



Atlantic Council

ENERGY & ENVIRONMENT PROGRAM

Produced Water: Asset or Waste?



Blythe Lyons

Produced Water: Asset or Waste?

Blythe Lyons

Nonresident Senior Fellow, Energy and Environment Program



© 2014 The Atlantic Council of the United States. All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means without permission in writing from the Atlantic Council, except in the case of brief quotations in news articles, critical articles, or reviews. Please direct inquiries to:

Atlantic Council
1030 15th Street, NW, 12th Floor
Washington, DC 20005

ISBN: 978-1-61977-054-6

May 2014



Foreword

The outlook for US oil and gas production impacts the United States' geopolitical strategy. On the domestic front, realization of the potential for self-sufficiency, if not outright independence, will depend on public acceptance. This acceptance, in turn, will be predicated on industry's success in developing integrated and sustainable water management practices. Water is key to unleashing domestic energy resources, especially the "unconventionals."

This report is one of several in the Council's Energy and Water Nexus Initiative series. The three major goals of this initiative are to promote sustainable policies with common sense recommendations, clarify the terms of the debate with fact-based information, and provide a gateway for the public and policy makers to experts and additional information.

Over the past five years, the Council has addressed several areas of the nexus, including electricity production, fuels extraction, and the municipal water sector. Today, the Council is focusing on an intersecting issue that both the energy and water industries can work on together: how to promote sustainable strategies for recycling and finding beneficial uses for produced water from oil and gas production.

The Council convened its "Produced Water: Asset or Waste?" workshop on June 24-25, 2013, to provide the energy and water industries with an opportunity to identify sustainable water use plans and technologies to meet the needs for treating produced water. Both industries were asked to discuss policy and regulatory recommendations that would encourage best practices. Other key stakeholders and experts discussed market opportunities and the investment outlook. The audience heard many different perspectives from Capitol Hill to organizations working on unique produced water projects. By holding forums with experts and stakeholder groups, the Council aims to both educate and encourage dialogues that can lead to solutions.

This workshop and report were made possible thanks to presentations by experts from Capitol Hill, universities, oil and gas producers, the water treatment industry, consultants, and the financial community. The Council would like to give special recognition to John Veil for his generous gift of time and advice in organizing the workshop and commenting on the report. Thank you also to those who attended the workshop as participants.

Frederick Kempe
President and CEO
Atlantic Council

Table of Contents

- Introduction** 1
- Section I: What’s at Stake?** 2
 - The Global Perspective 2
 - The US Oil and Gas Landscape 2
 - The Gas Shale Gale 2
 - The Oil Revival 4
- Section II: Key Workshop Insights** 6
 - Produced Water Outlook 6
 - Shifting Debate 6
 - Produced Water Treatment in the United States 7
 - Drivers 8
 - Expanding Opportunities 8
 - Barriers 9
- Section III: Recommendations** 12
 - Federal Government 12
 - Regulatory Approach 13
 - State Policies 14
 - Industry 14
- Section IV: Concluding Remarks** 16
- Appendix** 17
 - Defining Produced Water 17
 - Produced Water Characteristics 19
 - Produced Water Volume Projections 19
 - Current Produced Water Disposition Practices 20
 - Produced Water Treatment Drivers 20
 - Produced Water Managment Options 21
 - Produced Water from Conventional and Unconventional Sources 22
 - Conventional Onshore Oil and Gas 22
 - Conventional Offshore Oil and Gas 22
 - Unconventional Coal Bed Methane 23
 - Tight (Oil and Gas) Sands 24
 - Heavy Oil 24
 - Unconventional Shale Gas 25
 - Unconventional Oil-rich Shales 26
 - Summary Comparison of Practices in the Marcellus, Barnett, Bakken, and Eagle Ford 27
 - Barriers 28
 - Opportunities for Expanding Use of Produced Water 29



Introduction

US national security is enhanced by energy security. The United States is enjoying a unique opportunity to bolster its energy security by increasing domestic production of oil and gas resources. The recent explosion in domestic unconventional production will allow an expanded bandwidth of US responses to the turmoil in the Middle East and Europe. If further exploited, the move toward energy self-sufficiency also gives the United States a cushion to reassess its global strategic policies. Expanding the domestic resource base further provides the United States with an industrial advantage in global commerce.

This report focuses on some of the water-related issues impacting the United States' ability to unleash domestic energy resources. Sustainable and publically acceptable water management practices are essential for both conventional and unconventional oil and gas production. Recycling and beneficial reuse of the growing quantity of produced water that will be generated by oil and gas production have the potential to bolster public acceptance and use water resources wisely.

This report, based on a workshop held at the Atlantic Council on June 24-25, 2013, promotes the idea that sustainable water strategies require that produced water be considered as an asset rather than as a waste. It is intended to be a gateway resource for the public and stakeholders to selected in-depth reports, databases, and experts. It provides a summary of the issues, barriers, and recommendations for public policymakers as they grapple with strategies to treat produced water as an asset in the toolbox of water management practices.

The Atlantic Council's produced water workshop and report are not intended to substitute for industry technical conferences on trends, technologies and management options. Instead, the Council's goal is to expand the discussion to include policymakers and public groups whose voices are essential in the

development of a base upon which the United States can successfully enhance its energy, economic, and national security.

THE RECENT EXPLOSION IN DOMESTIC UNCONVENTIONAL PRODUCTION WILL ALLOW AN EXPANDED BANDWIDTH OF US RESPONSES TO THE TURMOIL IN THE MIDDLE EAST AND EUROPE.

The report is divided into four sections. Section I puts the produced water issue into perspective through a look at what's at stake both domestically and globally in the pursuit of sustainable energy and water policies. Section II summarizes the key insights gained from the workshop discussions. Section III contains the workshop participant's recommendations for regulatory activities, federal policy, state government actions, and industry approaches. Finally, the appendix contains the bulk of the information that was presented in the two-day workshop concerning produced water characteristics, volumes and current treatment options for: conventional onshore and offshore oil, unconventional coal bed methane, tight sands, heavy oil, unconventional shale gas; and a summary of produced water treatment options, barriers, technology needs, and opportunities.



Section I: What's at Stake?

The Global Perspective

The National Intelligence Council's *Global Trends 2030* report identifies seven global trends, shown in table 1, that will greatly influence world events; four of the seven directly pertain to the importance of addressing water issues.¹

The water-related trends that will shape global development in the future include:

- growth of the middle class that will demand more electricity and food, which will in turn require more water and more efficient use of the water already available;
- urbanization that will increase base load electricity demands for transportation, municipal needs, and heating and cooling, which requires water for fuels extraction and power plant operations and cooling; growing food and water pressures, especially in areas facing scarcities of both; and
- US energy independence, which will require the country to develop the right water strategies.

While the United States does not face a national water shortage, several regions face prolonged droughts, which leads to conflicts between water for energy production, municipal needs, and agricultural and livestock requirements. The United States has an opportunity to lead the world in resolving such conflicts, and address the water issues identified in the *Global Trends 2030* report, as it spearheads development of unconventional resources.

Many other countries are embarking on or considering programs to develop unconventional resources. Knowledge of best water management practices gained

in the United States can assist the great number of countries struggling to attain sustainable economic and social development. US companies will benefit as they showcase US-developed technologies and management services and thereby increase access to overseas markets. Success in developing US technology for shale plays, particularly those that lead to sustainable water practices, will feed into US companies' international operations and improve their bottom lines.

The US Oil and Gas Landscape

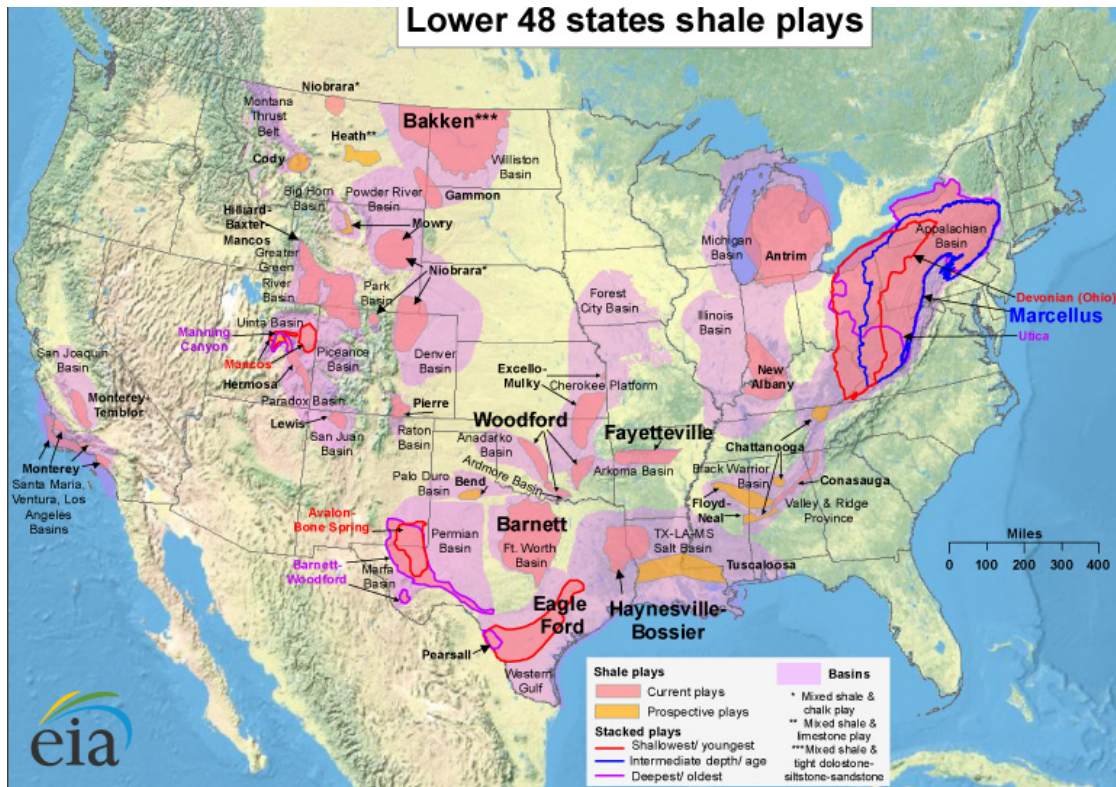
The increase in US oil and gas production, which began to ramp up in 2006, is mainly due to unconventional production techniques such as hydraulic fracturing in oil and gas shale plays.

The map on the following page shows over one dozen shale gas plays in the United States. They include: Antrim Shale, Michigan; Barnett Shale, Texas; Caney Shale, Oklahoma; Conesauga Shale, Alabama; Fayetteville Shale, Arkansas; Floyd Shale, Alabama; Gothic Shale, Colorado; Haynesville Shale, Louisiana; Collingwood-Utica Shale, Michigan; New Albany Shale, Illinois Basin; Pearsall Shale, Texas; Devonian Shales, Appalachian Basin; Chattanooga and Ohio Shales; Marcellus Shale, located in Pennsylvania, New York, Ohio and West Virginia; Utica Shale, New York and Ohio; and Woodford Shale, Oklahoma.

Oil-rich shale plays are located in San Joaquin and LA Basins (Monterey), California; Bakken, North Dakota; Avalon and Bone Springs, Texas; and Eagle Ford, Texas. In addition, there is the potential for a significant expansion of production from residual oil zones that have not yet been recognized in most forecasts.

¹ This key insight was pointed out by Tristan Abbey, professional staff member of the US Senate Committee on Energy and Natural Resources. See Abbey, "Produced Water," presentation at the "Produced Water: Asset or Waste?" event, Atlantic Council, Washington, DC, June 24, 2013.

Figure 1. US Shale Gas And Shale Oil Plays



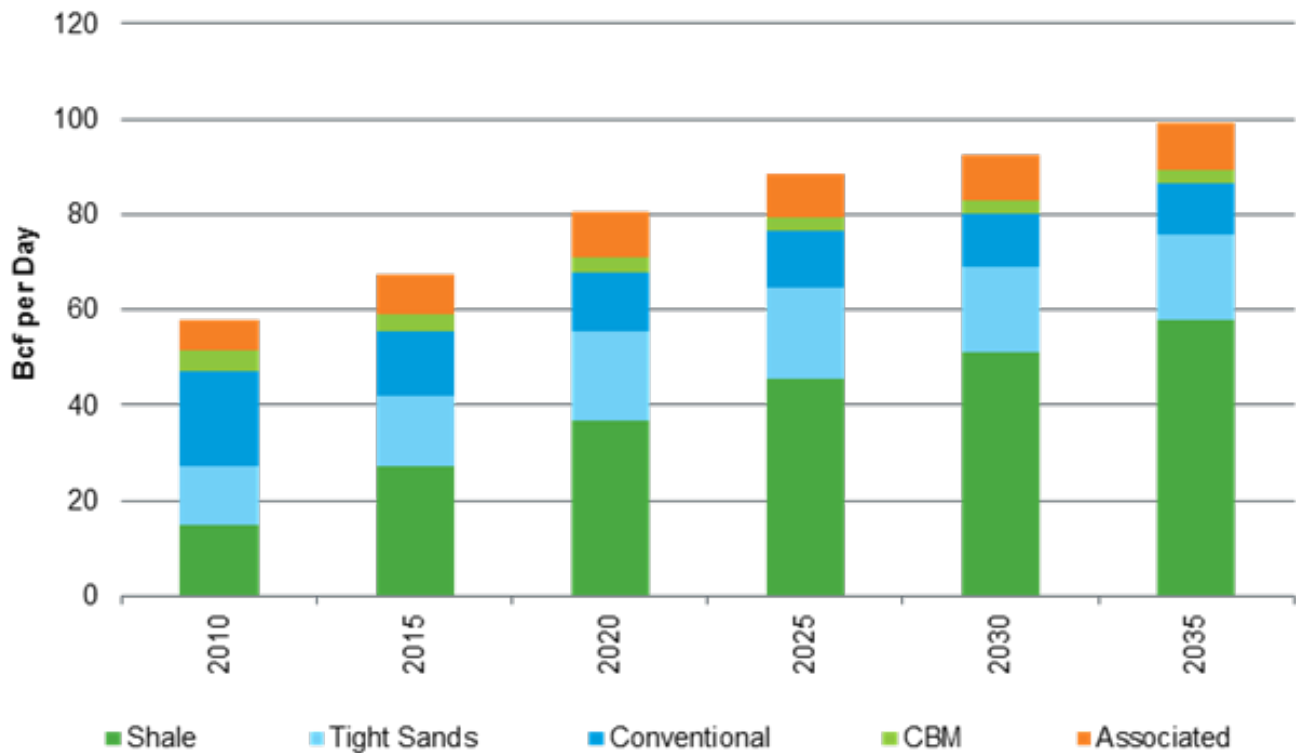
Source: US Energy Information Administration, *Review of Emerging Resources: US Shale Gas and Shale Oil Plays*, (Washington, DC: US Department of Energy, July 2011), p. vi, <http://www.eia.gov/analysis/studies/usshalegas/pdf/usshaleplays.pdf>.

Table 1: Global Trends Relating to Energy and Water Use

TECTONIC SHIFTS BETWEEN NOW AND 2030	
Growth of the Global Middle Class	Middle classes most everywhere in the developing world are poised to expand substantially in terms of both absolute numbers and the percentage of the population that can claim middle-class status during the next 15-20 years.
Wider Access to Lethal and Disruptive Technologies	A wider spectrum of instruments of war—especially precision-strike capabilities, cyber instruments, and bioterror weaponry—will become accessible. Individuals and small groups will have the capability to perpetrate large-scale violence and disruption—a capability formerly the monopoly of states.
Definitive Shift of Economic Power to the East and South	The US, European, and Japanese share of global income is projected to fall from 56 percent today to well under half by 2030. In 2008, China overtook the US as the world’s largest saver; by 2020, emerging markets’ share of financial assets is projected to almost double.
Unprecedented and Widespread Aging	Whereas in 2012 only Japan and Germany have matured beyond a median age of 45 years, most European countries, South Korea, and Taiwan will have entered the post-mature age category by 2030. Migration will become more globalized as both rich and developing countries suffer from workforce shortages.
Urbanization	Today’s roughly 50-percent urban population will climb to nearly 60 percent, or 4.9 billion people, in 2030. Africa will gradually replace Asia as the region with the highest urbanization growth rate. Urban centers are estimated to generate 80 percent of economic growth; the potential exists to apply modern technologies and infrastructure, promoting better use of scarce resources.
Food and Water Pressures	Demand for food is expected to rise at least 35 percent by 2030 while demand for water is expected to rise by 40 percent. Nearly half of the world’s population will live in areas experiencing severe water stress. Fragile states in Africa and the Middle East are most at risk of experiencing food and water shortages, but China and India are also vulnerable.
US Energy Independence	With shale gas, the US will have sufficient natural gas to meet domestic needs and generate potential global exports for decades to come. Increased oil production from difficult-to-access oil deposits would result in a substantial reduction in the US net trade balance and faster economic expansion. Global spare capacity may exceed over 8 million barrels, at which point OPEC would lose price control and crude oil prices would collapse, causing a major negative impact on oil-export economies.

Source: US National Intelligence Council, *Global Trends 2030: Alternative Worlds* (Washington DC: Office of the Director of National Intelligence, December 2012), p. v, http://www.dni.gov/files/documents/GlobalTrends_2030.pdf.

Figure 2. US Gas Supply Growth Outlook By Hydrocarbon Formation



Source: Mary Barcella, IHS Inc., February 7, 2014. This content is extracted from IHS Energy North American Natural Gas service and was developed as part of an ongoing subscription service. No part of this content was developed for or is meant to reflect a specific endorsement of a policy or regulatory outcome. The use of this content was approved in advance by IHS. Any further use or redistribution of this content is strictly prohibited without written permission by IHS. Copyright 2013, all rights reserved.

The Gas Shale Gale

Prior to the ramp up in 2006 in domestic resource production, gas production was at a steady rate of 50 billion cubic feet (bcf) per day.² Between January 2007 and July 2008, growth rapidly increased at a rate of 15 percent, from 49.7 bcf to 56.1 bcf. Currently, US production is around 65 bcf per day. To date, this growth has come primarily from the Barnett shale play. Future growth will likely come from the Marcellus.

Figure 2 shows projected growth in US gas supplies from shale, tight sands, coal bed methane, conventional sources and other associated gas sources. It shows that most of the growth will continue to come from shale plays, not tight sands.

The “shale gale” is expected to be sustained for a number of decades given the tremendous growth in US natural gas reserves and resources.³ Figure 3 depicts IHS Cera’s estimates for both conventional (non-shale) and unconventional shale proved reserves and total potential resources.

2 At this time, the Katrina and Rita hurricanes dampened production capabilities for a short period of time.

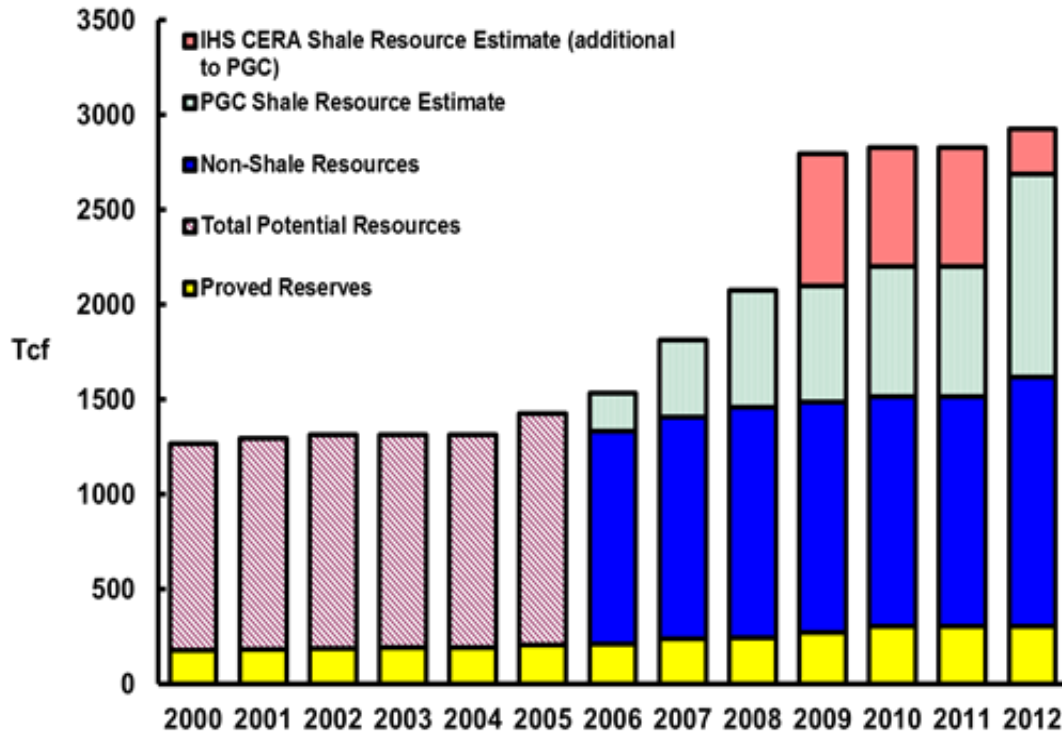
3 International Monetary Fund, *World Economic Outlook: Hopes, Realities, Risks* (Washington, DC: IMF, April 26, 2013), <http://www.imf.org/external/pubs/ft/weo/2013/01/>.

The Oil Revival

The United States became the global leader for new oil production in 2009. The International Energy Agency (IEA) in its *World Energy Outlook 2013* predicts that the United States will lead the world in oil production in 2015, moving ahead of both Russia and Saudi Arabia. In October 2013, US oil production exceeded imports for the first time in eighteen years.

THE “SHALE GALE” IS EXPECTED TO BE SUSTAINED FOR A NUMBER OF DECADES GIVEN THE TREMENDOUS GROWTH IN US NATURAL GAS RESERVES AND RESOURCES

Figure 3. US Natural Gas Reserves And Potential Resource Estimates

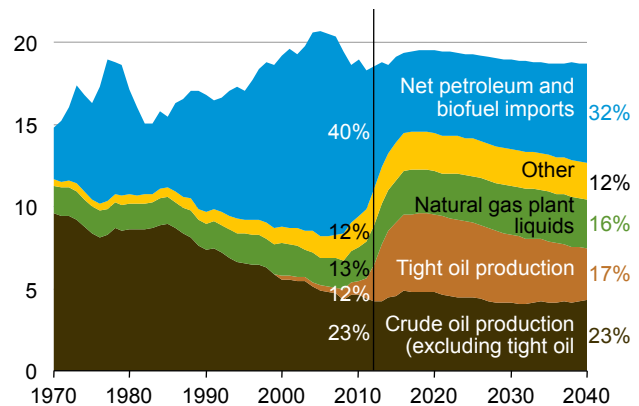


Source: Mary Barcella, IHS Inc., February 7, 2014. This content is extracted from IHS Energy North American Natural Gas service and was developed as part of an ongoing subscription service. No part of this content was developed for or is meant to reflect a specific endorsement of a policy or regulatory outcome. The use of this content was approved in advance by IHS. Any further use or redistribution of this content is strictly prohibited without written permission by IHS. Copyright 2013, all rights reserved.

The predicted revival of US oil production shown in figure 4 is based on increases in both crude oil and tight oil production. The US Energy Information Agency's *Annual Energy Outlook 2014 Early Release Overview* forecast shows that US crude oil production is projected to rise from the 2012 level of 6.5 to 9.5 million barrels per day (MMbbl/day) in 2019. This increase is significantly higher, by 22 percent, over the projection made just one year ago. The primary driver of the increased production outlook is the production from tight oil formations. According to the *Early Release Overview*, tight oil production increases from the 2012 level of 2.3 to 4.8 MMbbl/d in 2021, representing 35 percent of 2012 total crude oil production and 51 percent of total crude oil in 2021.⁴

The oil-rich shales have had a similar impact on oil production as have the gas shales. In the case of oil, the center of US oil production has shifted away from Alaska's conventional fields to North Dakota, where the oil-rich shales are located. There will also be rapid growth in the Permian Basin in Texas.

Figure 4. US Petroleum And Other Liquid Fuels Supply By Source, 1970-2040 (Million Barrels Per Day)



Source: Energy Information Agency, *Annual Energy Outlook 2014 Early Release Overview*, pp. 12-13, [http://www.eia.gov/forecasts/aeo/er/pdf/0383er\(2014\).pdf](http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2014).pdf).

⁴ Energy Information Agency, *Annual Energy Outlook 2014 Early Release Overview*, pp. 12-13, [http://www.eia.gov/forecasts/aeo/er/pdf/0383er\(2014\).pdf](http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2014).pdf).



Section II: Key Workshop Insights

This section presents key insights from the two-day workshop presentations and discussions. The information which supports these insights is summarized in the appendix.⁵ The reader is encouraged to access the workshop presentations for additional information.⁶

Produced Water Outlook

The outlook for oil and gas production promises considerable growth, with most of the growth in the near-term expected from unconventional shale plays.⁷ The tremendous potential for unconventional production rests on public acceptance, which in turn will depend on the extent to which concerns over water usage can be addressed to the public's satisfaction.

It is increasingly clear that produced water volumes will grow with the maturation of conventional oil and gas fields and the addition of unconventional production including the further development of coal bed methane and tight sands. However, the largest amounts of produced water come from conventional oil and gas—mainly oil. Contrary to commonly held beliefs and media reporting, less than 6 percent of produced water is related to shale gas. While updated totals are needed to reflect increases in domestic oil and gas production, it is believed that in the United States, annual produced water generation is approximately 21 billion barrels per year or 882 billion gallons per year in 2007, and produced water from shale plays is only a 6

percent fraction at 50 billion gallons per year. A recently published forecast by the Global Water Intelligence shows that the water volume in 2025 is likely to reach approximately 34 billion barrels annually by 2025.⁸

Apart from the fact that most produced water has high levels of salinity, there are no typical produced water characteristics. The volume and quality of produced water varies over time in the same well and according to the type of hydrocarbon developed. As a result, water management strategies must be tailored to the particular situation.

Shifting Debate

The context in which decisions regarding the treatment/disposal of produced water is changing because the public demands sustainable practices; disposal wells are not always available; the public is concerned that produced water disposal in injection wells might lead to earthquakes; and drilling for oil and gas is taking place in areas experiencing droughts that could benefit from use of properly treated produced water.

Water needs for agriculture will increase alongside an expanding US population. In areas where agriculture and energy production vie for increasingly scarce freshwater sources, the agriculture sector may no longer be willing to sell its water to the energy industry (unless there are substantial changes in food demand or major improvements in the agricultural utilization of water). In such circumstances, if the energy industry is willing to outbid the agriculture industry for water, the energy industry will have a “public relations” issue on its hands that will play further into the agenda of organizations and individuals who are pressing to stop hydraulic fracturing activities.

5 References for information presented in section II are provided in the appendix section.

6 Atlantic Council, Produced Water: Asset or Waste, <http://www.atlanticcouncil.org/publications/reports/produced-water-asset-or-waste>.

7 A conceptual model for a style of hydrocarbon accumulation used by explorationists to develop prospects in a basin, region or trend and used by development personnel to continue exploiting a given trend. A play (or a group of interrelated plays) generally occurs in a single petroleum system. Schlumberger, “The Oilfield Glossary: Where the Oil Field Meets the Dictionary,” <http://www.glossary.oilfield.slb.com/>.

8 “Water’s Growing Role in Oil and Gas,” Global Water Intelligence, vol. 12, issue 3, March 2011, <http://www.globalwaterintel.com/archive/12/3/market-profile/waters-growing-role-oil-and-gas.html>.

Determining an optimal water management strategy requires a new calculus for the US oil and gas industry. It must take into account growing water requirements, shortages in some regions, and the public's concerns over maintaining usable water supplies. While changes to current practices are coming gradually, they could be accelerated with a greater recognition of opportunities, increased collaboration between the energy and water industries, and better local, state, and federal policies that incentivize recycle and beneficial reuse.

Continuously developing technologies, best practices, and efficient operations, especially with regard to water (both for hydraulic fracturing and recycle and or reuse), will allow the oil and gas industry to weather times of low resource prices and increase the public's acceptance of their presence in the community.

Produced Water Treatment in the United States

The most common method for managing produced water from **offshore oil production** is discharge into offshore waters after required treatment. Since salinity is not a concern, approximately 91 percent is discharged into the surrounding ocean waters. Treatment rather than discharge is limited by factors that would make it costly. These concerns include the depth of the wells, distance of the offshore platform to the shore, and space and weight limitations at the offshore platforms on potential treatment equipment.

Discharge of oil and/or gas **onshore produced water** into surface waters is rare due to the US Environmental Protection Agency's (EPA) effluent limitations guidelines, the high cost of treatment of saline water, company policies, and liability concerns. Basic produced water management options include on-site evaporation; on-site injection into disposal wells; disposal at a centralized off-site underground injection site; transportation to and then treatment at a surface water treatment plant; on-site treatment by a mobile unit; on-site mixing of produced and fresh water for reuse in hydraulic fracturing operations (if it is an unconventional play); or treatment for beneficial uses.

There are three primary tiers for produced water management: first, minimize the amount of water that needs to be handled, second, treat for recycle or reuse where possible, and third, disposal with or without treatment as needed. Treatment aims to remove organics, hardness and metal components, and particulates as well as controlling for bacteria. In some cases, if organics and scaling compounds are removed, produced water can be reused without having to first remove the salts, referred to in terms of total dissolved solids (TDS).

The vast majority of onshore produced water, 60 percent, is recycled through enhanced oil recovery (EOR) operations and then about 40 percent is injected for disposal. Less than 1 percent of onshore produced water is recycled other than for EOR.⁹ In the future, disposal of water through injection may no longer be the default option.

Oil and gas producers seek the lowest cost option for produced water management. The primary considerations will be whether the option is feasible at the particular location, has regulatory approval, is sustainable over a sufficient period of time, and does not open the producer to long-term liability issues. The key point is that the producers' water treatment decisions are site-specific.

The workshop compared water management strategies in the **shale gas plays and the oil-rich shale plays** to demonstrate that choices are site specific and depend to a large degree on available injection well options, availability of fresh water for hydraulic fracturing, and local recycling policies. In the Bakken, most produced water is disposed of in injection wells. In the Marcellus, most operators in Pennsylvania reuse the produced water due to a lack of permitted injection wells and because low produced water volumes allow this approach. Some operators truck the water to Ohio for disposal in injection wells, but this option has been limited by Ohio regulators. In the Barnett, both reuse and injection well disposal are practiced. In the Eagle Ford area, most produced water is disposed of in readily available injection wells. While reuse may be inhibited by land-owner water agreements, new regulations that permit reuse may begin to change practices in this semi-arid region.

The water treatment industry of necessity must offer a wide range of services and technologies. The most appropriate and economic choice will vary based on location, conditions over the life of the well, and the physical characteristics of the produced water. Moreover, water management is not just about produced water. Many other considerations related to local public concerns must be taken into account.

Water treatment companies are providing a range of centralized and mobile solutions. Centralized versus mobile options depend on well field produced water volumes and transportation options. The trend is for combining recycling and disposal as opposed to outright

⁹ A recent report estimates that 2 percent of the produced water is currently recycled in hydraulic fracturing operations. Charles Kennedy, "Fracking-water Recycling, an Emerging Market," OilPrice.com, December 4, 2013, <http://oilprice.com/Energy/Energy-General/Frack-Water-Recycling-an-Emerging-Market.html>.

disposal. There is more use of brackish water and saltwater for hydraulic fracturing, and this increases the reuse of produced water. In addition, pit covers are increasingly used to prevent evaporation, which preserves more produced water for subsequent recycle and reuse.

Drivers

For the conventional oil sector, there is an expanding market for water-based EOR as current oil prices make it economically attractive to produce oil from older wells. As a result, there will be expanding quantities of produced water that will require treatment. For unconventional oil and gas production, which requires large quantities of water for hydraulic fracturing, there is likewise an expanding water treatment market for both flow back and produced waters. Changes in the fracturing fluids that can be tolerated, particularly those that allow the use of higher TDS water, are adding flexibility to the decisions surrounding produced water treatment.

Will produced water be seen as an asset rather than as a waste to dispose? Produced water may be treated for reuse rather than disposal for several reasons:

- lack of inexpensive local disposal infrastructure
- regional shortage of water resources
- company preference for a holistic water management program

Reuse can be promoted by state policies that require or incentivize such treatment.¹⁰ Colorado changed its rules to allow combining produced water in open pits and this has led to increases in treatment options. In Pennsylvania, because the state does not have many Class II injection wells, a very high percentage (almost 90 percent in some fields) of Marcellus play produced water is recycled. Treatment and reuse is desirable from a water management perspective, and in that environment, it is the lowest cost management option. Pennsylvania is also at the forefront of states that require water management reporting through its Department of Environmental Protection website. These developments are also driven by the goal of reducing the problems and costs associated with trucking. Further, in Texas, new regulations that incentivize recycle and reuse are having a positive impact. The Texas Water Recycling Association is helping industry to explore these options in an environmentally sensible and economically attractive fashion.

¹⁰ For example in the future, in Texas, legislative proposals HR 3537 and HB 2992 would mandate reuse and HB 2767 would establish liability and tort protection for those who reuse and recycle produced water.

From the unconventional producer's point of view, two key drivers are cost reduction and assuring an affordable, sustainable water supply going into the future.¹¹ Operators may optimize operations by recycling produced water at the site to reduce the need for costly freshwater. Onsite recycling reduces trucking costs to a disposal site and reduces freshwater truck delivery costs. But operators must look at the full life cycle and consider the variability over the long term of water needs and treatment costs to determine if the costs are justified, especially if there are adverse impacts on drilling effectiveness.

Reuse of produced water in shale plays is being helped by new families of chemical additives that allow companies to use higher TDS water blended with freshwater. Many thought desalination would have become the primary option for managing shale produced water, but at the current time, the trend is going in the blending direction.

To summarize, produced water treatment is becoming more refined. It is customized to the characteristics of the produced water and the purpose for which it is used next. Decisions about mobile or centralized treatment will depend on volumes and transportation costs and logistics. Pretreatment removal of organics, hardness, metals, particulates, and bacteria will be key to success. If organics and scaling compounds can be removed, produced water may be reused in some circumstances without costly TDS removal.

Expanding Opportunities

For the water treatment industry, there are tremendous market opportunities that may potentially be cost saving, and environmentally friendly. However, they will require deeper engagement and cooperation between the water and energy industries.

¹¹ For a snapshot of why recycling produced water is impacted by local disposal options and water cost/availability in Texas: "As the drought continues to take its toll on resources, more companies are considering the long-term benefits of water recycling, and state officials are trying to make that transition easier. Despite that momentum, recycling is far from a mainstream practice among oil and gas drillers because of the associated costs and the prevalence of disposal wells. For Fasken, Davis said, recycling is simply more expensive than using freshwater. This is partly because Fasken can get fresh groundwater at virtually no cost under the 165,000 acres of ranch that the company owns, and an underground piping system takes it straight to the mineral well. Most other operators pay relatively low prices for freshwater. Some estimates put its cost at just more than one cent per gallon, though Davis said he had heard figures as much as four times that amount. What is more, Texas is home to about 7,500 active disposal wells, making it relatively easy and cheap for drillers to dispatch their waste." Neena Satija and Jim Malewitz, "Water Recycling Minimal but Growing on Texas Oilfields," *Texas Tribune*, November 22, 2013, <http://www.texastribune.org/2013/11/22/water-recycling-minimal-growing-texas-oilfields/>.

Water treatment market opportunities arise in areas where there are water shortages. Additionally, there are expanding EOR-related market opportunities.¹² The overall produced water management market in North America is reportedly worth more than \$5 billion annually and the treatment sector worth about \$2.5 billion. The tertiary treatment segment, which includes services such as filtration, biologic treatment and desalination, may provide the largest growth potential as companies recycle more and more produced water in oil and gas operations for hydraulic fracturing. Growth will come as treatment becomes economical, environmentally better and finally, provides the best hedge against water shortages for fracturing operation. Beyond that, it is hoped the market for beneficial reuse of produced water will grow.

The growing treatment industry has identified three major service opportunities: fit for use treatment, transportation, and above ground storage. The treatment companies are carefully considering the economics of mobile versus fixed solutions, though it was recognized that in many situations, centralized facilities may not be appropriate. However, hubs may be better able to handle variability in produced water contaminates coming from many sources.

To convert produced water into an asset, the water treatment service provider must provide integrated services throughout the production chain. The provider needs to aggregate assets in a region and perform multiple services such as separating out the oil or gas, selling this product, treating the water and selling it to the next user, and providing disposal as necessary. To a certain extent, the service provider is technology agnostic; the service company provides value by optimizing the system.

Opportunities may be increased by expanding the use of produced water outside the oil and gas industry. While not commercially widespread at this point, entrepreneurs are examining the extraction of valuable minerals from produced water.¹³ Furthermore, warm produced water may be used for geothermal energy production.

Water rights associated with produced water can turn this waste into an asset. Beneficial reuse of produced water outside the oil and gas industry is limited due to water quality, water quantity, public perception, and sustainable production volumes over time. Nevertheless, beneficial reuse is occurring in some locations, particularly in arid areas such as Colorado and Wyoming. Water rights laws and evolving regulatory practices are key to successful projects in those states.

For example, in California, substantial volumes of produced water from Bakersfield are used for agriculture and cattle. Colorado and Wyoming also provide examples of how to supplement agriculture needs¹⁴ and augment Colorado River supplies. There is optimism that produced water in the Colorado River Basin can be treated for discharge to the Colorado River Basin, but it will require extensive and creative efforts to carve a path through landowner issues and other legal issues as well as regulatory obstacles. States must continue to test new permitting processes and discharge rules.

Barriers

Water management risks for oil and gas production have increased rapidly over the past half dozen years. This is due to regulatory compliance requirements, costs, concerns over water scarcity and quality, and industry's need to preserve its "social license" to produce the hydrocarbons.¹⁵

The two primary barriers to increasing produced water treatment and reuse are liability issues and the cost of treatment. Recycling the produced water can save money on trucking and disposal costs, but they are not totally eliminated. For example, the solid wastes such as boron, sulfates, and radioactive metals must be trucked away for disposal.

Cost currently represents the primary barrier given the relatively low value placed on water in many areas. Some of these costs include:

- thermal or mechanical distillation costs in the range of \$2-3 per barrel due to the energy intensity of the processes;
- crystallization cost of approximately \$3.50 per

12 For a discussion of such opportunities, see Amanda Brock, "The Compelling Case for Water-Based Enhanced Oil Recovery (EOR)," *Water Standard*, November 2013, https://www.dropbox.com/sh/jcfpbibjfq25w/jX4HyrW2Vf/AmandaBrock_WaterStandard_2013WaterMgmtHouston.pptx.

13 Eureka Resources, located in Willaimsport, PA, will begin in 2014 extracting oil, methanol and sodium chloride from produced water; Anya Litvak, "Method Makes Shale Waste Water Recyclable," *Pittsburgh Post-Gazette*, December 12, 2013, <http://www.post-gazette.com/business/2013/12/13/Method-makes-shale-waste-water-recyclable/stories/201312130058#ixzz2o2qlF4C8>.

14 For a discussion about the requirements for treatment of produced water to suit agriculture needs see United States Government Accountability Office, *Energy-Water Nexus: Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production*, GAO-12-156 (Washington, DC: GOA, January 2012), <http://www.gao.gov/assets/590/587522.pdf>.

15 For further information see *Future of Water in Unconventionals: Water Management Strategies Report & Water Market Opportunities Report*, Energy Strategy, IHS CERA, <http://www.ihs.com/products/cera/multi-client-studies/future-water-unconventionals.aspx>.

barrel due to the energy intensity of the process; and

- reverse osmosis, which is only applicable to less salty flowback or produced waters (less than twice the salinity of seawater), costs in the range of \$0.30 per barrel, but this technique suffers from fouling that increases energy requirements and decreases economic life.¹⁶

There are insufficient produced water treatment technologies at an acceptable cost that can address the myriad produced water needs. These include high levels of TDS, scaling ions, naturally occurring radioactive material (NORM), fouling of membranes, finding sustainable antifouling coating materials, bio-film inhibition, and the high amounts of energy consumed in treatment processes. Technology gaps mentioned at the workshop related to chemical recovery and less energy-intensive (hence lower cost) salt and organic separation technologies are crucial as well.¹⁷ Technology advancement is needed for potential recovery of chemicals. There is also a need for less energy-intensive techniques to separate salt and organics in the produced water.

In addition, liability issues vary between states and will need to be addressed by both state and federal legislation. Industry is especially concerned over liability issues involved with making produced water available for beneficial reuse. Liability issues do not surface if produced water is reused in oil and gas operations. At a minimum, until there are liability and tort protections for those who reuse and recycle produced water, opportunities will remain limited.

Despite the existence of these opportunities, the treatment industry faces some difficulties in finding funding in the current investment climate. Investors are concerned that the industry is too fragmented regionally and that there are too many niche players at this stage.

Regulatory uncertainty at the state and federal level, as well as regulatory variations across jurisdictions—state-

by-state and across federal and state lands—undermine companies from experimenting with new practices. While industry strongly prefers regulation by state authorities whom it believes are best informed about local conditions, a minimal level of federal regulation may be justified to address the wide variation in regulations, monitoring and enforcement across states. In addition, states will have to work across borders so there may be a federal coordination role that states might accept.

Siloed decision-making between government agencies as well as between the energy and water industries hinders integrated planning for sustainability. Sustainable approaches will require collaborative solutions, based on an integrated holistic view that takes into consideration the local population profile, water supply outlook, and water demands of all local users. While the conversation about sustainability and resource recovery has been focused on the oil and gas industry, it will also require the involvement of the agriculture and the electric utility industries as well.

Industry and government planners alike say that it is hard to obtain the necessary data that is required to improve policies. They need better reporting of water use and supply, and especially in formats that are comparable across industries, uses, and jurisdictions. More data on the costs of water in multiple uses is also required.

Industry is concerned that opponents¹⁸ of unconventional oil and gas development will attempt to remove the exemption of certain oil and gas exploration and production wastes from regulation as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act (RCRA).¹⁹ From the regulatory viewpoint, flowback fluid is a type of produced water. Both fall under the RCRA exemption. If produced water, and therefore flow back water, is treated or disposed of it must be handled in such a manner that it complies with the exemption, including the use of Class II disposal wells. This commonality is important. If the RCRA exemption were not to apply to produced water and its subset of flowback, the oil and gas waste stream management protocols would have fundamental and likely confusing revisions, impacting jurisdiction and permitting. This would be very disruptive to currently successful production practices.

16 Qilin Li, "Water and Energy Nexus: A Global Issue That Requires Local Solutions," presentation at the Water 2.0-Water Management & Nano Energy Summit, November 13-14, 2013, slides 40-42.

17 For further discussion, see Roland, Gina, and John Walsh, "Addressing Gaps in Water Treatment Technology," *Journal of Petroleum Technology*, 2013, pp. 82-90. Technology gaps mentioned include lighter weight and smaller footprint options to produce low-salinity produced water for reuse at offshore platforms; a one-size-fits-all technology that can treat variable chemical and oil characteristics of produced water; real-time, on-site and accurate produced water characteristics monitoring; advanced electro coagulation technology that addresses current problems of fouling, ability to treat high water volumes, and lowered costs; and desalination technologies that can achieve 80 to 90 percent desalination rates.

18 The Natural Resource Defense Council has petitioned EPA to reconsider. This issue was raised as to the question of whether EPA has jurisdiction over this.

19 In 1988, the US Environmental Protection Agency determined that control of exploration and production wastes under RCRA Regulations Subtitle C was not warranted. The definition of waste includes produced water.

The disconnect between surface versus mineral ownership is yet another concern in several states including Texas and North Dakota, where a large proportion of US oil and gas is produced. If the question of “who benefits” is not answered broadly, inclusively and accurately, the chances of getting good rules that do not underregulate or overregulate become slim. Poor legislation and regulations will result in political solutions that may not lead to science-based regulations. The severance of mineral rights from surface rights, combined with the legal concerns about eminent domain and an individual’s personal property rights, has the potential to impact the handling, disposal, treatment, and marketing of produced water. Subsurface water, whether fresh, brackish, or saline, associated with or without oil and gas production, lacks civil law clarity.

The licensed oil and gas operator, or entity that is authorized by the state to handle oil field materials, has the regulatory responsibility regarding produced water. Spills, cleanups, and authorized disposal have a clear regulatory path because produced water has long been considered a routine part of the oil field waste stream. Produced water that is used or treated for use does not have that history. Some property concerns include pore space trespass by injection, withdrawal without compensation, and private contractual commitments. Subsurface or ground water rights are

closely aligned with property rights, especially in Texas. Produced water is not commonly mentioned in oil and gas leases and may not be always considered part of the mineral estate. As value is added to produced water through treatment and reuse, water owners, usually surface owners, will expect some contractual guarantees to ensure they share in the increased value.

Congress is clearly grappling with determining the appropriate federal government role and how to potentially streamline the responsibilities of myriad government agencies in the energy and water arena. Congress recognizes that addressing energy water nexus issues is important, and that particular attention should be focused on treating produced water as an asset. However, congressional action has been impeded by a lack of both institutional memory and the absence of interaction between staff members. Congressional staff could benefit from engagement with stakeholders and experts through participation in meetings and conferences outside of Capitol Hill. While staffers often agree to speak at events, they may be so pressed for time that they do not engage in the resulting discussions.²⁰

²⁰ Fortunately, despite those limitations there are legislative proposals on the horizon. As of the time of writing this report, the Senate Energy and Natural Resources Committee has produced draft legislation, S. 1971, Nexus of Energy and Water for Sustainability Act of 2014. The House is also working on legislative proposals.



Section III: Recommendations

While treatment of produced water ultimately depends on economic and site-specific considerations, industry and government can join together to find common ground on policies that encourage recycling and reuse. The workshop participants offer these following recommendations for federal government action, a revised regulatory approach to water management, changes in state policies, and suggested industry approaches.

Federal Government

Apart from federal rule making (addressed below), there are functions that federal government agencies are well suited to do, including data collection, convening industry-government working groups, funding research, and supporting technology development. The workshop participants recognize that as of the time of writing this report, the Department of Energy is undertaking an assessment of its energy and water nexus programs and will be developing its own recommendations for future programs.

With regard to produced water management, the workshop participants make the following recommendations:

- As recommended by authors of previous Atlantic Council Energy-Water Nexus Initiative reports, the federal government should undertake better data collection at the watershed level on water availability (differentiated not only by surface and groundwater, but also according to type such as whether it is oil and gas produced water) and demand; better data dissemination; and agreeing on standardized definitions of and measurement of the data. The workshop participants recommend resumption, with full funding, of the US Geologic Service's efforts to undertake meaningful mapping of US water resources and integrate this with the work being done by labs such as Sandia National Laboratory to develop planning models. In addition, the 2009 Argonne National Laboratory study on
- produced water volumes should be updated to reflect the enormous changes in US oil and gas production to provide a baseline of data for future decision-making. (It is also important to note that industry could do a better job of sharing data.)
- The federal government must address the silo issue caused by the myriad government agencies that often times have overlapping areas of responsibility. The workshop participants support the creation of a federal coordination point person and/or office that serves as the main point of contact for and repository of information on energy and water issues. The extent to which this coordination office can perform other functions must be thoroughly debated by the affected agencies and their associated Congressional oversight committees. The workshop participants hope that the legislation recently proposed by Senators Murkowski and Wyden, Senate Bill 1971, Nexus of Energy and Water for Sustainability Act of 2014, dubbed the NEWS Act of 2014, will form the base for progress in addressing this silo and other issues.²¹
- There is a need to educate the public about the value of water and encourage public acceptance of using recycled water. Both the Department of Energy and the Environmental Protection Agency have legitimate roles to play here; they can include produced water recycling information in their education materials and public outreach efforts.

²¹ Under the proposed legislation, the secretaries of both the Departments of Energy and Interior would cochair a new committee to identify activities at the intersection of water and energy across the federal government; improve coordination on research and development; improve data collection and sharing; and promote collaborations between the public and private sectors. The legislation further proposes that the Office of Management and Budget would create a "cross-cut" budget to identify spending across the federal government related to energy and water activities.

- The Department of Energy, and other federal agencies and laboratories, have a vital R&D role to focus on the specific needs of the growing volumes of produced water, less energy intensive treatment technologies, and innovative solutions.²² It is worth further investigating whether the Department of Energy could become more involved in assisting the oil and gas and water treatment industries with knowledge sharing by convening workshops focused on specific issues in specific production regions. Congressional authorizing and appropriating committees should give the Department of Energy the support it needs to encourage technology development. With adequate funding, this department can invite energy and water companies to propose technology demonstration at privately owned well sites with federal and private sector cost-sharing. It can ensure the technology is properly vetted and then help advance technology deployment by publically disseminating the test results. This would be a win-win situation as the private sector companies maintain intellectual property while the government helps share the costs of proving whether water treatment technologies are reliable and affordable.
- Further federal government sponsored research on desalination technologies could be particularly beneficial for improving produced water reuse.²³ Efforts are needed to tailor desalination techniques to the specific needs for produced water (such as low energy zero discharge liquid technologies), which may be different than for traditional desalination for drinking water.
- Federal government regulators working on oil and gas/water treatment issues should spend time on the ground with their counterparts in the state government agencies to better understand the local needs for research and the impacts of federal rules and regulations.

22 For an exhaustive list of federal research projects related to produced water see US Government Accountability Office, *Energy-Water Nexus*, pp. 38-50. See also pp. 33-34 for information about technologies being developed and tested by Argonne, Sandia, Los Alamos, and the National Energy Technology Laboratories in the same document.

23 For further discussion about the issues and options regarding federal desalination research, see Nichole T. Carter, "Desalination and Membrane Technologies: Federal Research and Adoption Issues" (Washington, DC: Congressional Research Service, December 2013), <http://www.fas.org/sgp/crs/misc/R40477.pdf>.

Regulatory Approach

Federal statutes clearly allow the federal government to establish regulations.²⁴ The workshop participants recognize that the federal government's role in regulating unconventional oil and gas development is a hot political issue and that there will always be conflicts between industry and government on appropriate regulations. While recognizing that some federal standards can be beneficial, regulatory overreach does not unleash innovation.

The workshop participants recommend:

The federal government should avoid to the greatest extent possible, duplicate, overlapping and more onerous water related regulations on federal lands than those imposed by state regulators on similar geologic hydrocarbon formations.²⁵ The oil and gas industry should not have to deal with two sets of water rules for the same area. The most important criteria should be what the local geographic conditions require and how to encourage producers to treat and recycle the maximum amount of produced water without stifling the oil and gas industry.

- The debate about the federal government's role in regulating unconventional resource development must be resolved, and, at a minimum, a "detente" is in order to allow this important question to be addressed. Given that more than half of the states have been regulating oil and gas development for decades, the federal government should pause in its rulemakings to give states time to develop rules that produce the best results at acceptable costs. States are in a good position to address local water conditions, take into account local water rights laws, and provide incentives for produced water treatment.

24 For example, the Environmental Protection Agency issued air quality standards in April 2012 that will require reductions in harmful gasses from hydraulically fractured wells, storage facilities and pipeline infrastructure. The Bureau of Land Management is proposing rules on fracking on federal lands. The federal statutes that provide the basis for federal rulemakings include the National Environmental Policy Act, the Clean Air Act, the Clean Water Act, the Safe Drinking Water Act, Emergency Planning and Community Right-to-Know Act, the Endangered Species Act, the Toxic Substances Control Act, the Resource Conservation and Recovery Act, and Comprehensive Environmental Response, Compensation and Liability Act.

25 On November 20, 2013, lawmakers considered Protecting States' Rights to Promote American Energy Security Act, HR Resolution 2728, proposed by Rep. Bill Flores (R-TX). The bill, which cleared committee on a largely party line vote, would block Interior from enforcing any federal fracking regulation in states that already have similar regulations or guidance for fracking on the books. Opponents have argued, however, that the bill's language is too broad and would allow practically any state fracking requirement to supersede federal authority.

- The workshop participants note that a good approach to regulation requires continual collaboration between all of the actors, a “mindset change” on the part of industry and the state and federal regulators, and between industry and stakeholder groups. The workshop participants recommend that all groups adopt a holistic, integrated planning viewpoint and agree to incentives that allow for best possible, affordable practices. The end goal is policies and regulations that promote sustainable infrastructure development to encourage beneficial use and recovery of resources including both water and energy at an acceptable cost.
- The workshop participants suggest that federal and state regulators establish an ongoing dialogue. The primary purpose would be to provide regulators from different regions a forum to share best practices and to provide solid data comparing the effectiveness of various regulatory policies.
- Recognizing that not all states regulate equally well, a collaborative effort to determine best practices is needed. To accomplish this, gaps need to be identified. The workshop participants support a constructive dialogue between industry, the public, and multiple state governments. Such dialogue should include federal participation with the federal government representatives serving as facilitators, not arbitrators. In establishing broad agreement on produced water best practices and appropriate regulations, these efforts should also incorporate a consideration of both domestic and international issues as the oil and gas industry operates globally.
- The Environmental Protection Agency should seek state regulators’ input on how to stream line the National Pollutant Discharge Elimination System (NPDES) permit system to allow permits for beneficial reuse.²⁶
- Let the stream-lined regulatory approaches, like those taken in Texas and Canada, be given time to prove they produce acceptable results at the lowest cost. For example, Canadian Directive 081 and the revisions of the Texas Administrative Code Title 16 are good examples of regulatory approaches that are bearing fruit. State regulation should be designed for flexibility and based on sound science.
- Tax policy should be reviewed to level the playing field between customers of water recycling and customers of disposal facilities. The two are not exclusive, and combinations of recycling and disposal should be viewed favorably for tax purposes. Consider the Texas severance tax policy that incentivizes oil and gas producers to better use produced water as an example.
- Address issues such as who owns produced water and structure contracts so that the rights are specified. It is a critical requirement that the produced water ownership before and after recycling remains tied to the mineral that is developed. In other words, whoever develops the mineral is responsible for the associated produced water generated during production. If the exploration and production company recycles the water, then they have earned the ownership of the recycled water that would otherwise have been disposed of; this company should not have to fight the surface owner for it. For example, in Texas, state law provides that mineral estates are superior (in rights) to surface estates. If you own the minerals, the surface owner cannot prevent you from accessing those minerals. The rights with regard to water ownership and incentives for the best use of water rights may need to be improved.

Industry

The workshop participants recommend that industry consider the following ideas and approaches:

- While it is easier said than done, shift from a short-term to long-term view on the produced water issue that does not solely rely on an economic cost-benefit analysis. The public is looking for corporate policies that are based on an integrated, holistic view, considering population, water capacity, development in various sectors (municipal, industrial, and agricultural), in addition to developing the best solution for the oil and gas industry.
- Given the stakes-keeping the shale gas and oil boom alive while meeting appropriate environmental and sustainability requirements, it is of utmost importance for the oil and gas and

State Policies

The Council recommends these ideas for further consideration and discussion:

²⁶ In the United States, discharge of wastewater to surface water bodies requires a National Pollutant Discharge Elimination System (NPDES) permit. Injection of fluids (either for production activities or for disposal) requires a permit or other approval through the US EPA’s Underground Injection Control (UIC) program. Both of these federal programs can be delegated to states that have the interest and legal authorities to take over the programs. See J.A. Veil and J.J. Quinn, “Water Issues Associated with Heavy Oil Production,” Argonne National Laboratory, ANL/EVS/R-08/4, November 2008, http://www.veilenvironmental.com/publications/pw/ANL_EVS_2321_heavyoilreport.pdf.

water treatment industries to develop platforms for cooperation. Technical conferences and workshops are important avenues for disseminating information, but they do not substitute for forums in which representatives from both industries share technology information and real time needs as well as engaging in substantive, off the record discussions. Companies should consider the formation of a US energy and water industry group, like Canada's Oil Sands Innovation Alliance (COSIA), to share information about best water management practices and the technologies the energy producers are looking for from the water treatment industry. The Texas Water Recycling Association is another model of engagement to consider.

- Industry is no doubt frustrated with myriad meeting invitations; there is a “big business” in technical conferences. These conferences are important venues for sharing data and best practices as well as showcasing technologies. However, there is a need for a broader national conversation that includes the general public and affected stakeholder groups. The Council's workshop approach of convening technical experts with policymakers, regulators, and stakeholders can play a role in bringing facts and science-based information to the fore, and allowing industry and multiple stakeholders to engage in meaningful conversations. Full industry participation in these workshops is encouraged.
- Progress on produced water recycle and reuse is part of a larger need for inter-industry and industry-community engagement on the broad energy and water nexus issues. There appears to be a disconnect between the public's perception of, and the oil and gas industries' efforts, to pursue sustainable water use practices. Perception can be reality. With unconventional drilling taking place closer to homes and businesses, it is more important than ever that the public is educated about current industry practices. The industry may also need to put greater resources into addressing the societal impacts of water usage. Public acceptance depends on more than a positive economic benefit to the community. Industry should engage to a greater extent with local communities, explain its options and plans for sustainable water management strategies. A useful model is the Eagle Ford Task force that was created in 2011.
- As recommended previously by workshop speaker John Veil,²⁷ president of Veil Environmental, LLC, industry should further investigate other uses for and values in produced water. For example, Veil suggests industry examine the potential for capturing commercially viable products from solids, sludges or concentrated brine in produced water. Entrepreneurs could look for oil and gas wells located in formations likely to contain valuable minerals and work with the oil and gas companies to extract such mineral commodities. The workshop participants further recommends consideration of Veil's suggestion to look for formations that have particularly warm produced water. These have the potential to generate power from geothermal systems that could be used within oil and gas field operations to run pumps, compressors, and other equipment.

²⁷ John Veil has been recommending “out of the box” ideas to industry for the past five years. He estimates that some hydrocarbon formations may have particularly high concentrations of lithium or other minerals with commercial potential. For more information, see National Energy Technology Laboratory, “Produced Water Management Technology Descriptions: Fact Sheet—Feedstock for Other Products,” <http://www.netl.doe.gov/technologies/pwmis/techdesc/feedstock/index.html>. In addition, Dave Stewart, another workshop participant, is exploring the prospects for removing valuable chemicals and materials from produced water for resale.



Section IV: Concluding Remarks

The Atlantic Council’s produced water workshop moved the conversation forward with its conclusion that produced water is not always a waste but an increasingly valuable asset. Multiple challenges were identified. The industry is looking for ways to reduce the amount of freshwater necessary for horizontal drilling and hydraulic fracturing processes; to find cost-effective ways to treat produced water; to cut water transport and storage costs; to meet evolving and potentially prohibitive environmental and regulatory requirements; and to satisfy the public’s desire for sustainable water use in their communities. Over time there will be growing opportunities and increasing need to use

THE OIL AND GAS
INDUSTRY, THE WATER
TREATMENT INDUSTRY,
REGULATORS,
POLICYMAKERS, AND
THE PUBLIC CAN WORK
TOGETHER TO CREATE
AN ENVIRONMENT IN
WHICH SUSTAINABLE
PRACTICES ARE
ECONOMIC AND
BENEFICIAL TO THE
COMMUNITY

our produced water resources to meet water supply shortages.

The good news is that there is increasing collaboration between the energy and water sectors. The key to success will be breaking down the silos—both between these industry groups and between multiple government agencies. There is equally positive news of an awakening public dialogue concerning the proper valuation of water. This dialogue can be furthered by increased public understanding of growing water scarcity and the ever increasing, interrelated water requirements for food, energy, and municipal use.

The oil and gas industry, the water treatment industry, regulators, policymakers, and the public can work together to create an environment in which sustainable practices are economic and beneficial to the community. The industry cannot solve these issues with technology alone or in a bubble. It will require integrated strategies and interactive dialogues. A key component will be to further educate the public about what the industry is doing to address water concerns.

The conversation must be broadened outside of the energy sector. Water consumed by the extraction and processing of oil and gas represents less than 1 percent of total US water consumption. Going forward, water demand will be driven by increased population and associated water requirements for drinking, sanitation, recreation and food production. The United States will never fully address its water needs by focusing only on this energy sector one percent. Water use in the agriculture sector and waste water from industrial sectors must be factored into the equation. Integrated approaches to water management for energy, agriculture, industrial, commercial and municipal uses are essential. This will require collaboration between industries and a rethink of local, state, and federal policies and regulations.



Appendix

Defining Produced Water

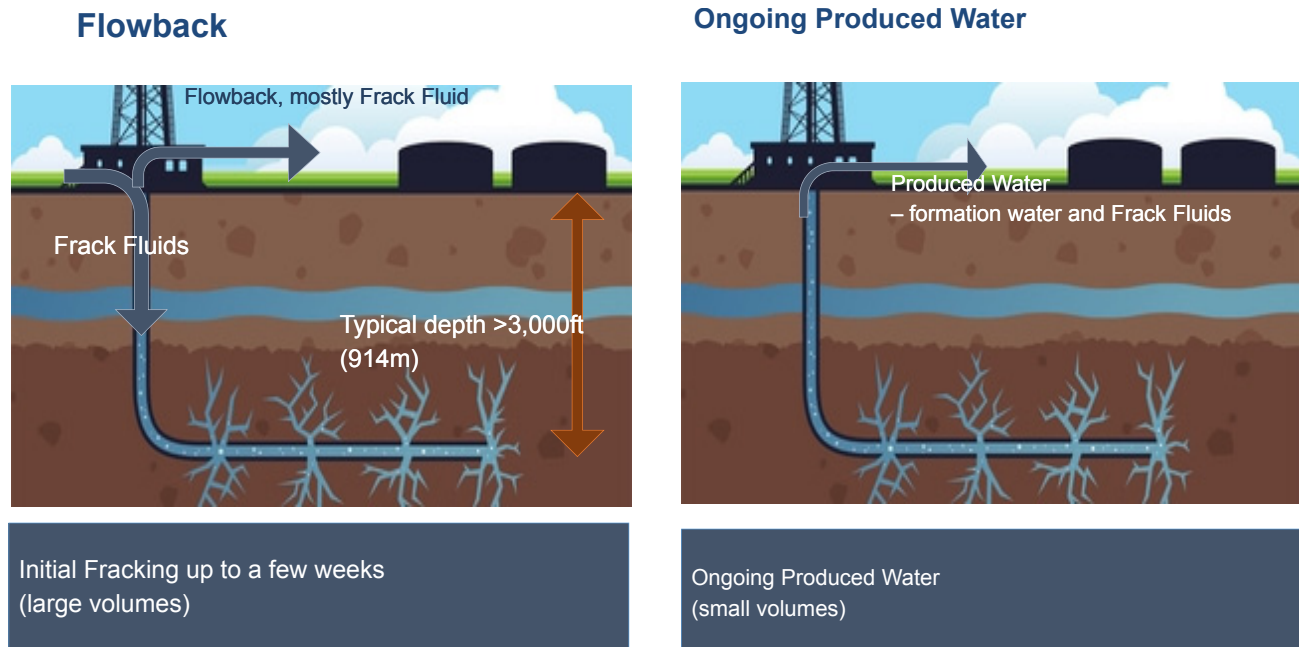
The terms “flow back water” and “produced water” are commonly misused. Some in industry refer to flow back not as a water type but as a process in which the hydraulic fracturing fluids, containing water, return to the surface. Flowback is a process defined by the Schlumberger online oil field guide as “the process of allowing fluids to flow from the well following a treatment, either in preparation for a subsequent phase of treatment or in preparation for cleanup and returning the well to production.”²⁸

In this report, flow back water refers to the stream of water and hydraulic fracturing fluids that comes back up

through unconventional wells for a few weeks right after the process is initiated. Some state governments have specified in legislation and regulations that flow back water is not to be considered produced water.²⁹

Flowback water is made up primarily of the water that was injected into the formation as part of the hydraulic fracturing process. In addition to the water and chemicals that were part of the original “fracturing fluid,” it contains concentrations of chemicals that were dissolved from the shale rock during the fracturing process. Flowback water shows rapidly increasing concentrations of TDS and other constituents over a period of a few weeks, while over the same time period, the flow rate drops off greatly. After

Figure 5. Flowback Vs Produced Water

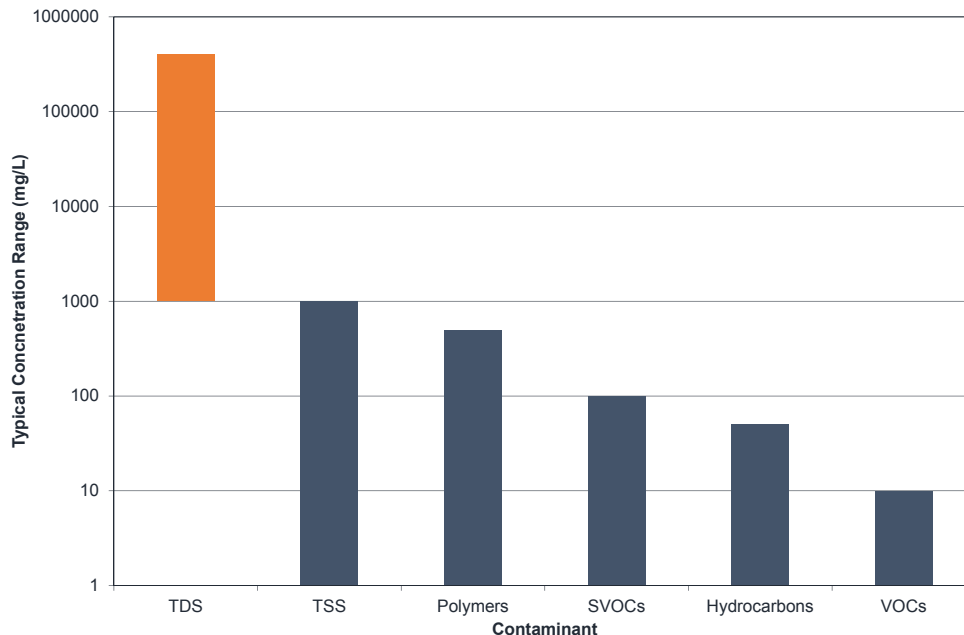


Source: Tyler Algeo, “Water Treatment Market Opportunities in Unconventional Oil & Gas,” presentation at the “Produced Water: Asset or Waste?” event, Atlantic Council, Washington, DC, June 24, 2013, slide 9.

28 Schlumberger, “The Oilfield Glossary.”

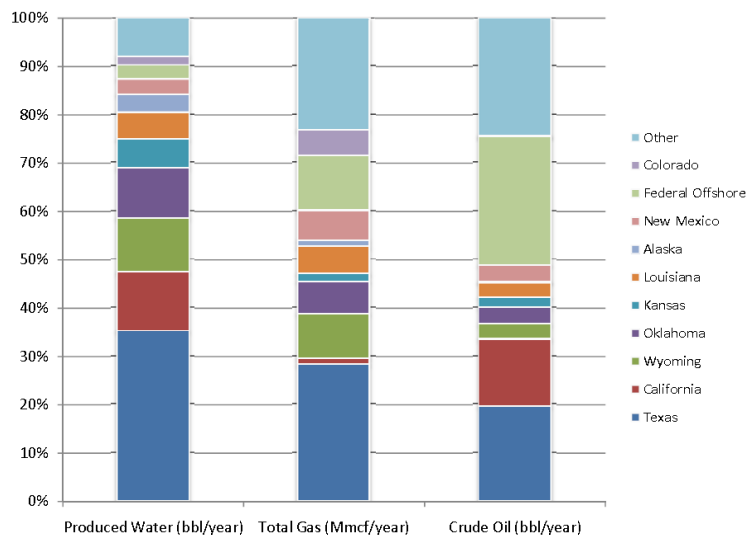
29 Ron Bosch, “Conventional Produced Water,” presentation at the “Produced Water: Asset or Waste?” event, June 24, 2013.

Figure 6. Common Characteristics Of Produced Water



Source: Tyler Algeo, “Water Treatment Market Opportunities in Unconventional Oil & Gas,” presentation at the “Produced Water: Asset or Waste?” event, Atlantic Council, Washington, DC, June 24, 2013, slide 11.

Figure 7. Projected Produced Water Volumes



Produced Water Volumes:

- US – 21 Bbbl/yr
- Wyo – 2.36 Bbbl/yr
- CO – 0.38 Bbbl/yr
- Ut – 0.15 Bbbl/yr

Recent data in Colorado suggests dramatic increase in volumes

Source: Dave Stewart, “Critical View of Technology Requirements,” presentation at the “Produced Water: Asset or Waste?” event, Atlantic Council, Washington, DC, June 25, 2013, slide 8.

Table 2. Hydrocarbon and Associated Produced Water Profiles

Type of oil and gas production	Produced water generated
Conventional oil and gas	Low volume initially Volume increases over time High lifetime volumes produced
Coal bed methane	High volume initially Volumes decrease over time
Shale gas	Initial flow is high Flow quickly drops to very low Low lifetime produced
Heavy crude	Most of the volume results from injected steam for steam flooding
Oil/tar sands	For in situ: most of produced water is injected steam, but there is some produced formation water (Oil sand mining and processing produces wastewater)

Source: John Veil, "Introduction to Produced Water," presentation at the "Produced Water: Asset or Waste?" event, Atlantic Council, Washington, DC, June 24, 2013, slide 16.

those first few weeks, the water flow rate is much smaller and more consistent, but it continues indefinitely for the life of the well.

Produced water is defined as follows:

"A term used to describe water produced from a wellbore that is not a treatment fluid. The characteristics of produced water vary and use of the term often implies an inexact or unknown composition. It is generally accepted that water within the pores of shale reservoirs is not produced due to its low relative permeability and its mobility being lower than that of gas."³⁰

Produced water can come from both conventional and unconventional wells; over 90 percent is currently associated with conventional production. It comes to the surface over the life of the well and can contain many chemical constituents. Produced water is water that resides in the formations containing hydrocarbons and contains salts (measured in amounts of TDS), toxic natural inorganic and organic compounds, chemical additives, NORM, as well as oil and grease associated with production.

Produced water consists of residual water from the original hydraulic fracturing fluids plus some water that was present in the shale or in adjoining formations. Some shale formations tend to return a larger or smaller percentage of the original frac fluid volume. For example, the Marcellus Shale is a "drier" shale, while the Barnett Shale is a "wetter" shale. The shale rock with all of its newly created fracture surfaces will retain some of the injected hydraulic fracturing fluid water in a process known as imbibition.³¹

30 Schlumberger, "The Oilfield Glossary."

31 Terry Engelder, "Produced Water Workshop: Geological Aspects of Water-Gas Shale Interaction," presentation at "Produced Water: Asset or Waste?" event, June 25, 2013.

In summary, flow back water can be thought of as water returning to the surface over the first few days to weeks after the well starts producing and then what follows is the long-term flow of produced water. Figure 5 helps to understand the difference between flowback water and produced water.

Produced Water Characteristics

Figure 6 lists common contaminants; and as would be expected, it shows that salt is the dominant concern.³²

Produced Water Volume Projections

In the United States, there are nearly one million wells producing oil and gas.³³ Data shows that the volume of produced water generated in the United States during 2007 was approximately 21 billion barrels³⁴ (the equivalent of 882 billion gallons for the whole year.) The total volume of shale gas flow back and produced water is in the range of 50 billion gallons per year. As shown in Figure 7 states, like Colorado and Wyoming, are experiencing surges in produced water production. Significant growth in produced water volumes is forecast. A recently published forecast by the Global Water Intelligence shows that water volume in 2025 will reach approximately 34 billion barrels annually by 2025.³⁵

Table 2 below provides a broad overview of how produced water volumes will differ over time and

32 Tyler Algeo, "Water Treatment Market Opportunities in Unconventional Oil & Gas," presentation at the "Produced Water: Asset or Waste?" event, June 24, 2013, slide 11.

33 John Veil, "Introduction to Produced Water," presentation at the "Produced Water: Asset or Waste?" event, Atlantic Council, Washington, DC, June 24, 2013, Slide 9.

34 C. E. Clark and J. A. Veil, "Produced Water Volumes and Management Practices in the United States," Argonne National Laboratory, 2009. The equivalent of 882 billion gallons per year.

35 Gina Rowland and John Walsh, "Management: Addressing Gaps in Water Treatment Technology," *Journal of Petroleum Technology*, October 2013, p. 83, http://www.mydigitalpublication.com/display_article.php?id=1510163&_width=

Table 3. Produced Water Volume by Management Practice For 2007 (1,000 Bbl/Year)

	Injection for enhanced recovery	Injection for disposal	Surface discharge	Total managed	Total generated
Onshore total	10,676,530	7,144,071	139,002	18,057,527	20,258,560
Offshore total	48,673	1,298	537,381	587,353	587,353
Total	10,725,203	7,145,369	676,383	18,644,880	20,995,174

Source: John Veil, "Introduction to Produced Water," presentation at the "Produced Water: Asset or Waste?" event, Atlantic Council, Washington, DC, June 24, 2013, slide 12.

Table 4. Produced Water Treatment Decision Drivers

Big picture issues	Location-specific issues	Cost and technology issues	Produced water issues
Water availability	Cost of freshwater	Cleanup costs	Organic fouling
Disposal options	Drilling schedules	Closure costs	Carbonate fouling
Storage	Permit obligations	Pit cover	Sulfate fouling
Liability	Landowner and contract obligations	Lining	Silica deposition
Transfer issues	Water volumes	Odor issues	TDS levels
Down hole issues	Hub or mobile technology	Storage	H2S
Public opinion	Scaling index	Regulations	NORM management
Environmental footprint	Saltwater leak	Transportation of water and waste	Microbial control
Corporate vision	Water availability	Compliance and monitoring	Local weather conditions
Regulations	Impact on fracturing performance	Brackish water—lower treatment cost but difficult logistics	
	Regulations	Freshwater—higher cost for thermal distillation but lower cost for storage and transport	
	Available pipes for transport		
	Induced seismicity		

Source: Based on Brent Halldorson, "The Shift Towards Recycling & Re-Use in Oilfield Water Management: 3 Unique Case Studies," presentation at "Produced Water: Asset or Waste?" event, Atlantic Council, Washington, DC, June 25, 2013, slide 2; David Alleman, "Water Management in the Bakken," presentation at the "Produced Water: Asset or Waste?" event, June 24, 2013, slide 4.

especially between types of production. Conventional oil and gas wells produce large volumes of produced water over their lifetimes. Unconventional gas play wells provide relatively little amounts of produced water. Too great a flow of water from an unconventional gas well will actually reduce the productivity of the well.

Current Produced Water Disposition Practices

In the United States today, a minimal amount of produced water is treated for beneficial reuse purposes; the majority of produced water that is not disposed is used for EOR. As shown in Table 3, 91 percent of offshore produced water is discharged to the ocean, and 98 percent of produced water from onshore wells is sent to injection wells. Sixty percent of water sent to injection wells is for EOR and 40 percent is disposed.³⁶

Produced Water Treatment Drivers

Cost is the most significant factor in produced water management and treatment.³⁷ However, there are myriad factors to be taken into consideration in determining the optimal water management strategy. Factors that dictate treatment decisions include big picture company policy issues, location specific factors, choices regarding technology, cost considerations and characteristics of the produced water. Decisions are site specific and must take into consideration the logistics of transporting water and wastes, the availability and cost of source water, the local disposal options, and the water storage options. The final decision will rest on bottom line costs.

Table 4 summarizes key the factors to consider.

37 For a summary of the cost factors, see US Government Accountability Office, Energy-Water Nexus: Information on the Quantity, Quality, and Management of Water Produced during Oil and Gas Production, GAO-12-156 (Washington, DC: GAO, January 2012), pp. 23-25, <http://www.gao.gov/assets/590/587522.pdf>.

36 John Veil, "Introduction to Produced Water," slide 12.

State regulatory policies as well as the availability of (affordable) disposal options are other key drivers. For example, recently Texas revised the Texas Administrative Code Title 16 Sections 3.8 and Chapter 4 Subchapter B to reduce permitting times. These provisions took effect on April 15, 2013. The revisions reduce the time to obtain permits for operators that share produced water for recycling. These provisions eliminate the need for a Texas Railroad Commission permit if operators are recycling fluid on their own leases or transferring fluids to another operator's lease for recycling. The changes also establish a tiered approach for the reuse of treated fluids, including both authorized reuse of treated fluids (produced water) in oil and gas operations and provisions for reusing the fluids for other non-oil or gas field related uses. In contrast, in Pennsylvania, recycling decisions are driven by a lack of local disposal wells and increased transportation costs of trucking the produced water to injection wells in Ohio. Another important factor has been changes in Pennsylvania's surface discharge standards that required relatively expensive treatment before disposal.

Produced Water Management Options

There are three primary tiers of managing produced water.³⁸ The first is to minimize the amount of water that needs to be handled. To keep produced water from the entering the well, mechanical blocking devices, or water shut-off, chemicals can be employed. To keep produced water from reaching the surface, an operator may use down-hole separation or sea floor separation techniques.

The second tier, which pertains primarily to onshore treatment, is to treat for recycle or reuse where possible. This involves injection for recovering more oil; injection for future use; or injection for hydrological purposes, agricultural use, industrial use, drinking water, and other domestic uses.

The third tier is disposal (through discharge, injection, evaporation, or commercial offsite disposal) with or without treatment as needed. Practices to remove salt and other inorganic material from produced water would include membrane processes, ion exchange, capacitive deionization, or thermal distillation. Practices to remove oil and grease and other organics from produced water would include physical separation, flotation, coalescence, combined physical and extraction, solvent extraction, or adsorption.

Such treatments would be performed in order that the solids/chemicals/other components in produced water

can be properly disposed given permit requirements.³⁹ The techniques for removing salts are rarely used at offshore wells because there are few concerns about discharging highly saline waters into the ocean waters. If the water is to be disposed, it can be discharged (as in offshore production), injected into disposal wells, evaporated, or sent to an offsite commercial disposal site.

Primary shale gas options for produced water include disposal of the produced water into injection wells either on or off-site; treatment in order to reuse produced water for on-site or neighboring site hydraulic fracturing; and treatment for disposal of both the water and solids.⁴⁰ Until recently, some producers recycling produced water were treating it to almost fresh water quality. However, producers are now testing the use of produced water mixed in with fresh water and other methods such as:

- high TDS gel and friction reducers to recycle high TDS fluids that facilitate slick water completions;
- bacterial treatment (necessary because recycled water promotes bacterial growth); and
- other pretreatment to remove TSS, oil, bacteria, and metals.

Figure 8 summarizes the treatment technologies mentioned above that will address the typical contaminants in produced water.

Water service companies are bringing an integrated approach to the produced water treatment market, offering a full suite of services, including transportation, recycling, water sales, treatment, and disposal. Services are tailored to the individual drilling operators' needs so that water can be recycled for local needs at affordable costs.

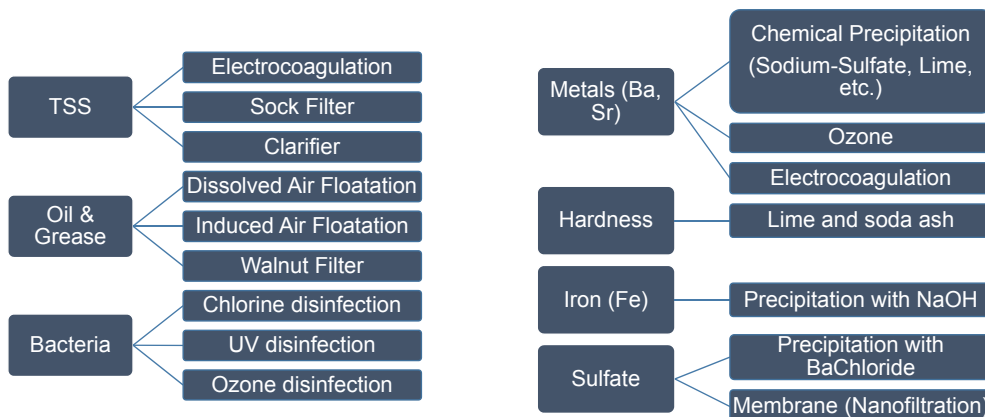
It is equally important to develop a produced water treatment plan that takes into account the region's particular long-term needs. Buttressing the holistic management concept are life cycle analyses based on regional area needs which serve as an important planning tool for produced water management. The Gas Technology Institute (GTI) has developed a life cycle analysis model that provides a framework for companies, stakeholders, and regulators to create sustainable produced water treatment strategies based on data-driven decisions. The schematic of GTI's model is shown in figure 9.

38 John Veil, "Produced Water from Offshore Conventional Wells," presentation at the "Produced Water: Asset or Waste?" event, June 24, 2013, slides 23-31.

39 For further in-depth information, the reader is encouraged to access the "Produced Water Management Information System" website at National Energy Technology Laboratory, <http://www.netl.doe.gov/technologies/PWMIS>.

40 Tyler Algeo, slide 14.

Figure 8. Primary Treatment Technology Trends



Source: Tyler Algeo, “Water Treatment Market Opportunities in Unconventional Oil & Gas,” presentation at the “Produced Water: Asset or Waste?” event, Atlantic Council, Washington, DC, June 24, 2013, slide 12.

Produced Water from Conventional and Unconventional Sources

This next section presents the “meat and bones” of the information from the workshop. For each conventional and unconventional type of hydrocarbon development, information is given for water needs/produced water volumes/characteristics and treatment, reuse, and disposal options.⁴¹ There is considerable variability in produced water quality over time in an individual well, from well to well in a play, from field to field and from formation to formation. There are no typical produced water characteristics.

To highlight the major differences that can be found among shale plays, the Barnett and Marcellus shale gas plays are compared and contrasted and the Eagle Ford and Bakken oil-rich shales plays⁴² are described in the same way. These differences point to why water management strategies must be tailored to the particular situation.

Conventional Onshore Oil and Gas

Water needs/produced water volumes/characteristics

- Little water is needed to initiate conventional wells but will be required to enhance oil recovery as the well ages. Little water is produced in the early age of conventional wells but increases significantly over

41 For excellent additional information, please see www.veilenvironmental.com for a comprehensive series of reports related to produced water prepared by John Veil primarily, and colleagues. For further information regarding the water needs for the hydraulic fracturing technology used in unconventional oil and gas production, please see Francis O’Sullivan, “The Water Intensity of Hydraulic Fracturing-Scale Cost and Uncertainty,” MIT Energy Initiative, http://www.bcenergychallenges.com/_docs/O_Sullivan_Francis.pdf.

42 This term refers to shale rich in kerogen—clearly different from shale oil.

the lifetime of the well.⁴³ The water-to-oil ratio for the United States is estimated to be over 10:1.⁴⁴

Treatment, reuse, and disposal options

- Strategies depend on the stage of production—primary, secondary, or tertiary. Since the future of conventional oil production will be from tertiary recovery efforts, utilizing produced water for EOR will be important. Water that is not used for EOR is typically sent to Class II salt water disposal wells.

Conventional Offshore Oil and Gas

Water needs/produced water volumes/characteristics

- Ninety percent of US offshore oil and gas comes from the Gulf of Mexico, from 2,750 platforms. For the latest year of available data, annual produced water volume was 587 million barrels.
- Since salinity is not an environmental concern, over 91 percent of produced water is discharged into the ocean.

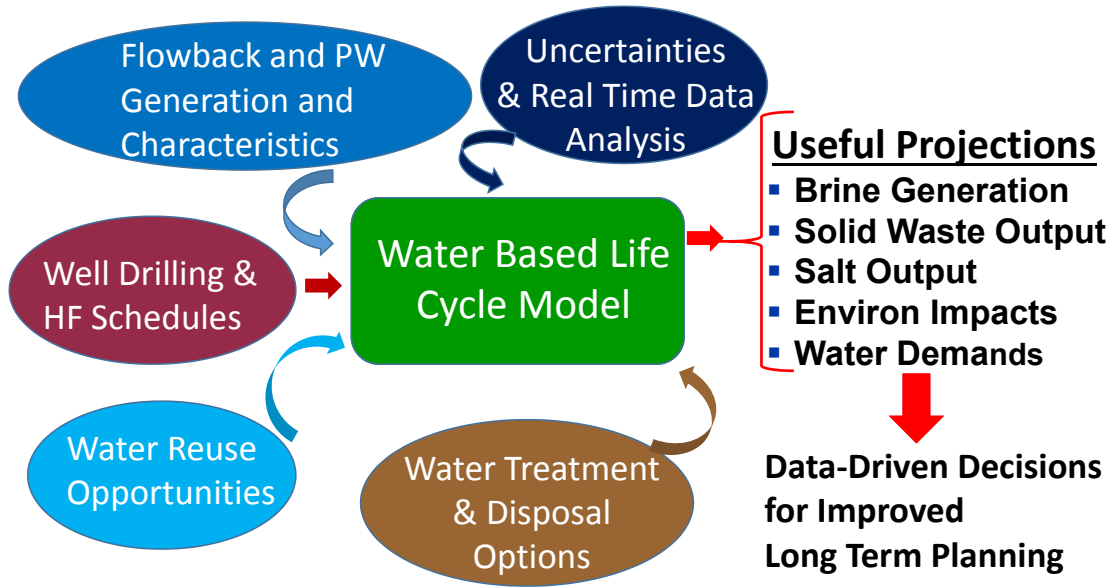
Treatment, reuse, and disposal options

- Environmental Protection Agency regulatory determinations in 1988 and 1993 established that most exploration and production wastes, including produced water, are not to be subject to the hazardous waste portions of RCRA. Permits are required, however, for discharge and injection of produced water. These effluent limitations guidelines include minimal discharge standards for offshore produced water. With the exception of Cook Inlet Alaska, zero discharges of produced water are allowed in coastal areas.

43 Ron Bosch, “Conventional Produced Water,” slides 20, 26, and 28 for the production profiles of each stage of production.

44 Note that 1 billion barrels of water is equal to 42 gallons.

Figure 9. Water Based Life Cycle Model Tracking of a Dynamic System



Source: Tom Hayes, "Shale Gas Water Modeling and Sustainability Planning," presentation at the "Produced Water: Asset or Waste?" event, Atlantic Council, Washington, DC, June 24, 2013, slide 7.

- Treatment technologies are primarily used to reduce free oil and dissolved organics in the produced water in order to meet the oil and grease discharge limits of 29/mg/l average and 42 mg/l maximum.⁴⁵ There is a wide variety of technologies used. Factors that play into treatment decisions include the water depth, costs, the size of the platforms, and restrictions on weight that the platform can handle limit treatment choices. Costs are a large factor as well. General National Pollutant Discharge Elimination System (NPDES) permits written by the US Environmental Protection Agency Regional offices contain limits on other parameters too.
- Water production is generally very high early in the life of the well and decreases rapidly thereafter. Gas production peaks a few years after peak water production. High water production at a well limits how often and how much a well can be pumped and thereby limits gas production. Water production at any given well may depend on the rate of recharge or whether water levels have been previously drawn down prior to drilling.
- The major constituents of coal bed methane produced water are primarily sodium chloride though in some cases sodium bicarbonate is present. Waters are generally low in sulfate, magnesium and calcium. Most wells exceed secondary TDS drinking water standards. For example, an average Powder Basin well produces water with less than 10,000 mg/l⁴⁷ while the San Juan Basin is very salty.

Unconventional Coal Bed Methane⁴⁶

Water needs/produced water volumes/characteristics

- Coal bed methane production is pressure driven and usually requires dewatering of coals to lower hydrostatic pressure in order to allow the gas to escape and then be trapped. Since most of the water is pumped out of the coal seam to lower the pressure, if extra water is required, and it is usually very little, it is generally trucked to the site from local sources. The produced water will vary according to the type of coal, depth of the seam, production area, and local environment.

Treatment, reuse, and disposal options

- A different set of water management options is used in each coal bed methane field, depending on the chemical characteristics of the water (particularly the TDS level). Where the TDS is low enough, water can be treated and reused or treated and discharged. In other fields, like the San Juan Basin, the produced water is very saline—most produced water is injected into disposal wells in that basin.
- There are potential beneficial uses for produced water with less than 3,000 mg/l TDS and acceptable

45 John Veil, "Produced Water from Offshore Conventional Wells," slide 31.

46 The section on coal bed methane is based on coal bed methane wells in the State of Alabama. See Nick Tew, "Characteristics of Coal bed Methane Produced Water in Alabama," presentation at the "Produced Water: Asset or Waste?" event, June 24, 2013.

47 Average standard is for 500 mg/l.

ratios of sodium adsorption.⁴⁸ Potential beneficial uses include aquaculture (in particular, shrimp farming); irrigation; use in drilling and frac fluids; and augmentation of municipal supplies.

Tight (Oil and Gas) Sands⁴⁹

Water needs/produced water volumes/characteristics

- For oil and gas from tight sand formations, fresh water is used early on to drill new wells. The higher the amount of liquids in the reservoir, the more gel required in the hydraulic fracturing fluid. This will impact the resulting produced water and necessary treatment strategies. Produced water volumes are large early on and have little water late in the well life.
- Many of the components in produced water come from hydraulic fracturing gels.⁵⁰ Produced water from these unconventional plays has more colloids and inorganic solids as compared to conventional wells. Typical components include, NaCl and other salts, dissolved gasses, gasses that transition to salts, inorganic solids, soluble organics, emulsoids, emulsifiers, suspended organics, and detritus.

Treatment, reuse, and disposal options

- Produced water is used to refracture wells. While today little EOR is practiced in tight sand formations, in thirty or more years, there will be increased usage of produced water for EOR. This will occur as engineering advances enable the use of produced water to re-wet gas bearing formations.
- Treatment decisions are driven by the need to manage biologic contamination, limit pipe corrosion and manage poisonous gas. Industry has little incentive to search for other potential beneficial reuse options because the oil and gas industry requires so much water for its operations. The water treatment industry has not developed infrastructure for standardized treatment solutions.

48 In agriculture uses, high levels of TDS and subsequent sodium adsorption by plants is toxic.

49 This term refers to low permeability sandstone reservoirs. Hydrocarbon production from tight reservoirs can be difficult without stimulation operations. Stimulation of tight formations can result in increased production from formations that previously might have been abandoned or been produced uneconomically. The term is generally used for reservoirs other than shales. Schlumberger, "The Oilfield Glossary."

50 Bosch, "Tight Sand Produced Water," presentation at the "Produced Water: Asset or Waste?" event, June 24, 2013, slide 17.

Heavy Oil⁵¹

Water needs/produced water volumes/characteristics

- Almost 40 percent of heavy oil production in the United States takes place in California.⁵² There are large amounts of produced water generated from each field. In the top ten oil producing fields in California, each field produces oil and produced water in these amounts, expressed in million bbl:
 - Midway-Sunset 29.30 oil and 224.21 produced water
 - Kern River oil 26.19 and produced water, 315.11
 - Belridge, South oil 23.62 and produced water 305.29
 - Elk Hills oil 13.93 and produced water 167.63
 - Cymric oil 13.69 and produced water 107.04
 - Wilmington oil 13.26 and produced water 492.14
 - Lost Hills oil 10.74 and produced water 134.24
 - San Ardo oil 7.27 and produced water 114.42

51 Traditionally, heavy oil (whose synonym is bitumen) is presumed to cover viscous liquid oils and oil sands (called tar sands in the United States). As a general rule, heavy oil has an API gravity of less than 22°. See J.A. Veil and J.J. Quinn, "Water Issues Associated with Heavy Oil Production," Argonne National Laboratory, ANL/EVS/R-08/4, November 2008, http://www.veilenvironmental.com/publications/pw/ANL_EVS_2321_heavyoilreport.pdf. This term refers to any liquid petroleum with an API gravity less than 20°. A designation for a hydrocarbon fluid with a gravity of 10° API or lower, based upon the classification of the US Department of Energy. Its synonym is bitumen. Schlumberger, "The Oilfield Glossary," <http://www.glossary.oilfield.slb.com>.

52 "Much of the oil found in California is extremely heavy... [California's] fields are estimated to contain more than 40 percent of the country's heavy oil. At some point the crude is too viscous to flow easily without enhanced oil recovery techniques (EOR). While water flooding had been used for many years (and continues to this day), new approaches to the challenge of producing California's heavy oil began in the 1960s with the application of thermal methods. Early attempts with bottom hole heaters and injected hot water gave way to cyclic steam stimulation (pumping down steam to heat the oil and thus reduce its viscosity, then pumping out the oil), and then to full-fledged steam flooding (injecting steam through injection wells and recovering oil from producing wells).... The single highest producing county in the state is Kern County, which alone accounts for approximately three-fourths of the state's crude oil output." See Independent Petroleum Association of America, "The Story of California Crude," <http://oilindependents.org/the-story-of-california-crude>.

- Coalinga oil 5.54 and produced water 57.78
- Ventura oil 5.08 and produced water 50.15
- The Canadian oil sands contain extra heavy oil, also known as bitumen. Eighty percent of those deposits require steam injection. (It is interesting to note that in situ operations require less water than surface mining.) Average water usage for surface mining operations is two to four barrels make up water plus eight to ten barrels of recycled water per barrel of oil. In situ mining requires 0.25 to 0.5 barrels of makeup and 2.5 to 2.75 barrels of recycled water per barrel of oil.⁵³ For traditional mining operations, fresh water is typically drawn from nearby rivers, such as the Athabasca River. For in situ operations, water for primary operations can be drawn from fresh water aquifers and from mine tailings water ponds.
- The steam to oil ratio (SOR) has a direct impact on the size of the water treatment plant and investment required. On average, in situ mining operations requires 0.25 to 0.5 make up water, produces 2.5 to 2.75 barrels of produced water, produces 10,000 BPD of bitumen and at an average SOR of 3, resulting in 30,000 BPD of water. Even though the average SOR for typical in situ mining operations in Canadian tar sands is 3, projects vary widely, from an average of 1.92 to 6.55.⁵⁴
- Canadian tar sands produced water is managed within a fairly closed cycle that aims to achieve a 95 percent recycle rate at in situ sites, with a small remaining percent to be cleaned and returned to the local watershed. Treatment option choices are driven by companies' desires to reduce bottom line costs-particularly for energy, to achieve corporate sustainability goals, and to meet the requirements of the Energy Resource Conservation Board Directive 081.⁵⁵ Integrated process and produced water strategies include reducing the amount of process water stored in tailings ponds by using that water as a primary water source and by upgrading waste water treatment; reducing produced water treatment needs by improving "dirty water" boilers; retrofitting plants with improved evaporation systems for produced water; improving ceramic membrane and reverse osmosis technology to clean produced water; and finally, disposing of the remaining brine (truck off site or inject in a deep well) if zero liquid discharge is not achievable.⁵⁷ The trend in innovative water treatment technologies is mostly for thermal treatment with some focus on ceramic membranes.

Unconventional Shale Gas⁵⁸

To further make the point that there is great variability between the volumes, characteristics and treatment options from various plays, the Barnett and Marcellus gas shale plays were compared.

Water needs/produced water volumes/characteristics/treatment options in the Barnett

- In 2006, a survey showed that the source of water for hydraulic fracturing operations was 60 percent from groundwater. In 2012, 20 percent came from groundwater. However, it is difficult to pinpoint whether the hydraulic fracturing water is from groundwater or source water; the source is often company specific. There is a trend toward using

Treatment, reuse, and disposal options

- In California, produced water disposition varies by geographic location and regional needs. State-wide during 2012, 1 and 2 percent were sent into the municipal sewer system and surface water bodies, respectively; 20 percent was lost due to evaporation; 73 percent was injected; and the remaining 4 percent was unaccounted for. The vast majority of the injected water was for EOR and 30 percent was disposed of in injection wells. At Bakersfield, much of the produced water evaporates. In the Kern area, it is piped to citrus growers and other agriculture purposes. At Midway Sunset, produced water recharges groundwater basins. Ironically, in areas where there is produced water from steam flood EOR operations, the water is cleaned to the point where it can be discharged to agriculture or to streams that flow to the ocean. The produced water that has been deemed "too clean" for the fish is often "dirtied up" before release.

⁵³ Alan Daza, "Produced Water Treatment for Enhanced Oil Recovery in the Canadian Oil Sands," presentation at the "Produced Water: Asset or Waste?" event, June 24, 2013, slide 9.

⁵⁴ Ibid.

⁵⁵ The COSIA organization is helping Canadian tar sands companies to collaborate on best practices and zero liquid discharge (ZLD) technology development.

⁵⁶ Directive 081 requires companies to reduce fresh water use per barrel of oil produced, to maximize water recycling, and where possible, to avoid using fresh water by using water from deep saline aquifers or from recycled industrial waste water. NPDES stands for national pollution discharge elimination system. Daza, slide 9.

⁵⁷ JP Nicot, "Source and Fate of Hydraulic Fracturing Water in Texas," presentation at the "Produced Water: Asset or Waste?" event, June 25, 2013, slide 5.

⁵⁸ For further information, please see John Veil, "Shale Gas Water Management-Experiences from North America," presentation at the Society of Petroleum Engineers Distinguished Lecturer Program, Krakow, Wisconsin, March 24, 2013. According to Veil, a typical unconventional shale gas well requires approximately 5 million gallons of water for hydraulic fracturing.

brackish rather than using recycled produced water. However, both practices are fairly minor: 5 percent is from recycling and reuse and 3 percent from brackish sources. It appears that there is adequate source water supply at present.⁵⁹

- The volumes of produced water show a dramatic drop off in volume after twelve months of production in Barnett shale play wells.⁶⁰
- Most of the water is injected into disposal wells. Passage of Texas Administrative Code Title 16 Section 3.8, effective April 15, 2013, may serve to encourage produced water recycling. The regulations will reduce the time to obtain permits for recycling produced water at oil or gas production sites.

Water needs/produced water volumes/characteristics/treatment options in the Marcellus

- Source water for drilling operations comes primarily from surface water sources. Compared to water withdrawals for public supply, domestic uses, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power production, water withdrawn for Marcellus shale play use is 0.32 percent.⁶¹ Producers are increasingly able to use high TDS hydraulic fracturing water.⁶²
- Marcellus produced water typical characteristics include high TDS of 150,000 to 300,000 ppm; hardness of 20,000 to 35,000 Ca ppm; barium of 4,000 to 10,000 Ba ppm; and chlorides of 80,000 to 150,000 Cl ppm.⁶³
- Produced water management is being shaped by changing Pennsylvania and Ohio regulatory requirements. The Pennsylvania Department of Environmental Protection does not allow discharges of produced water unless it is treated so that TDS levels are below 500 mg/L. In April 2011, producers were notified they would not be permitted to discharge to surface bodies. There are few in-state Class II disposal wells available. Furthermore, due to seismic events that may or may not be related to injection of produced water in Ohio wells, Pennsylvania producers may face challenges or higher costs to ship produced water out of state.

59 Veil, "Shale Gas Water Management—Experiences from North America," slide 30.

60 Nicot, slide 9.

61 Veil, "Shale Gas Water Management—Experiences from North America," slide 25.

62 Venkee Sharma, "Produced Water Management Trends & Challenges," presentation at the "Produced Water: Asset or Waste?" event, June 24-25, 2013, slide 13.

63 Ibid., slide 9.

- Between 2011 and 2012, there were significant changes in the amount of produced water that was recycled and reused. In 2011, 35 percent was reused, 1 percent was stored, 7 percent went to injection wells, and 57 percent was sent to an industrial facility. In 2012, 65 percent was directly reused with little treatment, 2 percent was stored, 15 percent was disposed of in injection wells, and 18 percent was sent to an industrial facility. In the future, treatment options will be driven by transportation costs which can make up 50 percent of overall costs and the emergence of disposal options in West Virginia. Apart from reuse of produced water, treatment of the produced water to remove/crystallize the salts and deal with NORM in the produced water will be required.⁶⁴ In summary, recycling is the primary option choice, with little or no treatment. For Marcellus areas with affordable transportation to disposal facilities in Ohio or West Virginia, treatment will not be chosen. When wastewater is treated, most likely in the central and northeast Marcellus areas, the trend is toward using centralized treatment centers.

Unconventional Oil-rich Shales

As in the section above on shale gas plays, next the Eagle Ford and Bakken plays are compared.

Water needs/produced water volumes/characteristics/treatment options in Eagle Ford

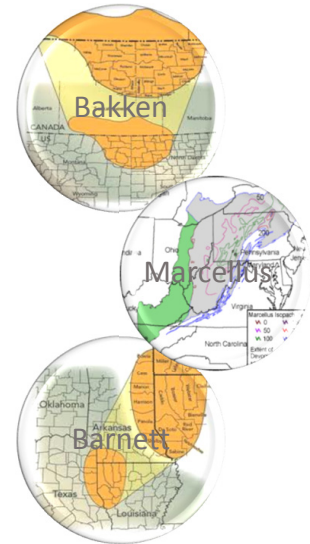
- Except in counties close to the Rio Grande, fresh water availability does not pose a significant roadblock to hydraulic fracturing. However, some companies reduce fresh water use as a matter of sustainable corporate policy. Brackish water or municipal waste waters are considered to be superior sources of reducing fresh water except where these water sources are scarce or expensive and where ample volumes of produced water are easily/economically treated and transported for reuse.
- The optimum circumstances favoring the use of produced water occur when high quality source water is not readily available; the produced water's quality and availability is high; the transportation and logistics of using it reduce an operator's costs; there is chemistry compatibility of the produced and fracking waters; and there is high compatibility of the produced water with the reservoir.⁶⁵
- Generally, Eagle Ford produced water contains problematic components, including TDS, suspended

64 Ibid., slide 14.

65 Steve Jester, "Evaluation of Produced Water Reuse for Hydraulic Fracturing In Eagle Ford," presentation at the "Produced Water: Asset or Waste?" event, June 25, 2013.

Figure 10. Comparison Of Produced Water Treatment Approaches Across Different Shale Plays

- **Bakken: Most PW is disposed of via injection wells**
- **Marcellus/Utica: Many operators in PA reuse PW due to a lack of injection wells**
 - **Low PW volumes facilitate this approach**
 - Operators in Ohio (Utica) typically use injection wells
 - Operators in Western PA may truck water to Ohio for disposal
- **Barnett: Both reuse and disposal via injection wells are common**
- **Eagle Ford: Most PW is disposed of via injection wells even though the climate is semi-arid**
 - Reuse in many areas is inhibited by land-owner water agreements
- **Fayetteville: UIC disposal is common but limited in some areas due to induced seismicity concerns**



Source: David Alleman, "Produced Water Management in Unconventional Resource Plays: Strategies and Technology Needs," presentation at the "Produced Water: Asset or Waste?" event, Atlantic Council, Washington, DC, June 25, 2013, slide 13.

solids, iron, scaling elements, boron and oil residue, and organic matter. There are additional issues in high temperature play areas. Due to low produced water volumes at well sites, typically 20-30 bbl/day, it may be too costly to collect water from hundreds of sites to provide source water for hydraulic fracturing one well (except in areas of extreme scarcity).⁶⁶

- Reuse can be inhibited by regulatory requirements as well as by land-owner water agreements. Many landowners have agreements that require the oil and gas company to drill water wells on the landowner's property and then use and pay for this water.⁶⁷
- Most of the produced water is disposed of via injection wells. As in the Barnett shale area, recycling may increase due to the passage of the Texas Administrative Code Title 16. Disposal will remain the preferred option until Texas passes legislation limiting deep well injection, mandates recycling, and treatment costs are reduced.

Water needs/produced water volumes/characteristics/treatment options in the Bakken

- Water supply for hydraulic fracturing is not an issue at present. It is drawn from fresh groundwater, municipal fresh water and Lake Sakakawea. Municipal gray water is not a promising option due to limited supplies from a small population. Use

of water from saline aquifers, such as the Dakota, is uneconomic at present. Operators procure from their own sources, or by purchasing it from water depots or trucking companies; it is generally transported to well sites by truck.

- Produced water quality is highly saline and ranges from 30,000 to 250,000 TDS. The salinity varies both over time and by well.
- The vast majority of produced water is disposed of in Class II injection wells; 80 percent is injected and about 20 percent is reused for more hydraulic fracturing operations.

Summary Comparison of Practices in the Marcellus, Barnett, Bakken, and Eagle Ford

The workshop compared and contrasted water management strategies in the shale gas and the oil-rich shale plays to demonstrate that choices are site specific and depend to a large degree on available injection well options and local water availability. In the Bakken, most produced water is disposed of in injection wells. In the Marcellus, most operators in Pennsylvania reuse the produced water due to a lack of permitted injection wells and because low produced water volumes allow this approach. Some operators truck the water to Ohio for disposal in injection wells. In the Barnett, both reuse and injection well disposal are practiced. In the Eagle Ford area, most produced water is disposed of in readily available injection wells. While reuse may be inhibited by land-owner water agreements, new regulations that permit reuse may begin to change practices in this semi-arid region. Figure 10 summarizes the produced water treatment approaches in the Bakken, Eagle Ford, Marcellus, and Barnett plays.

⁶⁶ Ibid., slide 11.

⁶⁷ J. Daniel Arthur and David Alleman, "Water Management in the Bakken," presentation at the "Produced Water: Asset or Waste?" event, June 25, 2013, slide 13.

Barriers

To achieve a new mindset on produced water as an asset and not a waste, a number of barriers must be addressed.

Myriad Perspectives

It is not surprising that it is hard to change perspectives on produced water as an asset rather than as a waste.⁶⁸ The energy and water industries, which consist of a multitude of specialized operators, have different perspectives. The oil and gas producers look for least cost and least failure risk options. Drillers are concerned about the time to obtain permits, liability concerns and worries over back up plans if the treatment plant does not function as promised, or when needed. The freshwater trucking companies stand to lose business if water requirements are reduced. Disposal well and fresh water producing companies have no incentive to convert produced water through treatment. Oilfield service and water treatment companies have the most to gain from policies that encourage produced water treatment.

Finance Barriers

Investors are stymied by longer than hoped for (three to five year window) pay back periods and a lack of clear regulatory standards. Venture capital and private equity activity are slowly developing.⁶⁹ The investment opportunities have improved now that removal, treatment, recycling, and disposing of the wastewater has been approved for “master limited partnerships (MLP).”⁷⁰ Ninety percent of the income from preapproved sources in these partnerships receives tax incentives.

Property Rights Barriers

The disconnect between surface versus mineral ownership is a fundamental concern. The severance of mineral rights from surface rights, combined with the

legal concerns about eminent domain and an individual’s personal property rights, has the potential to impact the handling, disposal, treatment, and marketing of produced water. Subsurface water—whether it is fresh, brackish, or saline or associated with or without oil and gas production—carries a clear regulatory responsibility, but there is a lack of civil clarity. For example, the licensed oil and gas operator, or entity that is authorized by the state to handle oil field materials, has the regulatory responsibility regarding produced water. Spills, cleanups, authorized disposal, or recycling have clear regulatory requirements because produced water has long been considered a routine part of the oil field waste stream. However, produced water that is used or treated for use does not have that same “clarity of regulatory requirements.” Some property concerns include pore space trespass by injection, withdrawal without compensation, and private contractual commitments. Particularly in Texas, subsurface or ground water rights are closely aligned with property rights. Produced water is not commonly mentioned in oil and gas leases and may not be always considered part of the mineral estate. As “value is added” to produced water through treatment and subsequent reuse, water owners, usually surface owners, will expect some contractual guarantees to ensure they share in the increased value.

Liability Concerns

Liability inconsistencies across states impact those multi-state operations. Industry is especially concerned over liability issues involved with making produced water available for beneficial reuse. Liability issues do not often surface if produced water is reused in oil and gas operations. Until there are liability and tort protections for those who reuse and recycle produced water, opportunities will be limited.

Changing and Uncertain Regulatory Requirements

The 2005 Energy Policy Act exempted water from hydraulic fracturing operations from Safe Drinking Water Act regulations requiring underground injection. However, several federal agencies are either examining or have already proposed new water-related disposal rules. The Department of Interior in 2012 proposed a rule requiring companies to disclose hydraulic fracturing chemicals for operation on federal and Indian lands. In 2012, the Environmental Protection Agency proposed federal air pollution limits for oil and gas production areas. In the state of New York, there are hydraulic fracturing bans; more than twenty towns have banned it; and over sixty towns have temporary bans. Many states have enacted requirements for disclosure of chemicals in such operations. Ohio temporarily halted permitting of new disposal

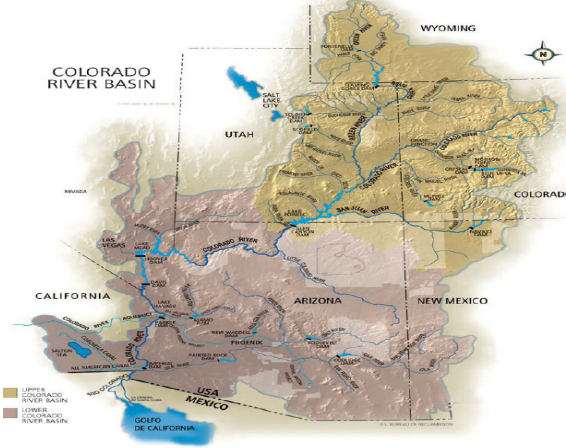
68 Mitch Burroughs, “Fossil Fuel Produced Water: Asset Or Waste?,” presentation at the “Produced Water: Asset or Waste?” event, June 24, 2013, slide 2.

69 Su Gao, “Status and Trends of Investing in the Shale Water Space,” presentation at the “Produced Water: Asset or Waste?” event, June 25, 2013, slide 10.

70 The MLP does not pay taxes from their profit so money is only taxed when unit holders receive distributions. Thus, the cost of capital for the MLP is lower and typically result in higher returns yield from MLPs, thus the interest in MLP investments. The MLP is a type of limited partnership that is publicly traded on a securities exchange. Only enterprises that engage in certain businesses (real estate, natural resources) can qualify, with 90 percent of their income derived from approved sources. Limited partner provides capital and gets periodic income distribution from the MLP’s cash flow. General partner is involved in managing the MLP and compensation is linked to performance of the venture. Gao, “Status and Trends of Investing in the Shale Water Space,” presentation at the “Produced Water: Asset or Waste?” event, June 25, 2013.

Figure 11. Beneficial Produced Water Use in the Colorado Basin

Upper Colorado River Basin (Green River Play) – at 2 bbl’s/MCF – 70,000,000 AF or potentially 500,000 to 1,000,000 AF per year



Source: Dave Stewart, “Critical View of Technology Requirements,” presentation at the “Produced Water: Asset or Waste?” event, Atlantic Council, Washington, DC, June 25, 2013, slide 14.

wells due to seismic concerns. Vermont has banned fracturing entirely.⁷¹

Costs

A primary barrier is the additional cost of treating rather than disposing the produced water. In the current environment of low gas prices, producers are looking to reduce, not increase, their treatment costs.⁷² Related to the treatment costs is the issue of what the energy industry must pay for water supplies to initiate hydraulic fracturing operations. Tensions are building in certain areas of the country because the energy industry is willing to pay quite a bit more than the agriculture industry for water. For example: in Colorado, the agriculture sector typically pays \$15/acre ft., but oil and gas companies have bid \$35/acre ft.

Silos

The energy and water sectors have traditionally not engaged fully on treatment technologies primarily due to the concern that new technology/treatment will bring increased cost and failure risks. Silos remain between government agencies as well as between the energy and water industries. Utilities must join in the conversation as well. Sustainable approaches will require collaborative solutions, based on an integrated holistic view that takes into consideration the local population profile, water supply outlook, and expected development in various sectors.

71 David Muchow, “Increasing Investor and Public Support for Fracking: The Real Risks, Truth, and Public Trust,” presentation at the “Produced Water: Asset or Waste?” event, June 25, 2013, slide 11-12.

72 During the workshop, these costs were mentioned: Breakeven gas prices range from low of 1.30-1.70 in Eagle ford and South West Marcellus, but most production requires \$5/mcf and some \$6-7 MCF. With a range of cost for water handling at well site, transporting and reinjecting water of 20-70 cents per MCF.

Technology gaps

There will be no technology silver bullet, and at present there are no revolutionary technologies on the horizon. There will be incremental improvements to some specific treatment processes and perhaps some cost reductions. However, a technology portfolio will be necessary to address the wide variation in conditions. Produced water treatment prospects would be aided by new, less costly technologies to separate salts and organics at lower temperatures (i.e., at lower costs due to reduced energy requirements) and that could recover chemicals in the produced water to help offset high treatment costs.

Opportunities for Expanding Use of Produced Water

Produced water can be recycled and reused for exploration and production and beneficially used outside the oil and gas industry. The range of options includes

- EOR, which will be more widely used in the future;
- recycling produced water in field operations;
- injection for hydrological purposes to restore aquifers and river flow;
- agricultural use;
- industrial use; and
- drinking water and other municipal uses

Figure 11 summarizes a current project to augment water supplies in the Colorado River basin. There is another ongoing project in the Slater Dome area of southwest Wyoming and northwest Colorado where produced water is sold. Produced Water Development,

Produced Water: Asset or Waste?

LLC which is currently designing/building/owning/operating treatment facilities and selling the produced water to water resource agencies from coal bed methane produced water.

Incentives are key to increasing the beneficial reuse of produced waters. Texas provides a good example of how regulations can incentivize recycling. In March 2013, Texas adopted a rule that defines recycle as “To process and/or use or re-use oil and gas wastes as a product for which there is a legitimate commercial use and the actual use of the recyclable product.”⁷³ The rule waives recycling permits that had been required if operators recycled fluid on their own leases or transferred their fluids to another operator’s lease for recycling. Texas specifically allows for “centralized commercial solid oil and gas... recycling.”⁷⁴

73 Texas Administrative Code. “Economic Regulation, Railroad Commission of Texas, Environmental Protection, Commercial Recycling, General; Definitions.” Title 16, Part 1, Chapter 4, Subchapter B, Division 1, Rule §4.204. December 4, 2006. [http://info.sos.state.tx.us/pls/pub/readtac\\$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=16&pt=1&ch=4&rl=204](http://info.sos.state.tx.us/pls/pub/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=16&pt=1&ch=4&rl=204).

74 Steve Tarallo, “Sustainable Solutions for Oil & Gas Produced water,” presentation at the “Produced Water: Asset or Waste?” event, June 24-25, 2013, slide 19.

Atlantic Council Board of Directors

CHAIRMAN

*Jon M. Huntsman, Jr.

CHAIRMAN, INTERNATIONAL ADVISORY BOARD

Brent Scowcroft

PRESIDENT AND CEO

*Frederick Kempe

VICE CHAIRS

*Robert J. Abernethy

*Richard Edelman

*C. Boyden Gray

*Richard L. Lawson

*Virginia A. Mulberger

*W. DeVier Pierson

*John Studzinski

TREASURER

*Brian C. McK.

Henderson

SECRETARY

*Walter B. Slocombe

DIRECTORS

Stephane Abrial

Odeh Aburdene

Peter Ackerman

Timothy D. Adams

John Allen

*Michael Ansari

Richard L. Armitage

*Adrienne Arsht

David D. Aufhauser

Elizabeth F. Bagley

Sheila Bair

*Rafic Bizri

*Thomas L. Blair

Julia Chang Bloch

Francis Bouchard

Myron Brilliant

*R. Nicholas Burns

*Richard R. Burt

Michael Calvey

James E. Cartwright

Ahmed Charai

Wesley K. Clark

John Craddock

David W. Craig

Tom Craren

*Ralph D. Crosby, Jr.

Thomas M. Culligan

Nelson Cunningham

Ivo H. Daalder

Gregory R. Dahlberg

*Paula J. Dobriansky

Christopher J. Dodd

Conrado Dornier

Patrick J. Durkin

Thomas J. Edelman

Thomas J. Egan, Jr.

*Stuart E. Eizenstat

Julie Finley

Lawrence P. Fisher, II

Alan H. Fleischmann

Michèle Flournoy

*Ronald M. Freeman

*Robert S. Gelbard

*Sherri W. Goodman

*Stephen J. Hadley

Mikael Hagström

Ian Hague

Frank Haun

Rita E. Hauser

Michael V. Hayden

Annette Heuser

Marten H.A. van Heuven

Jonas Hjelm

Karl Hopkins

Robert Hormats

*Mary L. Howell

Robert E. Hunter

Wolfgang Ischinger

Reuben Jeffery, III

Robert Jeffrey

*James L. Jones, Jr.

George A. Joulwan

Stephen R. Kappes

Maria Pica Karp

Francis J. Kelly, Jr.

Zalmay M. Khalilzad

Robert M. Kimmitt

Henry A. Kissinger

Peter Kovarcik

Franklin D. Kramer

Philip Lader

David Levy

Henrik Liljegren

*Jan M. Lodal

*George Lund

*John D. Macomber

Izzat Majeed

Wendy W. Makins

Mian M. Mansha

William E. Mayer

Eric D.K. Melby

Franklin C. Miller

*Judith A. Miller

*Alexander V. Mirtchev

Obie L. Moore

*George E. Moose

Georgette Mosbacher

Bruce Mosler

Thomas R. Nides

Franco Nuschese

Sean O'Keefe

Hilda Ochoa-Brillembourg

Ahmet Oren

Ana Palacio

Thomas R. Pickering

*Andrew Prozes

Arnold L. Punaro

Kirk A. Radke

Joseph W. Ralston

Teresa M. Ressel

Jeffrey A. Rosen

Charles O. Rossotti

Stanley O. Roth

Robert Rowland

Harry Sachinis

William O. Schmieder

John P. Schmitz

Anne-Marie Slaughter

Alan J. Spence

John M. Spratt, Jr.

James Stavridis

Richard J.A. Steele

James B. Steinberg

*Paula Stern

Robert J. Stevens

John S. Tanner

Peter J. Tanous

*Ellen O. Tauscher

Karen Tramontano

Clyde C. Tuggle

Paul Twomey

Melanne Verveer

Enzo Viscusi

Charles F. Wald

Jay Walker

Michael F. Walsh

Mark R. Warner

J. Robinson West

John C. Whitehead

David A. Wilson

Maciej Witucki

Mary C. Yates

Dov S. Zakheim

HONORARY DIRECTORS

David C. Acheson

Madeleine K. Albright

James A. Baker, III

Harold Brown

Frank C. Carlucci, III

Robert M. Gates

Michael G. Mullen

William J. Perry

Colin L. Powell

Condoleezza Rice

Edward L. Rowny

George P. Shultz

John W. Warner

William H. Webster

LIFETIME DIRECTORS

Carol C. Adelman

Lucy Wilson Benson

Daniel J. Callahan, III

Brian Dailey

Kenneth W. Dam

Lacey Neuhaus Dorn

Stanley Ebner

Chas W. Freeman

Carlton W. Fulford, Jr.

Edmund P. Giambastiani, Jr.

John A. Gordon

Barbara Hackman

Franklin

Robert L. Hutchings

Roger Kirk

Geraldine S. Kunstadter

James P. Mccarthy

Jack N. Merritt

Philip A. Odeen

William Y. Smith

Marjorie Scardino

William H. Taft, IV

Ronald P. Verdicchio

Carl E. Vuono

Togo D. West, Jr.

R. James Woolsey

* Executive Committee
Members
List as of January 17, 2014

The Atlantic Council is a nonpartisan organization that promotes constructive US leadership and engagement in international affairs based on the central role of the Atlantic community in meeting today's global challenges.

1030 15th Street, NW, 12th Floor, Washington, DC 20005

(202) 778-4952, www.AtlanticCouncil.org