas-to-liquids
GWPC  Ground Water Protection Council (US)
HSSE  Health Safety Security Environment
IOC   international oil company
IOGCC Interstate Oil and Gas Compact Commission (US)
IP    intellectual property
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSG</td>
<td>Karoo Supergroup</td>
</tr>
<tr>
<td>LNG</td>
<td>liquefied natural gas</td>
</tr>
<tr>
<td>mcf</td>
<td>thousand cubic feet</td>
</tr>
<tr>
<td>mmcf</td>
<td>million cubic feet</td>
</tr>
<tr>
<td>MLR</td>
<td>Ministry of Land and Resources (China)</td>
</tr>
<tr>
<td>MPRDA</td>
<td>Mineral and Petroleum Resources Development Act (South Africa)</td>
</tr>
<tr>
<td>MWR</td>
<td>Ministry of Water Resources (China)</td>
</tr>
<tr>
<td>NDRC</td>
<td>National Development and Reform Commission (China)</td>
</tr>
<tr>
<td>NEPA</td>
<td>National Environmental Policy Act (US)</td>
</tr>
<tr>
<td>NESHAP</td>
<td>National Emission Standards for Hazardous Air Pollutants (US)</td>
</tr>
<tr>
<td>NPDES</td>
<td>National Pollutant Discharge Elimination System (US)</td>
</tr>
<tr>
<td>NOC</td>
<td>national oil company</td>
</tr>
<tr>
<td>OPA</td>
<td>Oil Pollution Act (US)</td>
</tr>
<tr>
<td>REACH</td>
<td>Registration, Authorization and Restriction of Chemicals (EU)</td>
</tr>
<tr>
<td>SDWA</td>
<td>Safe Drinking Water Act (US)</td>
</tr>
<tr>
<td>SEAB</td>
<td>Secretary of Energy Advisory Board (US)</td>
</tr>
<tr>
<td>STRONGER</td>
<td>State Review of Oil and Natural Gas Environmental Regulations (US)</td>
</tr>
<tr>
<td>SWD</td>
<td>Salt Water Disposal</td>
</tr>
<tr>
<td>SGEIS</td>
<td>Supplemental Generic Environmental Impact Statement (New York state)</td>
</tr>
<tr>
<td>SMS</td>
<td>Short Message Service</td>
</tr>
<tr>
<td>SPDES</td>
<td>State Pollutant Discharge Elimination System</td>
</tr>
<tr>
<td>tcf</td>
<td>trillion cubic feet</td>
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<tr>
<td>TCP</td>
<td>Technical Cooperation Permit (South Africa)</td>
</tr>
<tr>
<td>TMS</td>
<td>transport management system</td>
</tr>
<tr>
<td>WEI</td>
<td>Water Exploitation Index (EU)</td>
</tr>
<tr>
<td>WWTP</td>
<td>wastewater treatment plants</td>
</tr>
<tr>
<td>ZWD</td>
<td>zero-water discharge</td>
</tr>
</tbody>
</table>
References

8 Based on data from the FracFocus website, http://fracfocus.org.
12 Ibid.
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39 “Europe, Africa, Asia governments assess shale development policies,” The Oil and Gas Journal, 2 July 2012.


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63 Waterless fracking technologies (for instance, using propane/ liquid CO2) are being investigated, but these are still in early stages of development.


65 Personal communication with John Veil, Veil Environmental LLC, 2012.

67 Ibid.


69 Personal communication with Radisav Vidic, University of Pittsburgh (2012).


73 Proppants are sized particles mixed with fracturing fluid to hold fractures open after a hydraulic fracturing treatment. These include naturally occurring sand grains, man-made or specially engineered proppants.


78 Produced water is an operational term used to describe the wastewater produced once the well is in operation.


83 Ibid.


85 Total Dissolved Solids (TDS) is a measure of inorganic and organic substances in a liquid. Its levels are indicators of the levels of salinity of different waters.


90 Personal communication with Radisav Vidic, and William Kepler, Whiteford Professor and Chair, Department of Civil and Environmental Engineering, University of Pittsburgh, 2012. Used with Permission.

91 Friction reducers are additives, generally in slurry or liquid form, used to reduce the friction forces experienced by tools and tubular in the wellbore.


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