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Water Management in Shale Gas Development

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WORLD GAS CONFERENCE

Water is a critical consideration in shale gas development

~ 5m gallons per well (~1000 water truck movements)

	Civil/site prep	Drilling	Completion/fracking	Flowback	Production
	Build access roads, construct and install well pads, prepare site for drilling	Drill vertical and horizontal wells	Complete wells with steel and cement casings Release gas through hydro-fracking	Capture, store and treat returned fracking fluids	Capture, store and transport gas Decommission
Typical timelines	60 days	15-60 days	15-30 days	20 days	5-40 years
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 (approximately 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

Source: Accenture Water and Shale Gas Development PoV

Current Situation

Basin-specific considerations and solutions

The sourcing options, water composition, flowback/production volumes, and disposal options differ across basins (even within a basin)

Water Sourcing options:

- freshwater
- flowback water (from reuse)
- alternatives to potable water
- alternatives to water

Use/Treatment of Flowback/Produced Water

- haul to disposal site - landfill or underground injection (primary method for produced water and for the waste stream coming out of water treatment)
- filter and reuse (increasing for flowback water)
- treat to drilling fluid quality
- treat to surface disposal (mostly not allowed in US)
- treat for agriculture use
- treat to freshwater

Challenges to more sustainable water practices

- Economics. In most basins, freshwater and UIWs still the lowest cost option
- Landowner often does not want brackish water on his/her land
- Landowner wants the water (if well is on his land) or disposal fee (if UIW is on his land)
- Do not want to risk delays to fracturing jobs
- Do not want to compromise fracturing jobs

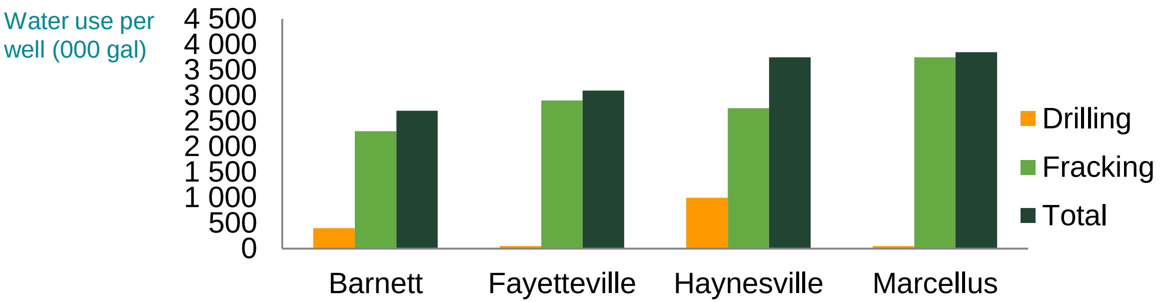
Source: Accenture Research

Current Situation

Comparison of water use and characteristics across basins

Comparison of water use in drilling and fracturing

Water use in drilling and fracking across four US shales



Comparison of flowback volumes

Produced water by US Shale Play

Shale	Initial water production (first 10 days) (gallons per well)	Long-term water production
Barnett	500,000 – 600,000	High
Fayetteville	500,000 – 600,000	Moderate
Marcellus	500,000 – 600,000	Low
Haynesville	250,000	Moderate

Source: Mantell, M., "EPA Hydraulic Fracturing Study Technical Workshop #4 Water Resources Management, "Chesapeake Energy, 2011. Available online at: www.epa.gov.

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 Galloons per MMCF
The unit of measurement used for comparisons of long-term produced water is gallons of water per million cubic feet (MMCF) of gas or hydrocarbon liquid equivalent

Comparison of water composition

Salinity of the flowback water from different US shales expressed in concentrations of TDS

Shale	Average TDS (ppm)*	Maximum TDS (ppm)*
Fayetteville	13,000	20,000
Woodford	30,000	40,000
Barnett	80,000	>150,000
Marcellus	120,000	>280,000
Haynesville	110,000	>200,000

*Parts per million

Source: "Cost-Effective Recovery of Low-TDS Frac Flowback Water for Re-use, "U.S. Department of Energy, June 2011, www.netl.doe.gov.

Source: Accenture Water and Shale Gas Development PoV

Current Situation

Overview of Technologies

Not Exhaustive

	Technology	Contaminants removed	Technology Description	Basin examples
Pre-treatment	Filtration	TSS	Pump water through basic filtration device to effectively remove total suspended solids	Fayetteville, Marcellus, Barnett
		Micro-filtration: TSS, microbes, Ultra-filtration: virus, odor	Waste water pass through membrane driven by low pressure (e.g. vacuum), TSS and microbes can not pass through due to pore size, therefore separated from water. Micro-filtration: pore size 0.1 – 3 micros, Ultra-filtration: pore size 0.01 – 0.1 micros	
	Chemical precipitation	Scale-forming chemicals (Ca, Mg, Fe)	Treatment chemicals/pH are added to the water to form precipitation, particles that settle. The treated water is then decanted to remove those particles	Marcellus, Barnett
Desalination	Thermal-based technologies	TDS (~ 200,000 ppm)	Distillation/Evaporation system use energy to heat up and evaporate water, leaving behind all dissolved salts in concentrated brine or as solids (zero water discharge)	Barnett, Marcellus
	Membrane – reverse osmosis	TDS (~ 50,000 ppm), microbes	Force water passing through a RO membrane from high salinity side to the high purity side, the applied pressure must be in excess of the osmotic pressure of dissolved contaminants Large molecules and ions can not pass through the membrane	Barnett, Woodford
Post-treatment	Electro-coagulation	TSS, metal ions, oil & grease	Passing waste water through electrolytic equipment neutralizes the electrostatic charges on suspended solids and oil droplets to facilitate agglomeration or coagulation and resultant separation from the aqueous phase. The treatment prompts the precipitation of certain metals and salts.	Haynesville, Utah
	Biocide/UV	Microbes	Use biocide or UV treatment to control bacterial growth. UV lights kills bacteria via damaging its DNA and stopping growth	Haynesville

Source: Accenture Research

Current Situation

Technology choices depend on the “Treat To” objectives

	Pre-treatment		Desalination		Post-treatment	
Objective: Treat To	**Filtration**	**Chemical Precip.**	**Thermal**	**Membranes**	**Electro-coagulation**	**Other (e.g. biocide, UV)**
Filter and reuse in fracturing fluid	✔					✔
Treat to drilling fluid	✔	✔	✔	✔	✔	
Treat to surface disposal (rarely allowed)	✔	✔	✔	✔	✔	✔
Treat for agriculture use	✔	✔	✔	✔		
Treat to freshwater	✔	✔	✔	✔	✔	✔
Haul to disposal site- landfill or underground injection	✔					
Sample basins	Barnett, Fayetteville, Marcellus	Marcellus	Barnett, Fayetteville, Marcellus	Barnett, Marcellus, Woodford	Haynesville, Utah	Barnett, Haynesville, Marcellus

Source: Accenture Research

Current Situation

Water Movements

Overview of Logistics Requirements

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

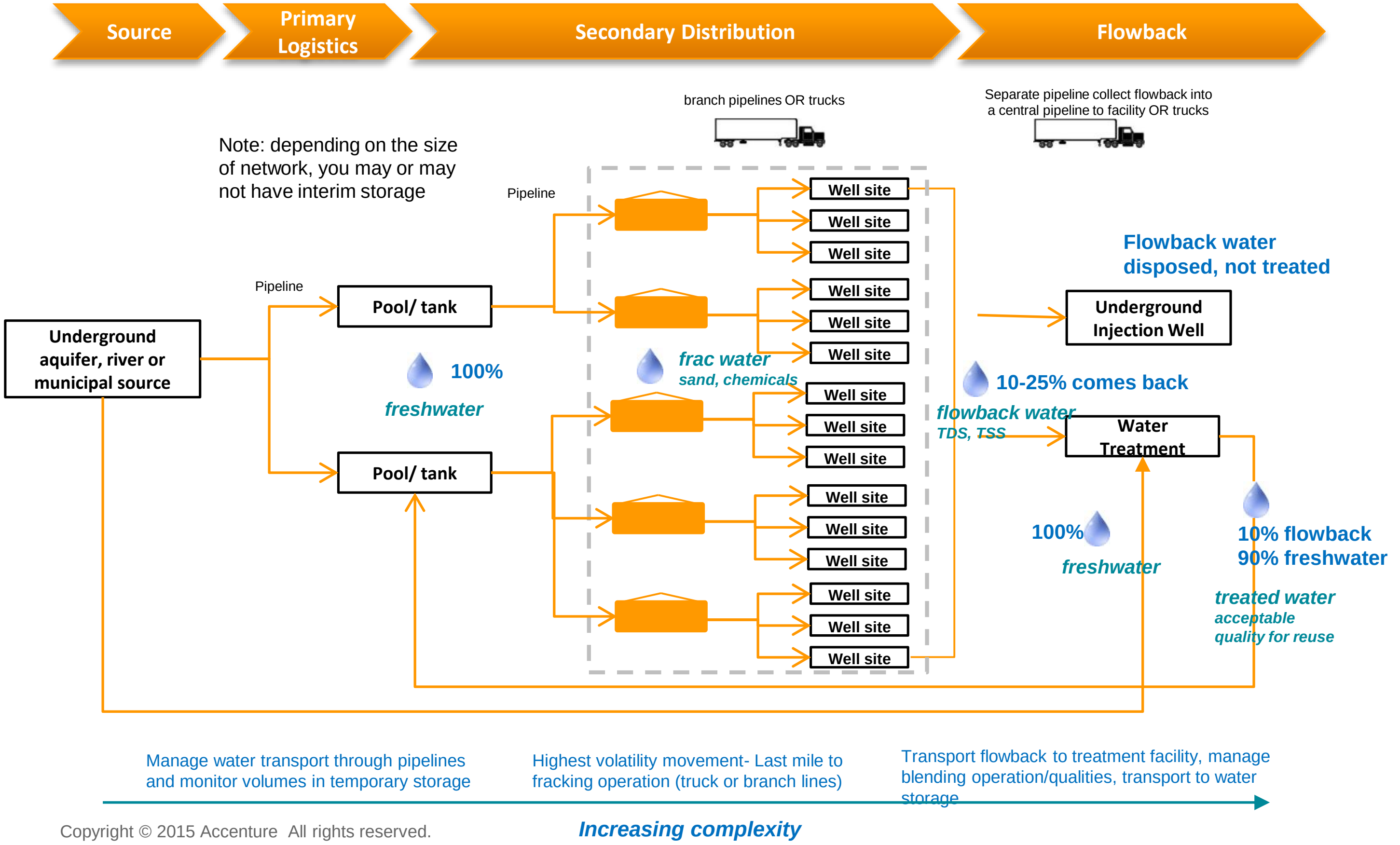
Challenges

1. Regulatory Compliance
2. HSE Exposure
3. Local Community Impact
4. Delivery assurance for dynamic, volatile operations
5. Commercial Viability
6. Access to talent

Source: Accenture Water and Shale Gas Development PoV

Current Situation

A day in the life of a droplet of water



Source: Accenture Research

Trends

Reuse and Alternatives to Potable Water

Horn River

Background:
Horn River Basin contains a moderately saline water (35,000 ppm TDS), in a high strength, high permeability rock matrix capable of supplying thousands of barrels of water per hour

Operators: Apache, EnCana:
- Sourcing: a closed loop system using 35,000ppm brine from a dedicated deep reservoir as fracking fluid
- Flowback water: cleaned and re-injected

Marcellus

Flowback water:
TDS: high (120,000ppm), TSS: modest (210ppm),Hardness: high (34,000ppm), Oil & Grease: low (30ppm).

Operators: e.g. Chesapeake:
- Sourcing: Reuse flowback water (10 ~15% of total water required)
- Flowback water: filtered (100 & 20 micro)
- Produced water: low volume, disposal well & advanced water treatment (limited)

Suppliers: e.g. AquaPure(distillation, filtration)

Fayetteville

Flowback water:
TDS: low (13,000ppm), TSS: low, Hardness: low

Operators: e.g. Southwestern Energy:
- Sourcing: Reuse flowback water
- Flowback water: filtration (collected in ‘frac tank’, hauled to the next sites,100% reuse)
- Produced water: modest volume, class II injection well

Suppliers: e.g. Ecosphere Technologies (Ozionix)

Coal Mine Water

Discussion: University of Pittsburgh, Pennsylvania Department of Environmental Protection
Challenge: Pennsylvania and the surrounding region have substantial amounts of coal mine water (CMW) in abandoned, closed but actively managed, some have suggested that it could be used as a water source for hydraulic fracturing operations

Conclusions:
- Use CMW for fracturing is technically viable
- Cost of using CMW based on operating/maintaining existing CMW facilities is lower than the cost of building new water treatment facilities
- Many CMW sites are close to drilling areas

Propane Gel

Background:
Operators in the Eagle Ford wants to minimise water souring/disposal costs . Operators also expressed concerns about the fact that water fracking can damage the fragile Eagle Ford Shale formation.

Operators: e.g. BlackBrush:
- Sourcing: Propane gel enables waterless fracking (95% ~100% water reduction)
- Flowback water: eliminate much of the flowback water

Suppliers: e.g. GasFrac

Nitrogen Foam

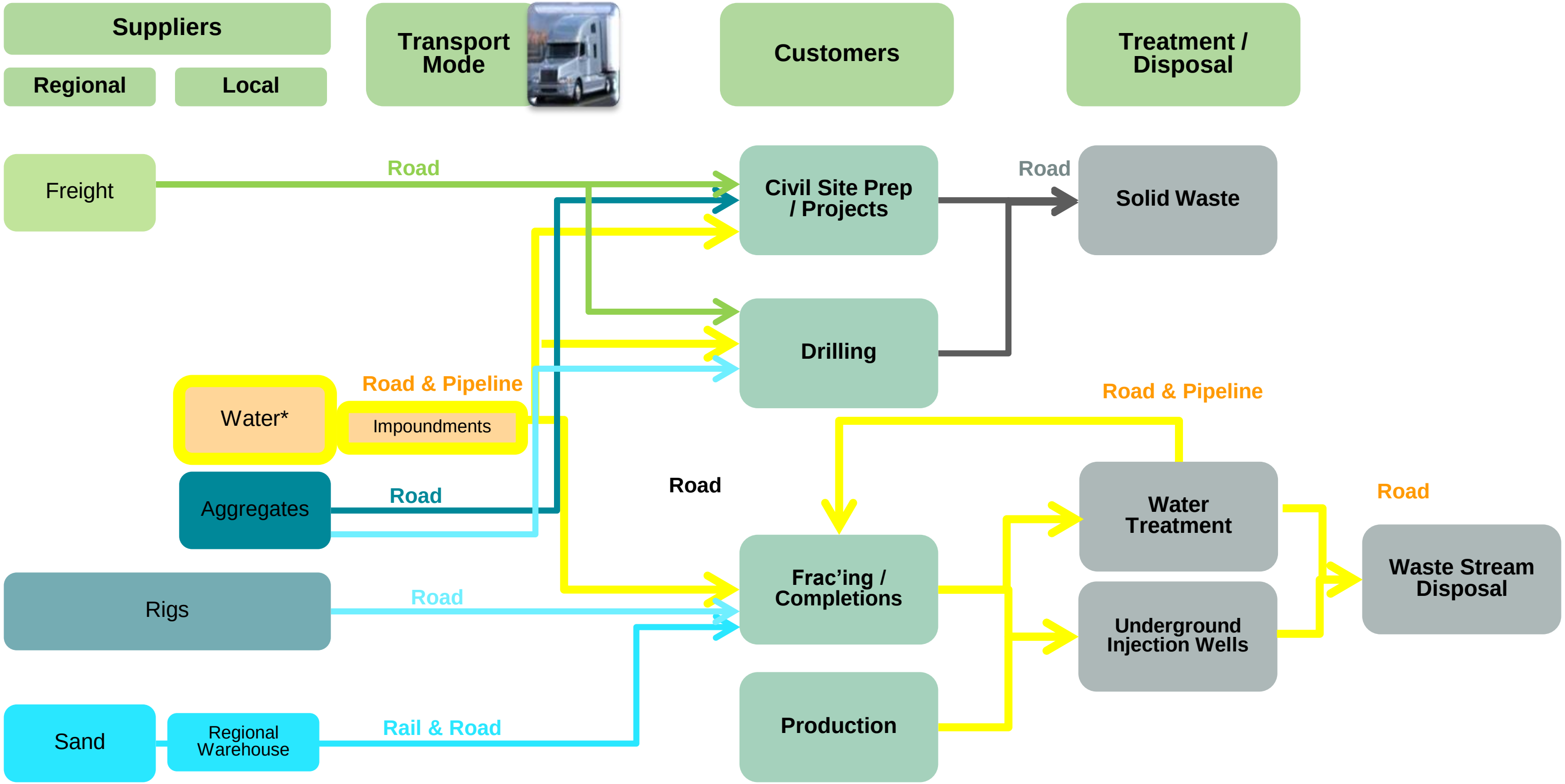
Operator: Chesapeake,
Supplier: Baker Hughes
Technology: Uses ultra lightweight proppants injected into a high-pressure nitrogen or carbon dioxide stream. This creates flow stream of >90% gas, facilitating flowback

Aim: Reduce the amount water used in fracturing/ reduce flowback water
Benefits: Achieve upto 95% reduction in fracking water, no polymer residue or formation damage, liquid disposal nearly eliminated

Source: Accenture Research

Trends

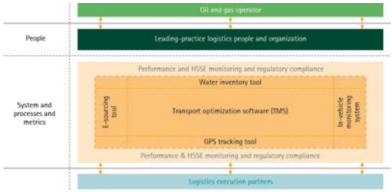
Optimise movements of which water is a key movement but not the only one



Source: Accenture Research

Reduction in Road Movements

Leading Logistics Practices



- Best Practice Transport Management
- Collaborative 2/3PL Sourcing Strategy
- Setup of Flexible Supply Chain
- Focus on People Logistics
- Supply Chain Unbundling
- Demand Planning, BoM Management

On Site Solutions

- Onsite water wells
- Onsite water treatment
- Onsite disposal wells

Chesapeake Aqua Renew program: At each Marcellus and Utica well site, produced water is transferred to central locations where suspended particles are removed through either gravitational separation or through filtration. The water is tested for salt and other mineral content to determine the rate at which it can be blended with freshwater to ensure proper quality and quantity for reuse by Chesapeake operations

Pipelines

Anadarko Petroleum Corp.

Anadarko Petroleum Corp. (APC) has 14 rigs drilling about 30 horizontal holes per month in Colorado. To address the associated infrastructure growth, APC has installed a water supply pipeline network for **"on-demand water."** Over a year, the use of this pipeline system eliminates 3.75 million miles of truck traffic, 750,000 gallons of diesel consumption and resulting emissions, and reduces surface disturbance by limiting on-site storage needs.

Source: Chesapeake, Anadarko, Accenture Research

Trends

4PLs and World Class Logistics Operations

Water logistics best practice processes and in vehicle and tracking systems

Planning

- Automated upload Frac Plan from frac's team
- Utilise data from previous performance
- Build schedule and define costs, optimal routes & carries

Carrier Notification

- Flexible choice for notification
- The driver will be made aware of the preferred routes and notified with any changes in plan

Carrier Acceptance

- The driver has flexibility and can provide confirmation/ acceptance through portal via SMS, email or phone

Carrier Pick-Up

- Monitor on water withdraw levels to ensure truck capacity is fully utilised
- In vehicle monitoring for HSSE performance tracking & reporting
- GPS automatically 'Check in' the driver on arrival to site

Carrier Journey& Drop-off

- In vehicle monitoring for HSSE performance tracking & reporting
- GPS provides visibility on driver location and checks against the plan
- Real-time notification to avoid congestions

Freight Billing

- Self invoice based on captured distance and time of all vehicles
- Accurate performance measure for all carriers
- Eliminate the risk of overpayment

Reporting , Analytics & Compliance

- Automated system to generate reporting
- Full visibility of all logistics to allow comprehensive reporting
- Opportunities to drive cost reduction

Source: Accenture Research

Opportunities for Innovation

Diversity of options, technologies and suppliers creates opportunities for innovation and competitive advantage

1

Ecosystem of suppliers who can cover:

- Combinations of techs
- Operations and services,
- Ultimate waste disposal (from water treatment)
- Expand to key basins

2

Chemical Net Balance

End to end consideration of chemicals use. Eg. pre-treat water to remove properties in water that cause corrosion or scaling, so corrosion inhibitors and anti scalants not needed in fracturing fluid

3

Water Movements

- Road transport vs. closed loop system and pipelines
- Basin-wide logistic management solutions (e.g. share excess capacity with other operators)

6

Technology R&D

- Continuous improvement existing technologies to lower the costs
- New innovations to use alternative water source (e.g. mine drainage and for disposal) and for use of wastewater (eg. industrial uses)

5

Optimization of water treatment, field operations/ activities

- Centralised vs. on-site treatment
- Blending
- Holistic approach to assess / optimise water reuse in field operations

4

Different **operating models** flowback vs. produced water

- Flowback water: very diverse set of options
- Produced water : much fewer options and opportunities to work basin level

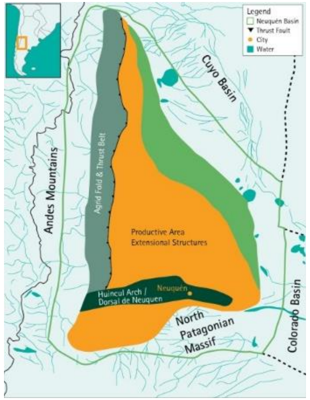
Source: Accenture Research

In Focus: Argentina, China, Poland, South Africa

Argentina

Neuquén Basin Shale Gas Prospective Area and Basemap

- 774 tcf (EIA)
- 2,400 meters
- Adequate water, regional stress



Poland

Map of Poland's Shale Gas Basin

- 67 tcf (local)
- 2,500- 3,800 meters
- Not under water stress

China

Shale Gas Distribution in China

- 882 tcf (local)
- 3,000-5000 meters
- Seasonal water shortage

South Africa

Map of Operators' TCP coverage in the Karoo Basin

- 485 tcf (EIA)
- 2,500 meters
- Low average rainfall

Source: "World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States," U.S. Energy Information Administration, 2011, www.cia.gov

Implications for Argentina, China, Poland and South Africa

Argentina

Best situation of the 4 countries. Concerns regarding disposal. Opportunities for reuse and new UIW wells

- Provincial Regulation
- Low population density
- Access to surface waters
- Water availability ppn adequate
- Some regional water stress
- High consumption local agriculture
- Overlaps w/ hydrocarbon region
- Well established infrastructure of roads and natural gas pipelines

China

Challenged across all dimensions with time needed to build infrastructure. Opportunities for alternatives to potable water (city waste water). Reuse and productive use important. Will lead innovation in water use for unconventional development

- National and Provincial
- High population density
- Water resources scarce, unevenly distributed
- Seasonal water shortages
- Sensitive to geological changes
- Poor surface conditions
- Highly mountainous

Poland

High development and water disposal costs in Europe, but good water availability and infrastructure

- National Regulation
- Low population density
- Not a water stress area
- Access to surface waters
- Agricultural land
- Higher fuel costs

South Africa

Most challenged of the 4 countries with severe shortage of water and infrastructure. Non potable water sources and reuse critical

- National Regulation
- Low average rainfall, high evaporation
- Semi desert area
- Water stress area with poor population
- Many residents live in settlements with limited water and sanitation
- Relatively poor road infrastructure

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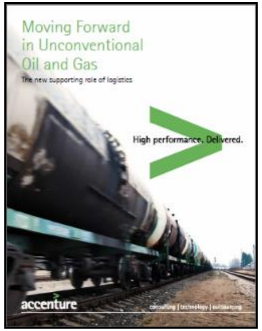

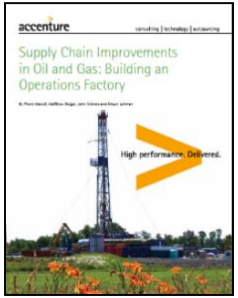

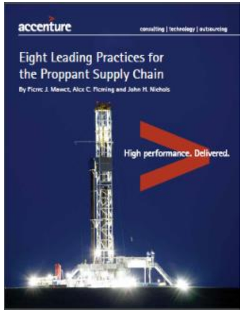

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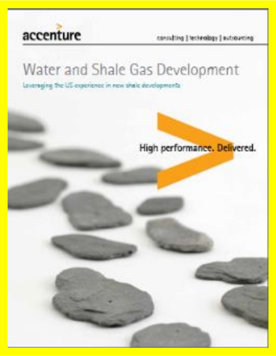

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