Sustainable Produced Water Policy, Regulatory Framework, and Management in the Texas Oil and Natural Gas Industry: *2019 and Beyond*

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Introduction

The dramatic increase in oil and natural gas production from Texas is historic. In many ways, including economic growth, technological innovations and political as well as regulatory policy, it is not hyperbole to say that "Texas fuels the world."[1] Texas produced water (PW) policy and practices can be said to fuel some of the most critical operations in the oil and gas industry.

> Today's challenge is that Texas must simultaneously source large amounts of water for fracturing operations in arid, if not drought impacted areas, while at the same time managing millions of gallons of PW from onshore unconventional operations.

Recognizing the emerging importance of energy and water issues, in July 2014 the Atlantic Council published the white paper, *Sustainable Water Management in the Texas Oil and Gas Industry*, by John Tintera and Blythe Lyons.[2] Five years since the 2014 report's publication, it is clearer than ever that water management will be key for Texas's ability to maintain its production capabilities and remain the linchpin of the US oil and gas boom. During the last 5 years, low prices and pipeline capacity constraints impacted the Texas oil and gas industry.[3] Today's challenge is that Texas must simultaneously source large amounts of water for fracturing operations in arid, if not drought impacted areas, while at the same time managing millions of gallons of PW from onshore unconventional operations.

Many of the 2014 white paper's recommendations have been implemented. For example, it called for the preservation of state management of oil and gas production wastes under the Resource Conservation and Recovery Act (RCRA). While the RCRA Subtitle C exemption requires legislation to change it, environmental organizations had sued the Environmental Protection Agency (EPA) to address production wastes under RCRA Subtitle D. On April 23, 2019 the EPA announced that it would not pursue any action under RCRA Subtitle D -i.e., that existing state frameworks were effectively managing wastes from oil and natural gas production. The 2019 Texas Legislative session considered and passed several proposals that address the 2014 report's recommendations on PW ownership, regulatory authority, recycling tax incentives and programs to increase recycle and reuse (R&R.)

PW management, a critical business component of every upstream oil and gas producer in Texas, deserves a fresh look in terms of policies, regulations and practices in the rapidly evolving midstream oil and gas industry. The changing federal regulatory atmosphere provides an opportune moment for Texas policy makers and industry members to highlight, frame and comment on specific issues and successes regarding PW. There is also a need to keep the public informed about technologies and trends that will continue to make R&R more efficient. It is time to update the data in the 2014 report.

The Texas Alliance of Energy Producers (the Alliance) and the Independent Petroleum Association of America (IPAA) have teamed up to publish an update of the 2014 paper, with a focus on PW management, the *Sustainable Produced Water Policy, Regulatory Framework and Management in the Texas Oil and Gas Industry: 2019 and Beyond.* This paper: highlights Texas oil and gas production; profiles PW; outlines PW volumes, re-use rates and disposal well capacity; examines PW treatment and technology options; discusses changes in Texas's policy and regulatory framework; summarizes drivers and headwinds; examines the evolution of PW management strategies over the past five years; provides recommendations; and concludes with what Texas has done well and could do better as well as what it will take to move the needle on using and/or discharging PW outside oil and gas fields.

The white paper's content is based on a review of studies published in the past five years as well as in-depth interviews with a diverse and inclusive group of experts in the industry, regulatory, consulting, data analysis and management, non-governmental, non-profit and academic fields. Its intended audience is the public, Texas state regulators and lawmakers and federal government representatives. The white paper represents the views solely of the co-authors.

The Alliance and IPAA gratefully acknowledge primary source material contributions from Sourcewater Inc., B3 Insight, DrillingInfo, BrightSky Environmental, Miller Consulting, Inc. and Dr. F. Todd Davidson, IdeaSmiths. The report would not be possible without financial support from XTO Energy and BP. Furthermore, the authors, the Alliance and IPAA would like to thank the following individuals, companies and organizations for their insights provided during interviews with the report's authors: Concho Resources Inc; Gabriel Collins, Baker Institute of Public Policy at Rice University; J.P. Nicot, the University of Texas at Austin Bureau of Economic Geology; Zacariah Hildenbrand and Kevin Schug, CLEAR Research Team, University of Texas Arlington; Environmental Defense Fund; EOG; Fountain Quail Energy Services; Goodnight Midstream; Advisian, a Worley Company; Marathon Oil Company; Matador Resources Company; Permian Basin Water Management Council; Produced Water Society; Solaris Water Midstream; Texas Railroad Commission Commissioner Wayne Christian; Texas Royalty Council; WaterBridge Resources, LLC; and XRI.

What's at Stake

Net US energy imports have reached a 54-year low as the drumbeat of impressive export news beats on.[4] The Energy Information Administration's *2019 Annual Energy Outlook* predicts that the US will export more petroleum and other liquids than it imports beginning in 2020, which has not happened since the 1950s.[5] Crude oil net imports began declining in 2018.[6] Net exports of natural gas will continue their growth spate.[7] US natural gas production and exports are surging and expectations are that gas production will continue to rise in 2020.[8, 9] The US became a net gas exporter in 2017 for the first time in 60 years and 2018 output maintained this record.[10] As of March 2019, the US has been a net gas exporter for more than 12 consecutive months.[11] BP's Statistical Review of World Energy 2019 reports another "new record": growth in 2018 US oil production (including natural gas liquids) of 2.2 million barrels of oil per day (b/d) is the largest annual increase for any country, in any year on record.[12]

The US energy independence goal has been largely accomplished due to its unconventional production capability, the driver behind the US industry's resurgence. The most recent *World Energy Outlook* reports that US oil production is almost a record-breaking 12 million barrels per day. Approximately half of this production is due to unconventional oil production, which rose from a half a million barrels per day in 2010 to approximately 6 million barrels per day in just 8 short years. This unconventional production rate is forecasted to continue rising to over 9 million barrels per day in the 2020s.[13]

The US energy independence goal has been largely accomplished due to its unconventional production capability, the driver behind the US industry's resurgence.

As the US has achieved this oil and gas powerhouse status, Texas has established itself as the leader of US oil production and a major contributor to increasing gas supplies. The 75,000-square mile Permian Basin is the work horse of Texas's oil fields. As of March 2019, Permian production exceeded 4 million barrels of oil per day.[14, 15] Industry analysts foresee the possibility this could double.

US oil and gas production and associated export prowess create waves of opportunity and positive impacts both nationally and internationally for the US. US foreign policy is profoundly improved by the flexibility to achieve foreign policy goals without the fear of a major disruption to US oil supply and, hence, the economy. Additionally, the geopolitical risks associated with sanctioning the exports of suppliers who might run afoul of US foreign policy goals are greatly reduced. US production cushions the country against severe gasoline price increases due to self-imposed or internal political strife related to production limits from other nations.

Not only is US national security improved, the national economy benefits from increased production. The US petrochemicals industry is experiencing a resurgence. Plentiful, American, well-priced natural gas supplies increasingly fuel electricity generation capacity, generally replacing carbon-intensive coal plants reaching retirement.[16] Texas, the linchpin of US production, enjoys benefits in the realms of employment and industrial development which lead to rising tax revenues that fund public health, education and infrastructure improvements.

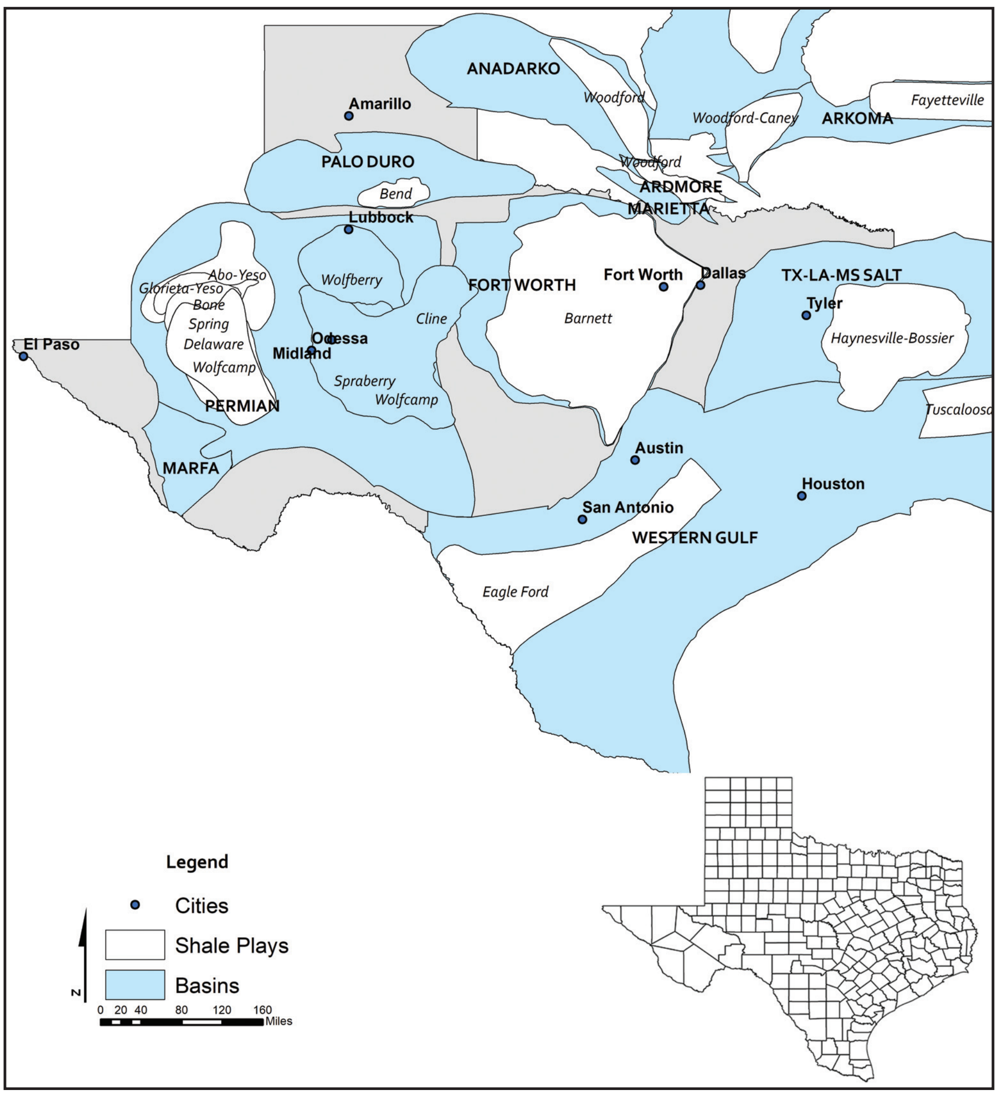
Five years ago, the 2014 white paper argued that the oil and gas industry's development of an integrated and sustainable water management strategy would support US energy self-sufficiency. The "energy independence mission" has largely been achieved. However, to keep US production dominance alive, the Texas oil and gas industry must maintain its "social license" to operate through a variety of activities that include developing good water management strategies and maintaining public support by exhibiting to the public that the industry is using water wisely and sustainably.

Oil and Gas Production and Forecasts in Texas Basins

Overview

As shown in Figure 1, **Major Basins and Shale Plays in Texas,** production in Texas comes from six major regions or units: the Permian Basin in west Texas; the Anadarko Basin/Granite Wash and Palo Duro (or Bend) Basins in the Panhandle; the Barnett Shale in the Fort Worth Basin; the Western Gulf Coast Basin in southwest Texas (which includes the Eagle Ford Shale); and the historic East Texas Field, which contains the Haynesville-Bossier Shale. The primary producing Permian sub-basin regions include the Delaware Basin, the Central Basin Platform and the Midland Basin. Important Permian plays include the Bone Spring (tight sandstone oil), Wolfcamp (producing most of the shale oil in the Midland Basin), Abo (tight sandstone oil), Spraberry (tight sandstone oil), Wolfberry (shale/tight sandstone oil), Wolfbone (shale/tight sandstone oil) and Cline (shale oil).

Figure 1. Major Basins and Shale Plays in Texas



Source: Data for map sourced from EIA Maps of Oil and Gas Exploration, Resources and Production. https://www.eia.gov/maps/maps.htm.

Texas's oil and gas fields are the most productive in the country. In late-2016, multiple new oil discoveries and more cost-effective drilling technology led to a dramatic increase in tight oil production across the US, a large portion of which is focused in the Permian Basin of West Texas. In 2017, Texas generated 23 percent of the total US natural gas production and 38 percent of the total crude oil production.[17] This translates to more than 1.26 billion barrels of oil (including crude and condensate) and more than 8.08 billion cubic feet of gas (including gas well gas and casinghead gas) in 2017 alone, according to the Texas Railroad Commission (RRC.)[18]

As of February 2019, the state of Texas had approximately 186,000 producing oil wells and over 100,000 conventional producing gas wells.[19, 20] Gas may also be produced as associated gas from an oil well, thus many wells are combined oil and gas wells. Almost half of the oil wells and 20 percent of the gas wells are within the Permian Basin, according to RRC data.

In November of 2018, DrillingInfo recorded more than 13,000 horizontal wells in the Permian Basin and more than 11,000 wells in the Fort Worth Basin.[21] In the Permian, horizontal drilling is most common within the centers of the Midland and Delaware Basins; within the Central Basin Platform and along the basin margins, vertical drilling predominates. Lateral well technology developed in the mid-2000s led to an increase in horizontal drilling in the Permian Basin, but prior to this, wells within the Permian were vertical and most of these wells remain active. To drill this variety of wells across Texas, significant volumes of water are used and produced along with oil and gas.[22]

While most US gas is produced in the Appalachian region, Texas production has experienced large volumetric gains. A significant portion of this production is associated with increases in oil co-production in the Permian Basin and Haynesville Shale formation, which experienced increases of 32 percent and 34 percent, respectively.[23, 24]

Production from the Permian and other major basin powerhouses is supplemented by marginal and stripper wells. Approximately 10 percent of total US oil and natural gas in 2017 came from marginal wells. There are multiple definitions for marginal and stripper wells and occasionally they are used synonymously. Marginal wells can be defined as wells that require a high oil/gas price to be viable because of low production rates or high production costs. Stripper wells are defined by their production rate. These wells must produce less than 10 barrels or 60,000 cubic feet per day over a 12-month period, according to the Interstate Oil and Gas Compact Commission (IOGCC), or less than 15 barrels or 90,000 cubic feet per day over a calendar year, according to the Internal Revenue Service. The EIA reported that in 2017 there were approximately 785,600 wells across the US producing15 barrels of oil equivalent or less per day. In 2017, Texas reportedly had around 227,900 wells producing 15 barrels of oil equivalent or less per day that produced 94.3 million barrels of oil and 526 billion cubic feet of natural gas.[25] Marginal wells on land are commonly, though not always, stripper wells and are usually owned by small operators. Although it may be hard to imagine, almost every producing well will eventually become a marginal well.

Texas Oil Production 2014-2018

Total oil production in Texas increased from 1.16 billion barrels (3.2 million barrels per day) in 2014 to 1.62 billion barrels (4.4 million barrels per day) in 2018.[26] The majority of this production increase was from the Permian Basin region. Production in the Permian Basin grew from an average of 1.2 million barrels per day in 2012, to 1.6 million barrels per day in 2014, to over 4 million barrels per day in 2018. This dramatic increase in production from the Permian offset a contemporaneous decrease in production from all other major Texas basins, including the Palo Duro, Gulf Coast, Fort Worth, Anadarko and East Texas.[27] In southern Texas, the Gulf Coast Basin contains the Eagle Ford Shale, the second most productive unit in the state for oil. According to the RRC, the Eagle Ford is currently producing 870,000 barrels per day. The Anadarko Basin was producing 23,000 barrels per day in 2013, but production fell to approximately 5,200 barrels per day in 2018. After a peak in 2013 of 5,700 barrels per day, oil production in the Barnett Shale in the Fort Worth Basin decreased to approximately 800 barrels per day. New-well oil production in June 2019 increased in the Permian, Eagle Ford and Anadarko Basins.[28]

Texas Gas Production 2014-2018

Production in Texas reached 26.5 billion cubic feet per day in February 2019, compared to less than 21 billion cubic feet per day in January 2017.[29] DrillingInfo data show that average gross gas production in the Permian increased from 5.6 million cubic feet per day in 2014 to 10.9 million cubic feet per day in 2018. In contrast, gas production in the Barnett Shale and the Eagle Ford Shale decreased between 2014 and 2018.[30] The East Texas Haynesville-Bossier Shale natural gas production has been variable over the past decade, declining somewhat after a peak in 2012 from 1.2 billion cubic feet per day to one billion cubic feet per day.[31] According to the EIA 2019 Year-Over-Year Drilling Report, the Haynesville has seen the most dramatic increase in new-well gas production from 2018-2019, although all major Texas basins included in the report saw a moderate increase or at least maintained levels in new-well gas production.[32] New-well gas production in the Permian, Eagle Ford and Anadarko Basins has increased from May 2019 to June 2019.[33]

Texas Oil and Gas Production Projections to 2025

Under all price-sensitive-based scenarios, oil and gas production will grow. The low-price case from DrillingInfo indicates that by 2025, with a WTI crude price of $51.93, average crude oil production will increase to 6.9 million barrels per day and average gas production will increase to 33 billion cubic feet per day with a Henry Hub price of $2.96. The high-price case (WTI $75.00; Henry Hub $3.75) suggests that by 2025 average crude oil production could reach 8.9 million barrels per day and average natural gas production could reach 45 billion cubic feet per day.[34] Low prices will yield low production which will cause both a decrease in the overall water volume used for fracturing operations and a decrease in the volume of PW (see Produced Water section). Unsurprisingly, high prices will yield higher rates of production, which will increase the total volume of water used in the oil field and the total volume of PW coming from operations. Good times and high prices in the oil and natural gas fields of Texas will inevitably lead to high volumes of water to manage.

Increasing Production Leads to Increased Water Demands

Water demand for onshore drilling and completions increased in 2018 and will continue to increase.[35] The increase in water volumes used per well is linked to a concurrent increase in proppant intensity, lateral length and completion design, which are tied to the predominance of unconventional formations in the industry today.[36] Water use in the industry can be thought of as the "investment" of water in a well (fluids for initial fracturing, enhanced oil recovery and for other uses) which allows operators to ensure that production is the most efficient it can be and valuable energy resources are not left behind in the formation. This increases the volume of resources recovered per unit of surface area disturbed through production, increasing the efficiency of the industry and reducing some of the impacts. In the Permian alone, water use per well has at least increased from an average of almost 30,800 barrels per well in 2011 to around 267,000 barrels per well in 2016.[37] Some operators report operations in the Midland Wolfcamp play can use over 400,000 barrels of water total per well.[38] Still other sources report average water use per well around 500,000 to 650,000 barrels per well and rising with some fracturing operations exceeding 1 million barrels of water.[39, 40, 41, 42] A 2018 study from the Duke Nicholas School of the Environment normalized water use per well to lateral length and determined that water use per cubic meter of lateral space had also increased. This was most evident in the Permian Basin, where the study found that in oil wells, water use per cubic meter of lateral length had increased from approximately 24.5 barrels in 2011, to 119.5 barrels in 2016.[43]

Future water use will be in part determined by drilling productivity. Drilling productivity is modulated by oil and gas prices, where high prices usually indicate a spike in drilling. In unconventional plays, high prices would yield an increase in water needs for hydraulic fracturing operations. For oil development in unconventional basins, the previously mentioned 2018 Duke study concluded that if drilling rates are low and continue hovering around 2016 (low-price scenario) levels, the Permian Basin would expect water use per year to reach around 1.5 billion barrels by 2030. Reports indicate that the Permian Basin is already on track to exceed 1.2 billion barrels of water used this year (2019).[44] If, in a high price scenario, drilling rates continue to increase or approach the historically high rates of 2014, the Permian could potentially use 8.8 billion barrels of water by 2030. For unconventional gas development, the Eagle Ford Basin could expect to use almost 943 million barrels of water per year if drilling rates are sluggish. Again, if drilling rates continue to increase in a high price case, water use in the Eagle Ford could reach as high as 5.3 billion barrels of water per year.[45]

This is a large volume of water, but it is important to put it into context. The estimated statewide water use by the *entire* mining/oil and gas sector remains *less than 1 percent* of the total water used annually in Texas. Annual water use for agricultural irrigation and municipal use are significantly greater as of 2017, around 55 percent and 31 percent, respectively.[46] According to the Texas Water Development Board's (TWDB) 2017 Statewide Water Plan, by 2030 Texas could be using over 198.5 billion barrels of water per year statewide. In the most dramatic high-price scenario described above, Permian water use of 8.8 billion barrels of water per year would still only account for 4.4 percent of total statewide water usage, while the Eagle Ford would use only 2.7 percent of the total statewide water budget. In the low-price scenario above, the Permian would account for 0.76 percent of statewide water use and the Eagle Ford would use only 0.48 percent. In 2030, the TWDB projects that municipal water usage will reach 59.9 billion barrels of water and by 2070 municipal water use could grow to a staggering 87.2 billion barrels per year, almost 40 percent of the state's total water usage. Additionally, the TWDB anticipates that water usage by the oil and gas industry will begin to decline after 2030.[47]

Profile of Produced Water in Texas Basins

Defining Produced Water

Unconventional formations deviate from the typical sandstone and carbonate formations that previously dominated the energy industry. These unconventional resources have extremely low permeability, the ability of oil or gas to flow through the rock. To develop these unconventional resources, they may be hydraulically fractured by injecting water under high pressure into the reservoir formation to induce fractures, enabling the flow of oil and gas. Many of the wells in Texas, most significantly in the Permian and Fort Worth Basins, have been developed using horizontal drilling with hydraulic fracturing.

The water initially used to fracture the reservoir formation that returns to the surface, typically only for the first few weeks of a well's life, can be referred to as "flowback water."[48] In shale formations, only 20 to 30 percent of hydraulic fracturing water returns to the surface, while the remaining 70 to 80 percent remains within the tight shale.[49] The remaining water that is produced along with oil and gas during the lifecycle of a well can be referred to as PW.

PW may be derived from naturally occurring formation water in the producing or adjacent formations and can also include water that was injected into the formation to stimulate production. Depending on the chemistry of the surrounding rocks, PW may contain salts, oil and grease, naturally occurring radioactive materials, bacteria, organic and inorganic compounds and other solids.[50] The differences between flowback water and produced formation water are not germane for disposal purposes and many current recycling efforts. However, they could be significant if treatment and use outside of the oil field are planned. The US Geologic Survey (USGS) maintains a database of PW compositions across the country.[51]

Although they can be differentiated, data that distinguishes between flowback and produced water volumes is uncommon. Therefore, for the purposes of this report, references to PW are understood to encapsulate both produced and flowback water from wells.

Produced Water Volumes

Water to Oil Ratios

The Texas average barrels of water to barrels of oil ratio (WOR) is estimated to be around 7:1- a very large volume of water considering Texas oil production is around 5 million barrels of oil per day.[52, 53, 54] Because of this, huge volumes of water need to be managed in a cycle that includes various phases of treatment, transportation (trucking and pipeline), storage and finally disposal or reuse. The WOR of a well may also simply increase with time. A well that once produced at a ratio of 2:1 barrels of water to oil, may increase to 5:1 by its fourth year of production; WORs in the Delaware Basin can be twice as high as those in the Midland Basin, exceeding 10:1 in some instances. Hauling water away from well pads via truck can cost anywhere from $1 to 5 per barrel depending on travel distance and terrain, which can be prohibitively expensive when compared to the $.30 it reportedly costs to pipe water from a production well to a disposal well.[55] Moving water by pipeline however, is only efficient if a producer has easy access to a water pipeline and can collect large volumes of their PW by using this line. This typically necessitates contiguous acreage or the existence of commercial logistics solutions within a basin, a luxury many producers do not have. WOR may also be recorded as water to barrels of oil equivalent, which accounts for both oil and gas.[56]

Water to Gas Ratios

In addition to the water produced with oil, some water is co-produced with gas, which is known as the barrels of water to millions of cubic feet of gas ratio (WGR). Argonne National Labs 2009 study on PW in the US found that the average onshore WGR (for the 11 oil and natural gas producing states in the study with WGR data) was approximately 260 barrels of water per million cubic feet of gas and stated that only 13 percent of PW came from gas production.[57] In 2012, a study from the Groundwater Protection Council determined that the average national WGR was approximately 97 barrels of water per 97 million cubic feet of gas.[58] WGRs are not as commonly reported or discussed as WORs, which could be attributed to multiple reasons. Gas production typically produces less associated PW than oil production, thus the discussion framework and knowledge base surrounding WORs are more established and well understood than for WGRs. Additionally, many oil wells also produce gas, which may or may not be flared. Because of this, water production for a combined oil and gas well may only be reported as a water to oil ratio, without also reporting gas production (although the gas was not necessarily as instrumental in bringing the water to the surface as oil), thus a WGR for these wells would not be representative.[59] Moving forward, it is important to cultivate a better understanding of the relationship between gas production and PW volumes.

Produced Water Volumes 2014-2017

This report is generously informed by data provided by Sourcewater, Inc., B3 Insight and Drilling Info. Each company uses distinct proprietary methods and quality assurance protocols to develop and hone their data from varying data sources. Although some of the data included below represents similar information (e.g., annual PW volumes), the report authors share all sets of data with permission in the belief that ample and high-quality data provide a necessary and solid foundation on which to base good policy.

The data presented herein were collected and analyzed by these companies in part from information collected by the RRC regarding disposal volumes. These volumes are submitted as part of individual lease reporting by operators and may represent estimates. Additionally, each company has a proprietary data management work flow, leading to variances presented in the information provided in this report. Please refer to the contents contributor pages to find the contact information for Sourcewater, Inc., Drilling Info, and B3 Insight.

Given estimates that most of the PW from unconventional horizontal wells is subsequently injected into the subsurface via saltwater disposal (see *Water Disposal* section), statewide records of injection volumes most likely represent the most accurate estimates of PW volumes in Texas's oilfields.

Injection volumes are recorded based on where injection occurs, not where the water was produced, which could generate some error in these PW estimates. B3 Insight has recently completed an initial investigation into this discrepancy within the Permian Basin for 2017 to 2018 (see below), concluding that only small volumes of water are produced in one basin and moved to another for injection, making their effect negligible on the total estimate.

Table 1, **Sourcewater Annual Produced Water Data 2014-2017 for Major Texas Basins,** shows that the Permian Basin produced approximately 4.8 billion barrels of PW in 2014, which increased dramatically by 2017 to more than 5.4 billion barrels of PW. Table 1 includes PW volumes for five of the major Texas Basins and illustrates the dramatic contrast between the Permian and the other major Basins. As PW increased in the Permian from 2014 to 2017, PW production within the Eagle Ford and the Barnett decreased by more than 100,000,000 barrels in both plays.[60]

Table 1. Sourcewater Annual Produced Water Data 2014-2017 for the Major Texas Basins

Basins	2014 (MMbbl)	2015 (MMbbl)	2016 (MMbbl)	2017 (MMbbl)
Fort Worth (Barnett)	376.61	297.02	235.21	268.78
Gulf Coast (Eagle Ford)	335.29	288.11	195.1	222.76
East Texas (Haynesville-Bossier)	39.94	33.69	33.35	41.68
Permian	4,814.54	4,904.02	4,882.29	5,428.42
Palo Duro (Bend)	3.88	4.74	3.19	3.41

Source: Sourcewater, Inc.

The data in Table 2, **B3 Insight Statewide Produced Water Data 2005-2017**, was compiled by B3 Insight from the RRC's H-10 Annual Disposal/Injection Well Monitoring Report. Table 2 compares the four major basins' PW volumes in 2005, 2010, 2014 and 2017 (including both PW injected for disposal and secondary recovery). B3 Insight estimates that in 2017 the total statewide estimate of PW was more than 8.5 billion barrels of water. This represents a significant increase from 2005, where the total statewide estimated volume of PW was over 5.9 billion barrels of water. In 2017, the Permian Basin accounted for almost 66 percent of PW in Texas, an 8 percent increase from 2005. Other major basins, such as the Eagle Ford (3 percent), the Barnett (6 percent) and the Haynesville (3 percent), currently account for a comparatively small portion of statewide PW.[61]

Table 2. B3 Insight Statewide Produced Water Data 2005-2017

Basins/ Formations	2005		2010		2014		2017	
	MMbbl	% of total	MMbbl	% of total	MMbbl	% of total	MMbbl	% of total
Barnett	327.63	5.53	554.091	7.86	605.84	7.14	496.43	5.83
Eagle Ford	35.34	0.6	44.62	0.63	277.36	3.27	262.74	3.09
Haynesville-Bossier	246.11	4.15	338.18	4.8	327.9	3.87	248.67	2.92
Permian	3,452.73	58.23	3,875.48	54.99	4,977.91	58.69	5,578.87	65.52
Other Texas	1,867.95	31.5	2,235.36	31.72	2,292.85	27.03	1,928.38	22.65
Grand Total	5,929.77	100	7,047.73	100	8,481.87	100	8,515.09	100

Source: B3 Insight.

PW transport is based on logistics and cost, which will determine transport methods and destinations. Conventional vertical wells near basin boundaries produce smaller volumes of PW; transporting these volumes between basins may be more cost effective and may not have a marked impact on PW estimates based on injection records. However, some water management companies have reported moving PW from other basins (Delaware) to the Central Basin Platform.[62]

Additionally, the volume of PW used for new fracturing operations (thus not recorded in injection well volumes) is not accounted for in these estimates. Currently, the regulatory reporting and permit framework does not encourage the overall compilation of recycling volumes. The fraction of PW reused or recycled is not very well documented, but most anecdotal reports suggest that a relatively small volume (less than 10 and potentially less than 5 percent of PW) is managed through reuse or recycling (see *Treatment for R&R* section).

Produced Water Projections to 2024

Sourcewater, Inc. projects that by 2023, over 15 billion barrels per year of PW and 5 billion barrels of flowback water will be produced statewide in Texas. This assessment highlights one of the major concerns of this white paper - economically and sustainably managing this water when current PW management challenges are exacerbated with projected increases in PW volumes.[63]

In the Permian, where most of the oil is produced, B3 Insight forecasts PW output will reach almost 8.5 billion barrels by 2024.[64] At the February 2019 Permian Basin Water in Energy Conference, a McKinsey & Co. representative forecasted that PW in the Permian Basin will grow to between 7.5 billion and 8 billion barrels by 2025.[65] Additional projections from the Rice University Baker Institute indicate that from 2019 to 2023, Permian PW volumes could increase to more than 10 million barrels per day as oil production increases to more than 6 million barrels per day.[66]

Table 3, **B3 Insight Produced Water Projections for the Permian Basin,** shows annual PW production projections from 2019 to 2024.[67] Projections for the Permian Basin indicate that over the next five years the industry can expect somewhere between a 25 to 30 percent increase in the volume of PW, potentially reaching almost 8.5 billion barrels of PW per year by 2024.

Table 3. B3 Insight Produced Water Projections to 2024 for the Permian Basin

Year	MMbbl/year
2019	7,090
2020	7,400
2021	7,670
2022	7,990
2023	8,240
2024	8,510

Source: B3 Insight

Projecting future volumes of PW is dependent on many complex factors including drilling rates, water use per fracturing operation, which formations are economically viable to produce from and whether these formations have a little or a lot of water within them; consequently, projections can vary widely. The estimates present a significant range of volumes for planning purposes that are intriguing and clearly demonstrate the need for PW management to be flexible, prepared for growth and responsive to industry needs.

Produced Water Injection and R&R Treatment Data

Injection Options

Some estimates suggest that over 90 percent of PW from US onshore operations is managed through some form of injection.[68] The other management options include evaporation, surface discharge and reuse in oil and gas fields. In this white paper, we address both disposal and enhanced oil recovery (EOR) injection wells.[69]

What are injection wells?

Injection wells are used to move fluid from the surface into subsurface, porous geologic formations which vary from place to place but are typically sandstone or limestone. According to the EPA, fluids injected include water, brine (salt water) and water mixed with chemicals. Injection wells can be used to dispose of waste, enhance oil production, store carbon dioxide, and prevent salt water intrusion into aquifers. The EPA's Underground Injection Control (UIC) program regulates injection wells and groups them into six separate classes based on their function which allows consistent technical requirements to be applied. The authority to regulate these wells was delegated to the RRC in 1982.[70, 71] Monthly reporting of volumes and pressures began in Texas on January 1, 1983.

Over the decades, Texas has issued more than 50,000 injection permits for EOR and disposal operations. Currently, about 9,900 wells are actively injecting into a non-productive zone and more than 12,000 wells are injecting into a productive zone, typically for EOR purposes.[72]

When initially developing an oil well, the natural pressure of the reservoir combined with pumps provide enough lift to move the resource through the well bore to the surface. However, the pressure in the reservoir can decrease over time and alternate methods of production must be used to fully develop the resource. These methods are referred to as EOR (also "secondary" or "tertiary" recovery). They include gas, steam and chemical injection as well as water flooding.[73]

Although EOR can be used to more fully develop a reservoir, it is not suitable for use in all reservoir types. Unconventional reservoirs are typified by low permeability and high-density rocks which are not necessarily conducive to water flooding, steam injection, or carbon dioxide gas injection.[74, 75] In the Permian Basin, conventional wells in the Central Basin platform use water flooding to enhance recoveries, but in the unconventional Midland and Delaware Basins, water flooding is not common. However, in unconventional reservoirs, other post-fracturing practices such as refracturing after the initial fracture treatment and subsequent production decline, could be considered as an EOR project under some regulatory scenarios.

Volumes of Injection for Disposal

Table 4, **B3 Insight PW Injection Volumes for Disposal in Texas Basins 2005-2017,** shows the estimated volumes of PW disposed of in salt water disposal (SWD) wells in 2005, 2010, 2014 and 2017, as well as the percentage of disposal accounted for by each basin and the percentage of the total volume of injected water. In 2005, the Permian was disposing of only about 711 million barrels of PW per year, or about 30 percent of total annual disposal volumes. This percentage remained relatively consistent until about 2014-2016, when there was a significant increase, which mirrors the increase in production in the Permian. By 2017, the Permian Basin was disposing over 50 percent, about 2.3 billion barrels, of Texas's total PW volume. No other single basin accounts for anywhere near as large a portion of disposal volumes in Texas. Barnett, Eagle Ford and Haynesville disposed only 194 million, 256 million and 226 million barrels of PW, respectively, although the marked increase of disposal in the Eagle Ford between 2010 and 2014 and the consistently large volumes disposed of in the Haynesville are noteworthy in the larger discussion regarding statewide injection capacity.

Table 4. B3 Insight PW Injection Volumes for Disposal in Texas Basins 2005-2017

Disposal (Non-EOR Injection)		Barnett	Eagle Ford	Haynesville-Bossier	Permian (Total)	Texas (other)	Grand Total
2005	MMbbl	88.41	24.75	225.59	711.27	1,566.61	2,616.63
	% of total Disposal	3.38	0.95	8.62	27.18	59.87	100
	% of total all Injection	1.49	0.42	3.8	11.99	26.42	44.13
2010	MMbbl	290.61	33.98	309.45	884.28	1,861.02	3,379.33
	% of total Disposal	8.6	1.01	9.16	26.17	55.07	100
	% of total all Injection	4.12	0.48	4.39	12.55	26.41	47.95
2014	MMbbl	302.08	267.44	296.42	1,531.12	1,881.30	4,278.35
	% of total Disposal	7.06	6.25	6.93	35.79	43.97	100
	% of total all Injection	3.56	3.15	3.49	18.05	22.18	50.44
2017	MMbbl	194.5	256.22	226.00	2,317.20	1,553.30	4,547.23
	% of total Disposal	4.28	5.63	4.97	50.96	34.16	100
	% of total all Injection	2.28	3.01	2.65	27.21	18.24	53.4

Source: B3 Insight.

Volumes of Injection for EOR

It is currently estimated by Sourcewater, Inc. that 84 percent of injection wells within the Permian Basin are injecting for secondary recovery, while 72 percent of all Texas's injection wells are used for secondary recovery.[76]

In Table 5, **PW Injection Volumes for EOR in Texas Basins**, B3 Insight shows the estimated volumes of PW injected for EOR. In 2005, the Permian was already injecting around 2.7 billion barrels (of PW.) This accounted for more than 82 percent of the total EOR injection volume in the state. The Permian now injects almost 3.2 billion barrels, which is around 500 million barrels more than was injected in 2005. Even though the total water volume injected for EOR in the Permian increased by 500 million barrels from 2005 to 2017, it had no marked effect and the total percentage of EOR accounted for by the Permian has remained stable at 82 percent. This example illustrates the generally high influx of water into the market in all regions across the state since 2005.[77]

Even though total EOR volumes have increased, the percentage of statewide EOR injection from the Permian has decreased from about 46 percent to almost 38 percent in only 12 years. This could be a shift from conventional to unconventional production in the Permian Basin. It is possible that this portion (8 percent) of the total statewide injection volume has moved from EOR to disposal.

Looking forward, as PW volumes increase and conventional development in Texas decreases, injection volumes will continue to shift from EOR to disposal unless the industry finds another strategy. Projections on increasing PW volumes (approximately 6 billion barrels from the Permian by 2024; see PW Section) coupled with a steady, approximately 2 percent annual decrease in EOR volumes which will be shifted to disposal, suggest that by 2024, disposal volumes could reach approximately 4.14 billion barrels of PW annually. Produced water management is the water management challenge.

Table 5. PW Injection Volumes for EOR in Texas Basins

Injection for EOR		Barnett	Eagle Ford	Haynesville-Bossier	Permian (Total)	Texas (other)	Grand Total
2005	MMbbl	239.23	10.59	20.52	2,741.46	301.34	3,313.14
	% of total EOR	7.22	0.32	0.62	82.74	9.1	100
	% of total all Injection	4.03	0.18	0.35	46.23	5.08	55.87
2010	MMbbl	263.48	10.64	28.73	2,991.20	374.34	3,668.40
	% of total EOR	7.18	0.29	0.78	81.54	10.2	100
	% of total all Injection	3.74	0.15	0.41	42.44	5.31	52.05
2014	MMbbl	303.76	9.92	31.49	3,446.80	411.56	4,203.52
	% of total EOR	7.23	0.24	0.75	82	9.79	100
	% of total all Injection	3.58	0.12	0.37	40.64	4.85	49.56
2017	MMbbl	301.93	6.52	22.67	3,261.67	375.1	3,967.86
	% of total EOR	7.61	0.16	0.57	82.2	9.45	100
	% of total all Injection	3.55	0.08	0.27	38.3	4.4	46.6

Source: B3 Insight.

Injection/Disposal Well Permitting

A review of RRC disposal applications received versus permits issued from RRC data (supplied by Miller Consulting of Austin, Texas) demonstrated the volume of applications as well as the processing time for injection permits. As seen in **Table 6, Injection/Disposal Applications and Permits in Texas for 2017 and 2018**, in 2017, 1,789 injection/disposal permits were filed and in 2018 almost 2,099 permits were filed. Of these applications, 907 injection/disposal permits were issued in 2017 and 1,090 in 2018.[78] In 2018, 819 Permian Basin injection/disposal permits were filed.[79] According to RRC data, 724 permit applications for underground injection wells in the Delaware and Central Basins were approved through early April 2019, with some issued within 90 days. Some applications reportedly took almost a year for review and approval.

Reports indicate that permitting issues (increasing lengths of time it takes to issue a permit and decreased volumes of water approved versus sought for injection) are becoming common as the numbers of applications soar. Table 6 compares the applications and permits issued in Texas for 2017 and 2018.

Table 6. Injection /Disposal Applications and Permits in Texas for 2017 and 2018

Injection / Disposal ***Applications Received*** 01/01/2017 - 12/31/2018														
District														
Year	**1**	**2**	**3**	**4**	**5**	**6**	**6E**	**7B**	**7C**	**8**	**8A**	**9**	**10**	**Total**
2017	42	75	85	40	9	48	5	105	85	854	314	102	25	**1,789**
2018	42	107	98	43	13	64	2	83	85	1,109	309	111	33	**2,099**
Injection / Disposal ***Permits Issued*** 01/01/2017 - 12/31/2018														
District														
Year	**1**	**2**	**3**	**4**	**5**	**6**	**6E**	**7B**	**7C**	**8**	**8A**	**9**	**10**	**Total**
2017	22	54	45	26	4	14	2	78	44	339	203	69	7	**907**
2018	11	87	44	27	7	25	1	68	44	511	190	70	5	**1090**

Source: Miller Consulting, Inc.

If an application is protested, the permit process will be delayed until a hearing is held. The RRC thoroughly addresses the potential seismic effects of a proposed injection well through a "seismic review" of the geology and extenuating seismic risk factors in the area around a well. If a permit is recommended for a seismic review, the process could take six months or more as data is requested and reviewed by the regulator before a decision is reached.[80] The RRC stated that there are multiple common issues that impede application review including incomplete forms, incomplete data submissions and ignoring notice periods; however, major clarifications were most often needed for well performance and location justifications.

Additionally, the RRC is generally revising permitted injection allowances (volumes and pressures) downward, meaning that many applications must be updated to reflect a lower injection allowance and shorter perforated interval. Limiting injection allowances may help address at least four significant issues: 1) ensuring injection is confined to the permitted intervals; 2) avoiding over pressuring of these intervals; 3) ensuring there is no disposed water vertical migration through subsurface conduits; and 4) monitoring seismicity concerns. Seismicity issues arise because increasing disposal into subsurface layers without appropriate care can increase the pressure within active structures or faults in the formation and cause "induced seismicity." Permits must be issued carefully to prevent over pressuring from becoming more prevalent and increasing regional seismic activity.[81] Operators may also have to drill through these overpressured injection intervals to get to their target formations. This is the case in the Delaware Basin where injection is into the Delaware Mountain Group overlying the Wolfcamp (target).[82] According to one interviewee, the injection capacity in the historically used shallow disposal intervals is diminishing and they are becoming overpressured. In response to this, deeper disposal wells must be drilled. Some of the issues associated with deeper disposal wells include having to pass through the shallow, overpressured horizons and issues with induced seismicity from deeper formations. Another challenge is the lack of seismic data in deep zones to appropriately site disposal wells.

According to the TexNet Seismic Monitoring Program at the UT Austin Bureau of Economic Geology (TexNet), over 97 percent of earthquakes in Texas are below the level able to be felt by the population (approximately $M_{2.5}$). TexNet, which provides a record of all seismic events that have occurred, reports that seismic activity is occurring in four main areas: West Texas near the town of Pecos City; the Dallas-Fort Worth area; southeast of San Antonio; and outside of Snyder. Additionally, on October 20, 2018, a magnitude 4.4 ($M_{4.4}$) event occurred in the Panhandle near Amarillo.[83] Most of the state is not experiencing any seismicity. This information is available for public review online (http://www.beg.utexas.edu/texnet).

Data show that most injection wells do not appear to have a marked effect on regional seismic activity, as seismic events are focused in relatively discreet areas and disposal wells are widespread. To date, it would be difficult to conclusively determine correlation between seismic events and injection volumes in the western Delaware Basin and the Eagle Ford Shale areas. The group of seismic events east of Dallas do not appear to show a correlation between the presence of disposal wells and seismicity.[84, 85, 86]

Treatment

Data on current PW treatment and R&R volumes in Texas are variable and difficult to certify. Many of our interview subjects commented that their operations use over 80 percent PW to fracture a new well and many water midstream companies report that they are transporting tens of thousands of barrels of water per day in their water pipelines to treatment and R&R sites. Some companies, like Guidon, report the company has made it a priority to reuse 100 percent of PW in their horizontal drilling operations.[87] On the other hand, other information sources indicate that R&R comprises such a small portion of the Texas water management market (less than 1 to 5 percent) as to be negligible in the grand scheme of water handling. According to IHS Markit, approximately 4 to 5 percent of PW is "treated and recycled" in the industry right now although this figure is expected to grow by about 16 percent over the next four to five years.[88] The 2019 GWPC report offered reuse data for key basins across the US and for Texas, concluding reuse exceeds 10 percent in the Permian Basin, is negligible in the Haynesville Basin and is slightly over 1 percent in the Eagle Ford Basin.[89]

Good, reliable data sets on PW supply, use and disposal in the oilfield are necessary.

However, because R&R can currently mean any number of lifecycles for PW, it is difficult to ascertain exactly what the varied data represents. Data may refer to lightly treated PW used in the oilfield for a new fracturing operation, or in an EOR operation, or even to highly treated PW used outside of the oilfield in some beneficial way. Clearly, the lack of standardized reporting on PW R&R can be cause for confusion in the industry.[90] Knowing that good, reliable data sets help inform sound and useful regulation, it will be imperative for the industry to engage in how to best standardize PW terminology, reporting and disclosure.

Texas has over 100 facilities that provide treatment of wastes from oil and gas fields. These commercial surface waste facilities are defined by the RRC as facilities where the owner/operator receives compensation for storage, reclamation, treatment or disposal of oil field fluids or solid oil and gas wastes that are transported to the facility.[91] According to the RRC's online database of over 100 Commercial Disposal and Recycling Permits, only two facilities are listed that specifically handle "Fluids Recycling," and they are both located in District 8 (Midland).[92] Not every waste treatment facility handles the same types of waste (some handle solids, others handle water, etc.), thus not every location represents a PW treatment facility. Large, centralized systems like these can treat thousands to tens of thousands of barrels of water per day, according to midstream water interviewees, providing the industry with a quick and useful turn around point for PW.

Produced Water Treatment Technology: Options and Outlook

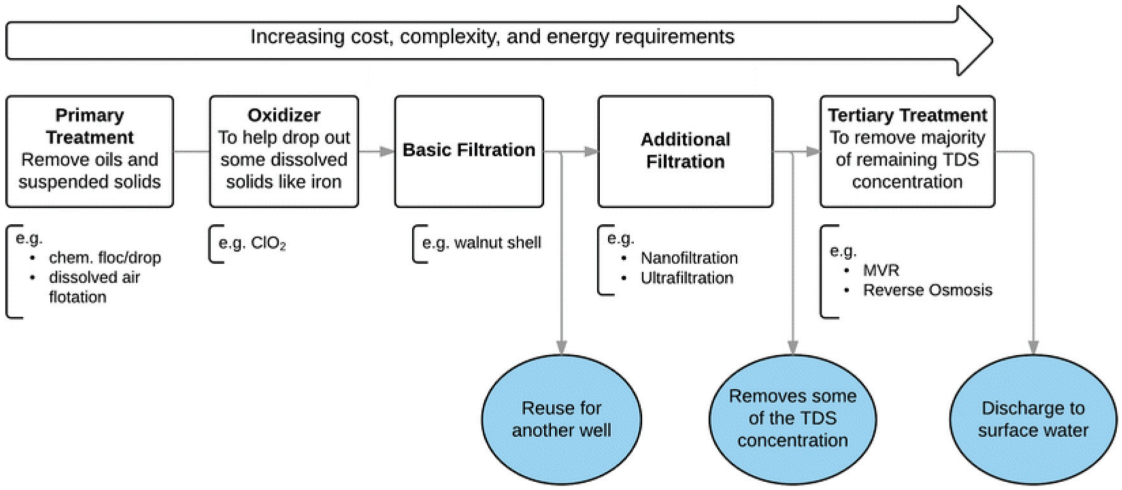
Management of PW is one of the most critical aspects to enable production of hydrocarbon resources in Texas. In fact, many wells in the Permian Basin produce 3 to 10 times the amount of water as compared to the amount of oil that is produced.[93, 94] This level of water production presents significant challenges for the operators, creating logistical, environmental and financial burdens that must be overcome. The following section reviews treatment options for use in and outside the oil and gas industry and future technology challenges as efforts to use PW outside the industry expand.[95]

Treatment Steps

PW treatment progresses through a variety of steps, depending on the intended use of the water. Figure 2, **PW Treatment Steps for Reuse or Discharge** provides an overview of the process steps that are required to achieve different desired outcomes for the treated water. If the goal is to reuse the water in subsequent fracturing operations, the PW only needs basic chemical and mechanical treatment. Some of these basic steps include removing oils and suspended solids as well as treating the PW with a biocide or oxidizer to help drop out dissolved solids and remove biologics that could damage wells if the water is used for an operation in the future. If, however, the goal was to eventually include intentional, permitted and controlled release to the environment, then tertiary treatment must remove more than just the total dissolved solids (TDS).

The future of water treatment requirements will depend on specifying the level of treatment that is desired. However, additional treatment comes with increasing cost, complexity and energy requirements.

Figure 2: PW Treatment Steps for Reuse or Discharge



Source: Glazer et al. (2017)

Desalinating PW

The most energy intensive, and thus costly, process step is tertiary treatment to desalinate water for uses outside the oil and gas fields. There are two prominent methods for desalinating water: 1) membrane separation and 2) thermal separation. Membrane separation is dominated by reverse osmosis (RO), which is the most developed, cost-effective method for desalinating water.[96] RO is used around the world for desalinating seawater and brackish water, including the Kay Bailey Hutchinson (KBH) Desalination Plant in El Paso, Texas.[97]

RO has been used in some limited cases for treating PW. However, the membranes used in RO are generally unable to handle water that has TDS that exceed around 50,000 mg/L.[98] (For reference, the TDS of common seawater is around 35,000 mg/L.) As the TDS level of PW rises, the cost effectiveness of RO begins to decline because of the very high reject rates (concentrated salt stream) and membrane fouling. Permian Basin PW can have salinity levels of more than 200,000 mg/L TDS, meaning that RO is unsuitable to treat most of the water produced in the region.[99] Higher cost areas like the Delaware Basin are seeing some significant recycling taking place using salt removal. It was reported during interviews that the costs range between $2.50-3.00 per barrel to take out salts.[100] At this point, recycling is an economic feasibility question, not a technical issue.

Existing and Emerging Tertiary Treatment Technologies

Due to the volume of water that is projected to be produced in Texas in coming years, there appears to be a growing push for the ability to discharge PW to the surface.[101] Discharging to the surface presents a variety of political and technical challenges. If surface discharge is ever widely adopted in Texas, it would likely hinge on the ability to desalinate the water considering the high salinity levels that are present in PW from the Permian Basin. An interviewee commented that there may be room for high level treatment for uses outside of the oil and gas fields, suggesting it may be logical to "bolt on" a treatment plant at a central "midstream" treatment center. This would allow the sale of distilled water, heavy brine and/or salt. To avoid the massive amount of capital needed to treat 100 percent of the volume, it could be started at 10 percent of the plant volume and increase as needed.

As such, the ensuing discussion will focus on existing and emerging tertiary treatment technologies because it is the most energy intensive and expensive step to clean PW. Technologies that have been reported to handle high salinity water (e.g. greater than 50,000 mg/L TDS) include but are not limited to the following: multi-effect distillation (MED); multistage flash (MSF); mechanical vapor compression (MVC); carrier gas extraction (CGE); membrane distillation (MD); and forward osmosis (FO).

Some technology has been tested for well over a decade, such as the Fountain Quail NOMAD evaporation system which reportedly has converted over 25 million barrels of PW into a product used for hydraulic fracturing. Other technologies, like MED and MSF are both proven methods for desalinating high salinity water. However, they are energy intensive and require large facilities to achieve economies of scale and thus are not well suited for the oil patch. MVC is a well-established technology and has been deployed to treat PW from oil and gas operations in Texas. MVC uses centrifugal compression to heat PW to generate steam, which can then be distilled to clean, desalinated water.[102] Several companies have commercialized variants of MVC, including Purestream and General Electric. Purestream's AVARA system has operated in Texas.[103]

CGE is a product in early-stage development. Gradient Corporation has built a pilot facility in Texas.[104] Gradient claims that the two-phase heat transfer that is used in their CGE system improves the energy efficiency of the process to produce steam.

Two emerging technologies for handling high salinity PW are MD and FO.[105] MD uses a vapor pressure difference to separate untreated water from desalinated water using a hydrophobic membrane. The pressure differential is produced using a source of thermal energy. One of the potential benefits of MD is that it can utilize low-grade heat and theoretically, is not limited by the PW's salinity. Pilot-scale studies have been completed using MD for treating salt water.[106]

FO uses a semi-permeable membrane and osmotic pressure to separate clean water from dissolved solids. The use of osmotic pressure (instead of hydraulic pressure) means that the treatment process has the potential to be completed with low pressure equipment, reducing cost and the likelihood of fouling the membrane. The entire FO process is completed with the water in a liquid-phase, rather than producing vapor like MVC or MD. A variant of FO has been implemented in the Permian to determine whether the technology can treat high TDS water under realistic operating conditions.[107, 108] A pilot FO facility was also tested in the Marcellus shale region using high salinity water showing the potential to reduce energy intensity compared to MVC.[109]

Zero-liquid Discharge Treatment

Zero-liquid discharge (ZLD) is defined as a treatment process that recovers all the water in a waste and reduces all the previously entrained contaminants to a solid waste.[110] ZLD has been discussed as an operating strategy to reduce the volume and weight of waste that needs to be disposed of and the resulting treated water would be available for reuse. However, by implementing ZLD, the solid waste product from the treatment process will inevitably concentrate the constituents that were originally diluted in the PW, making it more difficult to handle. If the PW contained naturally occurring radioactive materials (NORM), the concentrated solid waste might be more challenging to manage as compared to the conventional process of underground injection. The decision to shift to ZLD will create a tradeoff unique to each operator's situation to determine whether it is preferable to move smaller volumes of more concentrated waste.

Treatment Challenges

Not only can water quality change over the lifetime of the well, another challenge to consider is the fact that water volumes are typically the largest in the early days of operation and may drop off significantly as the well ages (although the water cut of the well increases overall, typically).[111] PW's declining volume presents a design challenge since more treatment capacity might be needed in the early days, as compared to when the well is older. This challenge can be compounded if PW characteristics change over time, requiring adaptation of disposal or treatment activities. Future pilot studies will likely need to consider how best to match the volumetric treatment capacity of new technologies with the expected temporal production from the well, in addition to assessing the need for temporary or long-term water storage. Employing tertiary treatment technologies on water streams of larger centralized treatment plants will eliminate the problem of highly variable water production during the life cycle of individual wells. Each of the technologies considered herein face challenges with being economically competitive compared to existing disposal practices. There is no silver bullet for replacing current disposal methods. In future years, however, disposal capacity might be limited, thus requiring more water treatment to be deployed. In December 2018, the Department of Energy kicked off a $100 million Energy-Water Desalina-

Each of the PW treatment technologies considered herein face challenges with being economically competitive compared to existing disposal practices. There is no silver bullet for replacing current disposal methods.

tion Hub.[112] The goal of the program is to advance the science with the goal of lowering the cost to desalinate water. Future advancements in desalination technology might eventually lead to an economically competitive solution to address the growing wave of PW in Texas.

Legislative and Regulatory Developments Impacting Produced Water

To provide an understanding of Texas's well-developed regulatory and legal framework, this section reviews the current set of rules governing the management of PW in Texas. This framework demonstrates Texas's leadership on water issues and provides the context for the incentives and investments into water in Texas, including opportunities for PW R&R, that will be considered by the Legislature.

Significant Texas Legislative and Regulatory Activity: 2012-2013

Texas officials updated the PW related regulatory framework with the five following initiatives: permit by rule; well drilling updates; fracturing chemical disclosure requirements; liability for recycling; and state water implementation fund. These initiatives significantly changed the way oil and gas production and oil field PW handling, disposal and recycling was conducted in Texas. Additionally, these initiatives set the stage for further progress.

> Texas's initiatives significantly changed the way oil and gas production and oil field PW handling, disposal and recycling was conducted in Texas. These initiatives set the stage for further progress.

Permit by Rule

Encouraging PW water recycling, the RRC in 2013 reworked the recycling regulatory framework to implement a Permit by Rule (PBR) concept. Produced water recycling is authorized by rule and may not require a submitted permit application and agency approval, depending on the type of facility. For example, no permit application is required if operators are recycling fluid on their own leases or transferring their fluids to another operator's lease for recycling.[113]

Well Drilling Updates

The regulatory definition of hydraulic fracturing was introduced in this 2013 rulemaking. In addition, extensive reworking and updating of regulatory requirements for new well drilling and completions in Texas oil fields were put in place.[114]

Fracturing Chemical Disclosure Requirements

The rule required a well operator to complete the Chemical Disclosure Registry form and upload the form on the Chemical Disclosure Registry on the Frac Focus website.[115] Operators were henceforth to provide information such as the total volume of water used in the hydraulic fracturing treatment(s) of the well, additives used in the hydraulic fracturing treatments, each chemical ingredient used in the hydraulic fracturing treatment(s) of the well and the concentration of each chemical ingredient.[116]

Liability for Recycling

Legislation was passed to amend the Natural Resources Code that specifies that a person will not be liable for a recycled product that has been transferred to another person with the contractual understanding that the treated product will be used in connection with the drilling for or production of oil or gas.

State Water Implementation Fund

Texas voters approved the transfer of $2 billion from its Economic Stabilization Fund (aka, "Rainy Day" Fund) into the State Water Implementation Fund, to be used for loans on water projects throughout the state.

Legislative and Regulatory Strides: 2014 to 2019

Texas has continued making legislative and regulatory strides to ensure authority keeps pace with the rapidly evolving business models of oil and gas production and PW. Key examples are:

TexNet Seismic Monitoring

In its 84th and 85th legislative sessions, the Legislature tasked the Bureau of Economic Geology with the University of Texas in Austin to help locate and determine the origins of seismic events in the state and, where possibly caused by human activity, identify possibilities to help prevent such events from occurring in the future. The TexNet Seismic Monitoring Program was established to accomplish these goals and has led to regulatory procedural changes that are continuing to this day.[117]

> Texas has continued making legislative and regulatory strides to ensure authority keeps pace with the rapidly evolving business models of oil and gas production and PW.

Setting Regulatory Jurisdiction

The 84th Legislative Session delineated the regulatory jurisdiction over oil and gas operations in Texas. It stated that municipalities and political subdivisions have the right to enact commercially reasonable regulations for surface activities and that the state, primarily through authority delegated to the RRC, has exclusive jurisdiction over sub-surface activities and oil and gas operations. Texas has a stable foundation for the consistent statewide implementation of regulations, which eliminates the risk of having multiple jurisdictions with an inconsistent quilt of regulations, a lack of technical regulatory expertise, or increased costs that would blunt the development of hydrocarbons.

Pecos Pilot Project

In 2015, the RRC issued a pilot project permit to irrigate a cotton crop in Pecos, Texas, using recycled treated PW from nearby oil and natural gas activity in the Delaware Basin. The project was designed to study, in a controlled and limited area, the use of treated PW to irrigate, non-edible crops with oil field PW treated to the necessary water quality standards.[118]

Identifying Federal Overlap

During the 85th legislative sessions, the Texas Legislature passed legislation (SCR 26) to identify federal regulations, especially those promulgated by the EPA, and determine whether they should be revised, delegated to state agencies, or eliminated to ease the overly burdensome regulatory patchwork on the Texas oil and gas industry.

Delegation of Authorities to Texas

In 2018, at the request of Wayne Christian, RRC Commissioner and gubernatorially appointed Official Representative of Texas to the Interstate Oil and Gas Compact Commission (IOGCC), the IOGCC passed a resolution (RESOLUTION 18.054 - Pertaining to the Delegation of Federal Regulatory Authority to State Government Agencies) urging the federal government to determine whether any additional regulatory authorities should be delegated to states to improve regulatory efficiency and effectiveness.[119]

Regulatory Review of Produced Water Injection Permits

All Class II oil field PW injection permits must now have a review and evaluation of historical seismic activity and seismic potential as part of the injection permitting process. First implemented by rule in 2015, the RRC continues to refine its permitting procedures with evolving internal reviews that allow regulators to evaluate and adjust volume, interval, pressure, for each permit based on the potential of injection inducing seismic activity. As of 2019, the RRC is preparing additional guidance to add predictability and efficiency to the existing injector permitting regulations. These could include coordinated seismic monitoring requirements as well as seismic response planning. No further rulemakings are anticipated at this time.

RRC Sunset Review Process

To ensure good governance, all state agencies undergo a performance review every 10 years by the Sunset Commission. The RRC successfully navigated the Sunset process in 2017. After initial recommendations for agency abolishment and multiple legislative reviews in 2011, 2013 and 2015, the 85th Texas Legislature authorized the continuation of the agency. The agency is led by three statewide elected officials serving staggered six-year terms. The RRC will not be under Sunset review again until 2029.

Regulator Enforcement and Transparency

Public transparency has been a growing theme in Texas and in early 2019 the RRC launched an Oil & Gas Inspection and Enforcement Data - Online Inspection Lookup (OIL).[120] The online OIL tool allows statewide searches of oil and gas inspection and enforcement information, including notices of violation and intentions to sever leases. RRC OIL allows anyone, anywhere, at any time to search online records of oil and gas well inspections and violations.

Orphaned Legacy Wells and Sites

The Legislature has developed a state-funded program to plug abandoned or orphaned wells. Since the well plugging program began in 1984, 36,610 abandoned wells have been plugged for $272 million. Additionally, Commissioners have approved cleanups under the RRC's site remediation section for 6,430 abandoned oilfield sites. The role of this program as applied to PW cleanup is essential and provides assurance that no long-term pollution threats remain from historic oil field activities.

86th Session (2019) Legislative Activity

Eminent Domain

The conflict between private property rights (e.g., concerning land or water), the power of state government and certain private companies acting under their authority to take private property for public use remains a flash point in Texas politics. The ability of producers to safely and efficiently get their product to market requires pipelines, but to date no compromise has yet been reached to address the public's demand for fairness and transparency. In the 86th Session, the issue was again discussed without resolution. Predicting the future path of eminent domain arguments is challenging but it is safe to assume that no matter what, the costs of pipeline transportation will rise, despite the significant differences in the regulatory frameworks of pipeline transportation of oil and gas and PW.

Produced Water Discharges and NPDES Delegation

In Texas, due to the existing federal NPDES requirements for onshore oil and gas operations, few discharges of PW are authorized. As a result, there is a lack of NPDES permits for oil and gas flowback and PW discharges, even when treated. Currently, any discharge authority would require both federal (EPA) and State agency (RRC) permits. However, the Texas legislature passed HB 2771 in May of 2019 which places the statutory authority of NPDES under the TCEQ (Texas Commission on Environmental Quality), as opposed to the RRC, for issuing permits for the discharge of PW, hydrostatic test water and gas plant effluent resulting from certain oil and gas activities.[121] It also directs the TCEQ to submit a request to the EPA to seek federal NPDES delegation to Texas of these types of discharges, eliminating the duplication of federal and state oversight. The water quality and treatment standards required to obtain a discharge permit would be determined by the regulator.

Produced Water as Property for Recycling Purposes

The Texas legislature has long held that ownership of water is not regulated the same way as oil field waste, which includes PW. The legislation, colloquially referred to as HB 3246 by Representative Darby, became law on September 1, 2019. It states "when fluid oil and gas waste is produced and utilized by or transferred to a person who takes possession of that waste for the purpose of treating the waste for a subsequent beneficial use, the waste is considered to be the property of the person who takes possession of it for the purpose of treating the waste for subsequent beneficial use until the person transfers the waste or treated waste to another person for disposal or use." The premise of the legislation is that this is an oil field waste issue and not a water ownership issue.

Produced Water Recycling Incentives

The role of state and federal government in encouraging business opportunities through incentives has been long established. Produced water recycling is now a candidate for this consideration. Recycling of PW is an environmental opportunity that requires policy support through an encouraging regulatory framework. It is also a competitive industry. As recycling technology advances and PW volumes increase, policy makers are considering financial incentives to solidify the recycling industry and ensure Texas, the center of American oil and gas production, continues to attract recycling investors.

Several pieces of legislation were submitted during the Texas 86th legislative session that would have provided tax relief or tax credits for documented PW recycling activities.[122] They typically involved some percentage of severance or other tax relief for oil and gas operators in exchange for the beneficial reuse of treated PW. However, none passed. Legislators expressed a need to see additional studies on economic impacts. Nongovernmental organization lobbyists expressed dismay at encouraging PW recycling for beneficial reuse without extensive testing. Recyclers stated the technology is here, the industry is evolving and the time is now to solidify the role of Texas as a leader in the recycling field, with incentives as a part of that role. Discussions and possible hearings over the next two years are possible as the issue is studied by legislators.

Infrastructure Concerns

The impact on local communities by the significant growth of the Texas oil and gas industry, especially in the Permian Basin - West Texas area, has been noted for years (due to trucking impacts on roadways and traffic as well as housing shortages from a rapidly expanding workforce). Several initiatives were considered in the spring of 2019 to address these concerns, with budget amendments to infuse capital into the construction and repairs to help support the infrastructure needed to extract the oil and gas. In the 86th legislative session, the Texas budget earmarked approximately $250 million for oil field area infrastructure improvements.

PW Management Drivers and Headwinds

This section first addresses the major factors that influence operators' PW management strategies, the "drivers." Next it reviews important "headwinds", including public perception, regulatory and political issues, that are hard to price, but nonetheless factor into water managers' decisions.[123]

Drivers

Increased Fracturing Water Demand Bumps Up Against Stressed Water Supplies

Water is a public concern in Texas and its cost and availability impact all users, even those that use comparatively low amounts of water.[124, 125] Texas has a rapidly increasing population that places ever increasing demands on water supplies, especially for municipal and irrigation needs.

As previously mentioned, significant increases in Texas oil and gas production will require increasing amounts of fracturing water. Demand will continue to grow due to an increasing number of wells, more complicated completion designs and proppant intensity. Increasing productivity and lateral lengths of wells could increase water needs further.[126]

Even though Texas is not experiencing severe drought conditions at present, local water sources are stressed in the Permian and Anadarko Basins.[127] Most source water is from groundwater in Permian and Eagle Ford.

Use of treated PW water helps alleviate fresh water supply concerns and shows operators to be good corporate citizens, which the public and investors alike increasingly value. Operators will burnish their green credentials by addressing water-related climate concerns by recycling PW (as well as using brackish waters) in fracturing jobs.

> The major drivers include increasing fracturing water demands, increasing freshwater and trucking costs, decreasing treatment costs, local climate and geological realities, company culture and increasing volumes of PW.

Operating Costs

Costs for sourcing fresh water and treating PW are reaching levels which have and will continue to encourage producers to integrate increasing volumes of treated PW, rather than fresh water, into fracturing fluids especially in the Permian Basin. The GWPC 2019 report provides information regarding the per barrel water acquisitions costs in seven Permian Basin counties with averages ranging from a low of $.48 per barrel in Howard Country to as high as $1.02 per barrel in Eddy County.[128] Fresh water prices can vary widely based on site specific issues such as landowner negotiations, demands or transportation logistics. In some cases, fresh water can be sourced at no charge for an operation. Sources for this report stated that fresh water prices range from $.50 to .75 per barrel,[129, 130] whereas costs to treat PW to a level acceptable for use in fracturing reportedly range from $.25 to $1.00 per barrel.[131] Gabriel Collins estimates Permian Basin treatment costs are $.30 per barrel.[132]

Some operators may attempt to lower production expenditures by outsourcing water management and choosing pipeline transport to a treatment or disposal facility. This management decision is dependent on the site-specific characteristics of the logistical challenges and cost comparisons an operator faces. For example, trucks arriving at disposal sites are experiencing backlogs, increasing waiting times and costs. Producers have thin profit margins and trucking costs are eating into these margins. Per barrel of water, in the Permian Basin, trucking water to a disposal site runs $2.00 whereas the costs for sending it via pipeline to a commercial versus a proprietary SWD well are $.75 and $.30, respectively.[133]

Increasing Volumes of Produced Water Improve Economics of Pipeline Infrastructure and Improve Recycle Opportunities

As referenced in the section, ***Produced Water Volumes 2014-2017,*** Texas total PW volumes have increased in twelve short years from 5.9 billion in 2005 to 8.5 billion barrels in 2017 and Permian Basin production reached 5.4 billion barrels. The section ***Produced Water Projections to 2024*** provides several future estimates, showing potential 2023 statewide volumes of 15 billion barrels of PW annually and Permian Basin projections ranging from 7.5 to 10 billion barrels. It is noteworthy that in a few short years, Permian Basin production will mirror total 2017 Texas production; opportunities lie therein.

Increased PW volumes support development of a pipeline infrastructure in the Permian Basin which ultimately supports PW recycle. The pipelines allow midstream companies to amass the volumes of water necessary for the operator to confidently rely on treated water to be available in the amounts needed, when needed. Gabriel Collins explains:

> The water infrastructure footprint in key parts of the Permian Basin is becoming both physically massive and geographically expansive. This helps create commercial critical mass and facilitates making water a marketable commodity. This snowballing is also how the smaller and midsize operators can potentially be tied into the networks the heavyweights are now building.[134]

Local Geology, Climate and PW Composition Continue to Matter

Geology, local climate and PW composition vary by basin and place parameters around the choice of water management strategies.[135] All strategies are localized depending for example, on water cuts and levels of salinity, as defined by the levels of total dissolved solids (TDS). The higher the TDS, the higher the treatment cost will be due to the cost of the energy associated with removing the solids. Produced water in the Permian Basin has very high water cut volumes per well and relatively high levels of TDS, with TDS concentrations in the range of 75,000 to 150,000 mg/L.[136] By comparison, Eagle Ford has a medium water cut level and a lower TDS concentration of 40,000.[137]

As water cuts rise dramatically, disposal of the PW becomes more complicated and costlier. In the Delaware Basin Wolfcamp play, water cuts have risen from approximately 70 percent to 80 percent in the first four years of production, though the absolute production decreases significantly with time due to natural well decline. The initial water-to-oil ratio of roughly 2 to 1 rises to nearly 5 to 1 by the fourth year and can eventually reach 7 to 1. Delaware Basin water-to-oil ratios are often twice that of the Midland Basin, in some cases reaching 10 to 1 level.[138] This issue drives PW choices.

Disposal Is the Default but Constrained Option

Disposal will continue to be the preferred PW management strategy and must remain a viable option. However, concerns are developing about the adequacy of injection well capacity as demand ramps up quickly. Some Permian sub-basins are currently constrained due to insufficient injection well capacity. Projected production growth will worsen the situation.[139]

New disposal wells face permit delays on several fronts. The number of permits being sought is currently at an all-time high. Permit objections by competing water management companies delay issuance.[140] As discussed in section **Injection Well Permitting**, seismic issues may lengthen regulatory reviews up to six months. One of the experts interviewed voiced concern about seismic issues in deep wells, especially in Southern Delaware Basin. Laura Capper, an industry consultant, said underground pressures are gradually rising in at least four counties on the Texas side of the Permian Basin.

Capacity constraints and potential disposal cost increases will incentivize more PW treatment-although it delays and does not reduce the ultimate demand on disposal. SWD well concerns, which include potential limits due to seismicity, increasing times to permit new wells, wait times for trucks delivering water for disposal, conservation district notification, plugging nearby old wells, are often the deciding factor in whether to recycle.

As disposal capacity becomes constrained, the market will rebalance and it may become more expensive to dispose of PW through subsurface injection. The Wood Mackenzie consulting company estimates in an aggressive future case from a 2018 study that disposal costs could increase to as much as $3 to $6 per barrel for disposal, compared to current prices which range from about $.50 to $2.50, generally.[141] According to Wood Mackenzie, increasing operational expenses could jeopardize oil production, as well as tip the scales toward other management strategies like R&R.[142]

One factor not often discussed is the reluctance of local field managers to recycle PW. Recycling PW requires significant management attention and resources to store, treat and move the water to where it is needed. For example, recycled water is more challenging to handle and more problematic if spilled than many other substances. It takes a lot less effort by local managers just to ship the water to a nearby SWD facility for disposal. Even when it is less expensive to recycle PW, it is still often sent to the local SDW. When given the choice, disposal is the default decision for many operators, although this is more often an issue with smaller operators. The larger operators are more likely and more able to follow corporate strategic directives for managing PW, while a smaller operator might struggle to make a water management program economical. When midstream water companies move into regions where smaller operators are abundant, it will be easier and more economical for small operators to pass their PW over to a water management company that is capable of managing the full water cycle. Once this shift occurs in a big way, water management companies will be able to make an economy of scale, a necessity for economical water treatment, by collecting large volumes of water from multiple small and large operators.

Headwinds: Political, Regulatory and Environmental Concerns

Community Impacts and Environmental Considerations

Community impacts and environmental considerations specifically related to PW (as opposed to oil and gas development in general) have been widely reported and acknowledged as valid concerns. Negative community impacts include increased truck traffic and associated infrastructure development/repairs that must be paid for by local taxes, accidents and emissions increases. Spill risks increase on site and during transport.

Academic experts and environmental groups have raised relevant questions and knowledge gaps for regulators and policy makers. Concerns include whether there is adequate information about the chemical composition (and its variability among and in basins) and possible downhole transformations as well as analytical methods for detection and monitoring of constituents.

During the EPA's PW study that took place from 2018-2019, environmental and academic groups articulated several points of issue regarding how to both determine PW treatment approaches and potential environmental impacts of expanding the use of PW outside the oil and gas fields.[143]

> While not easy to assign a dollar cost to these issues, several environmental, community, political and regulatory issues factor into whether operators opt for treatment over direct disposal.

The EPA noted that environmental groups' PW concerns include:

- Concern over potential toxicity and human health and ecological implications of discharges due to several factors including large number of chemical compounds used in exploration and production - little public data on potential toxicity;
- Chemistry is constantly changing as new chemical formulations enter the market;
- Unknown transformation of chemical constituents into other chemical compounds;
- Limited treatment technology performance data for many compounds;
- Water quality criteria do not exist for many constituents.[144]

Further, the EPA summarized the academic community's concerns as follows:

- Knowledge gaps include lack of adequate information about chemical composition, particularly PW characterization, including possible downhole transformations;
- Analytical methods for detection and monitoring of constituents are inadequate;
- Challenges include how to determine treatment approaches and effectiveness without knowing what's in the wastewater;
- Similarly, difficult to determine possible environmental impacts because of knowledge gaps; and
- PW variability in and between oil/gas fields complicates assessment.

The Environmental Defense Fund (EDF) collaborated with industry experts, academics and governmental representatives on a workshop and summary paper that recommended delays in moving forward with recycle of PW outside the oil and gas industry to learn more about the risks, specifically related to toxicity considerations.[145] The EDF initiative identifies knowledge gaps, research programs and other recommendations. EDF believes it is important to look as far ahead as possible regarding knowns, unknowns and risks associated with the R&R of this water. Additionally, the EDF recommends working to advance the science of water research now to fill any potential information gaps in the water space. Coupled with this recommendation, the EDF suggests that toxicological studies be completed on PW from across the country to establish a baseline profile and foster a more complete understanding of the chemistry and components contained within PW. Baseline toxicological studies like these may seem daunting but could potentially provide a mutually agreeable on-ramp to surface discharge of treated PW.

Changing Regulatory Climate on Disposal Wells

National seismicity concerns presaged changes in Texas's disposal well regulatory review process. Considering reports of gradually increasing pressure in West Texas disposal wells and the Oklahoma earthquakes that have been linked by some scientists to disposal wells, the RRC is taking steps to mitigate this potential issue.[146, 147] "Because of over-pressurization and concerns about seismicity, we are limited where we can permit injection wells," RRC's Jared Craighead was reported to have said by the Houston Chronicle, October 15, 2018.[148] Reportedly, new rules, pertaining to new wells only, will establish permitting criteria including a risk-ranking system.

Texas has implemented a three-step process regarding seismic activity. First, the Bureau of Economic Geology at the University of Texas in Austin has been funded to place seismic detectors across the state. This program, called TexNet, makes data available on the internet to the public. Second, the regulator requires historical seismic activity be considered for all injection permit applications. Finally, the regulator has the authority to halt injection activities at wells that are part of a seismic investigation. Regulatory guidance pertaining to new well permits will establish consistency in permitting criteria including a risk-ranking system.

Proposed changes to disposal well rules would broaden protection for groundwater and require the same kind of protection for other water formations, such as the brackish water aquifers. Operators would be required to certify that all unplugged wells within a quarter-mile of a new injection well are properly cemented to prevent them from becoming a conduit for waste fluid to move into aquifers. They would also be required notify local groundwater conservation districts about a proposed well. The list of property owners who receive notices would be broadened.

Air Emissions

As horizons expand for PW treatment, it's important to keep a close eye on potential issues. Air emissions from oil and gas production operations are scrutinized by the public and it should be anticipated that those from the PW treatment facilities will be as well. Given that the federal and state emission regulations are evolving, the permit process for PW emissions is subject to change with attendant compliance cost concerns.

Common air emission sources from PW industry include:

- PW surface impoundments including drilling site pits;
- PW truck loading and unloading;
- Separation systems used at disposal or recycling facilities; and
- Evaporation ponds.

PW can be a chemically complex liquid containing volatile organic compounds (VOC) and inorganic compounds such as hydrogen sulfide (H_2S). In Texas, PW from upstream facility storage tanks and truck loading is assumed to contain 99 percent water and at least 1 percent VOCs unless site-specific water sampling is incorporated into the permit.[149] The TCEQ requires site-specific sampling of the H_2S content of all streams necessary for estimating H_2S emissions. Operators can assume that the H_2S content equals that of the crude oil/condensate (without taking a 99 percent water reduction). Air emissions for these sources can be estimated using industry-standard software, process simulation and factors developed by the EPA and the TCEQ.

Best management practices for PW tanks and truck loading, when empty trucks arrive at a facility and are filled with PW, include:

- Truck loading should be submerged fill with vapor balance back to the tank with subsequent recovery or control device (such as a flare or enclosed combustor);
- Tank hatches and pressure relief devices stay closed;
- Tanks are submerged fill, painted white or light tan, maintained in good condition;
- Tank dump valves maintained properly to reduce oil layer build-up; and
- FLIR camera evaluations to confirm that the oil layer doesn't build up past 1 percent hydrocarbon assumption.[150]

Air emissions from evaporation ponds, also known as impoundments, may be complicated due to the highly variable flux chemistry of hydrocarbons and inorganics in the water. Neither the EPA nor the TCEQ has developed any "standardized" emission factors for PW ponds; however, software developed for wastewater treatment emissions estimations or a mass balance may be used. To reduce potential air emissions from ponds, treatment facilities should focus on efficient pretreatment of the water prior to its disposal to the pond.

Design and best management practices for treatment facilities include:

- Maximize pretreatment in enclosed vessels and tanks by installing oil/water separators and gun barrel tanks to remove the oil layer prior to dispensing the water to the pond. Route vents to a control device to reduce VOC emissions;
- If processing sour water and H_2S can exceed 24 parts per million by volume in the vapor space of the oil/water separator, must route vapors to a control device;
- Incorporate preventative maintenance, recycling and segregation of waste streams; and
- Plant roads and truck loading and unloading areas must be operated to reduce dust emissions, including watering, treatment with dust suppressant chemicals, oiling, paving and cleaning dust-producing surfaces.

Produced Water Spills

Texas regulators oversee PW throughout the entirety of its lifecycle, through waste management permits and manifests, as opposed to specific spill reporting requirements. There is a three-step permit process. First, to generate and handle oil field waste like PW from a wellbore, the oil and gas operator must be licensed and bonded and must adhere to the "no pollution" requirements of operating in the oil field. Second, to transport that waste, a waste hauler must also be permitted by the regulator and is required to maintain his equipment without leaks or spills and only take that waste to authorized facilities while tracking the waste with run tickets or manifests. Finally, a disposal or recycling facility must also be permitted by the regulator and follow all permit requirements, whether injecting the waste into the subsurface for disposal or recycling the waste.

The state regulator has used these permit requirements to ensure that the waste is properly handled and to conduct enforcement based on permit violations when spills occur. However, as midstream water management facilities continue to develop and higher volumes of water are transported to and from these facilities, frequently by pipeline, an operational upset at the facility may involve larger volumes of spilled PW.

Reporting of these upsets at high capacity facilities, like PW spills, may have value to the regulator, the public and the regulated community and could possibly be addressed in the facilities specific permit requirements. Without tightening regulations too much to raise compliance levels to unaffordable cost levels, the RRC could require systematic and public reporting of pipeline spills.

Water Transfers Across State Borders

Will the Texas and New Mexico politicians see water transfers within the Permian Basin that straddles the borders of both states as political hot potato issues? The permitting requirements and rules for drilling SWDs on the Texas side are perceived by some as more conducive to development than in New Mexico. There may be concerns by New Mexico representatives that activities in Texas might damage their mineral estate rights. Certainly, the midstream industry sees economic opportunity in this space.

Produced Water Ownership

PW ownership is a private property issue, however its management as a waste is the operator's responsibility under the existing regulatory framework. Shallower groundwater is considered the property of the surface owner. Private contracts typically determine the financial relationship between landowners and operators and subsequently operators and recyclers. Though the legislature and court system have yet to definitively address the issue, common law and legislative policy principles support construing some level of ownership in favor of the mineral estate. However, going forward, disputes may arise that must be settled by the courts or legislation.

As the potential commercial value for PW continues to grow, the question of its recycling is an issue that requires a careful balancing of property rights, conservationism, Texas's interest in recycling and the continued development of the energy industry. In response, the Texas legislature passed HB 3246 in May 2019 to address the recycling of fluid oil field waste (PW); it was signed by the Governor. The bill states that when fluid oil and gas waste is produced and used by or transferred to a person who takes possession of that waste for treating the waste for a subsequent beneficial use, the waste is the property of the person who takes possession of it for treating the waste for subsequent beneficial use. This honors the existing Texas statutes, where fluid oil and gas waste are defined under Chapter 122 of the Natural Resources Code as waste containing salt or other mineralized substances, while groundwater is defined under Chapter 35 of the Water Code. The legislation bridged that gap by focusing on waste regulation and ensures that PW can be readily recycled by oil and gas operators and service companies, unless otherwise expressly provided by a legally binding document.

98th Meridian Policy

An arbitrary geographic marker, the 98th meridian, has long been designated by the EPA as a tool to separate discharge permitting under NPDES rules. The meridian bisects Texas into land roughly east or west of Dallas. Under the current federal regulatory scheme, onshore discharges east of 98th meridian are typically not authorized. For onshore discharges west of 98th meridian whose "PW has a use in agriculture or wildlife propagation," beneficial use permit applications may be considered. Some may consider this division anachronistic and not reflective of the current technological advances in recycling nor the need for site specific permit conditions independent of broad national controls.

Role of WOTUS

The role of the Clean Water Act and its definition of Waters of the United States (WOTUS) should also not be overlooked. This controversial federal definition has been expanded through federal court action and as a result attracted significant attention from policy makers. The Clean Water Act provides for federal jurisdiction under the EPA over WOTUS. Any expansion of the definitions of these waters could readily impact the application of NPDES regulations on oil field discharges. This could inhibit the reuse of PW for irrigation of non-edible crops as well as further complicate and constrain discharge permitting.

Liability Issues

Decisions about treatment and reuse must weigh the risks of litigation/liability/regulatory actions against the benefits of lower production costs and easing the burden of dealing with large volumes of PW. Current midstream companies' reported practice is that at the point where a customer ties into the midstream company's system, that is the custody transfer point and the midstream takes ownership of the water including responsibility for leaks or spills.

Liability issues are at least two-fold: regulatory liability and civil liability. Non-compliance with regulations typically means regulators will impose fines. However, the greater risk is the authority of regulators to curtail operations. One of the key questions of every acquisition is what the compliance history of the property is. The answer to this question can make or break a business deal. However, regulators do not typically have the authority to assign damages. That is reserved for the civil courts. It should be noted that courts can consider the actions and findings of regulators and therefore regulatory decisions can at least tangentially influence civil actions.

Accommodation Doctrine and Mineral vs. Surface Owners

The "Accommodation Doctrine" has long been established by Texas courts and addresses the mineral owner's right, as the dominant estate, to use the surface to drill for and produce minerals. Access to groundwater, typically purchased from the surface owner for oil and gas extraction, is part of this doctrine.

During the paper's interviews it was learned that operators find a major hurdle to recycling is the surface owner's objections to a curtailment in their SWD well tipping fees or freshwater sales. The phenomenon, described as "frac ranching" by Gabriel Collins, shows the conflicts of interest that impact R&R:

> The opportunity to sell frac water and disposal services also opens the door for a host of landowners to make substantial returns - including many who are in areas with significant drilling activity, but who had largely been left out of previous booms because they didn't own mineral rights. Ranchers can now make many times more per year selling frac water and disposal rights than they did raising cattle. But produced water recycling threatens these rents, especially when offered at a price range palatable to operators. Conflicts are likely to result.[151]

As a result, waste water recycling has been perceived by some as a competitor for groundwater purchases. With the emergence of the midstream industry laying pipelines from well sites to treatment facilities and disposal wells, areas of disagreement and thus barriers to recycle are emerging between operators and landowners. Some midstream companies are voicing concerns with landowners that try and extract a royalty for water crossing their property. In some cases, midstream customers have voluntarily paid a recycle royalty just to "keep the peace" which makes recycling less competitive.

Encouraging recycling while balancing the rights of landowners and producers to negotiate contracts selling groundwater is an important policy decision. The ability to access minerals is a fundamental property right. So is groundwater ownership. All parties should be alert to any erosion of the Accommodation Doctrine by the courts or legislature when the inevitable friction points develop.

PHMSA and Pipeline Regulations

PW pipelines in Texas are regulated by state law and civil contracts, or through federal delegation of the Pipeline and Hazardous Materials Safety Administration (PHMSA). However, it is important to note that Texas regulations and virtually all state permits, forbid oil field pollution which includes pollution from the mishandling of PW. The existing state regulatory framework for producing, transporting, recycling, with multiple permits and manifests or reporting requirements, is combined with the numerous state field employees that inspect oil and gas facilities, including PW operations and maintenance activities, on a regular basis. Any expansion to federal pipeline regulations that would expand PHMSA jurisdiction to PW transportation would add burdensome and likely unnecessary regulations while having little positive impact on the state's ability to oversee produced and recycled water pipeline operations.

Evolution of Produced Water Management Strategies

Conventional Water Handling

Historically, the solution for handling water was to separate the PW from the oil and gas, complete minimal treatment and either use the water for subsequent production operations or sequester excess water underground in SWD wells.[152] In older conventional fields, excess water could be injected into the formation to enable EOR. In many areas, PW volumes were not as high as they are today; if they were, then the operator would pursue an advanced logistical solution such as the oil skimming operations at Yates field. (However, taking care of the PW was still a top ten cost for many conventional assets.) Water management was a "classic trucking operation" with plenty of available disposal wells on or off site. Costs were on the order of $.40 to .50 per barrel and an additional cost of trucks at $80.00-90.00 per hour.

> Historically, the solution for handling water was to separate the PW from the oil and gas, complete minimal treatment and either use the water for subsequent production operations or sequester excess water underground in SWD wells. With the advent of horizontal production, operators changed their approach to dealing with water and who does it.

With the advent of horizontal production, operators changed their approach to dealing with water and who does it. Today, pipeline transport is often a requirement for operators with multiple wells per pad. The tight formations where many operators are currently producing oil and gas in Texas are not well suited to accept waterflooding. As a result, the move towards hydraulic fracturing in unconventional shale plays has resulted in increased needs for treatment to enable recycle and disposal of water.

Treatment Level Determined by Trial and Error While Costs Decreased

As operators settled on the preferred hydraulic fracturing style - large volume slick water fracs - the industry zeroed in on the benefits of using treated PW. Operators learned slick water fracs did not require high quality (fresh) water for fracturing and that using PW in the mix often led to better results, as well as cheaper costs than using fresh or even brackish water. Trial and error showed treatment was needed to remove TSS, iron, oil and bacteria (but not chloride) and that it was important to keep PW water pits clean. Through the learning curve, operators realized the beneficial effects of lowering needs for freshwater as well as overall treatment costs. Industry is homing in on a "standard" for light treatment.

Water Management Infrastructure Buildout and the Midstream Water Management Companies

As oil prices revived, well counts rose and PW flowed in increasing amounts, the economics of piping water services improved substantially and the midstream model was born in the Permian and Delaware Basins. The RRC allowed commingling of PW in March 2013 from multiple operators thereby opening the door for the midstream services.[153] In the past, these service providers were offering disposal services and/or source water. Operators today often hire third-party midstream companies that specialize in integrated treatment and disposal of PW from the oil and gas fields for multiple operators. The midstream industry is more mature today in the Delaware Basin than in the Midland Basin. Some of those companies include Blackbuck Resources, Fountain Quail, Goodnight Midstream

LLC, H_2O Midstream, Layne Water Midstream, Oilfield Water Logistics, Rattler Midstream Partners, Select Energy Services, Solaris Water Midstream, San Mateo Midstream, Texas Specific Water Services, WaterBridge Resources, Waterfield Midstream and XRI.

According to IHS Markit, the water management market for the upstream (exploration and production) oil and gas industry in the US was worth approximately $33.6 billion in 2018, with the Permian Basin alone accounting for around $12.2 billion. Over the next five years, IHS Markit projects that the water management market will grow at a 3.9 percent compound average growth rate. Most of the market share, approximately 65 percent, is controlled by water logistics, including hauling, transfer and disposal.[154]

Operators who have turned to the midstream companies have access to an array of services.[155] Many of the midstream companies operate fleets of trucks to deliver freshwater, as well as dedicated pipelines to transport PW. The cost to transport PW for disposal can range from approximately $.30 per barrel to more than $2.50 per barrel for piping or trucking the water, respectively.[156] (However, large variations in price can exist based on a variety of operating conditions, including proximity to disposal wells.)

PW can be taken off for disposal or it can flow to a few key points where the midstream company can aggregate, treat and then send via pipelines back for recycle. A typical on-site treatment system includes the following:

- Oil-water separator (if needed) as often water has already gone through a gun-barrel separator. If the water is coming directly from a flowback, a separator may be required.
- Feed tanks. It is generally helpful to have some feed tank storage to allow for varying customer feed flowrates.
- Chemical flocculation followed by settling or flotation. This will typically oxidize iron (if present) often using polymer and pH adjustment (if needed).
- Post filtration. Clean pH-neutral brine is sent to customer containment for re-use. The treated water can be evaluated continuously and redirected if not meeting customer performance metrics.
- Dewatering of solids to dry filter cake (if customer prefers).

Examples of current midstream company systems include:

- XRI purchased the water treatment and recycling division of Fountain Quail Energy Services in April 2019 creating a water midstream company that embraces recycling as a part of their water management strategy.[157] To some this represented a pivotal moment for PW R&R opportunities.
- Solaris is building its Pecos Star System in Lea and Eddy Counties, NM. 200,000 bbl of water a day is treated/moved. The integrated system features multiple deep and shallow disposal wells and over 250 miles of large diameter pipeline that enable Solaris to aggregate water from multiple groups and recycle it.
- H_2O Midstream runs truck-less operations in Howard County include pipelines, storage, disposal wells.
- WaterBridge Resources has a partnership with the City of Fort Stockton, Texas, to purchase water resources for OGI operations. It has acquired Arkoma Water Resources, operator of 110 miles of water pipelines and EnWater Resources, of Midland and its water management assets including 100 miles of pipelines and five SWDs.

University Lands (UL) has instituted an innovative approach to water management using midstream company services.[158] As noted in a recent speech given by its CEO Mark Houser, UL has signed a contract for preferred vendor services with two companies, Fountain Quail and H_2O Midstream, for water management using water from UL lands.[159] In return, these companies have access to designated lands owned by UL. The contract does not require the lessee to use these providers, the latter must convince the producer their services are cost effective. (The contract does set the rate damage schedule which spells out what the companies can do and build on UL.) These contracts will increase the efficiency of water management. UL reports it hopes to demonstrate that "full cycle water management" reduces the total "cost of ownership" for those producers while also making it more environmentally friendly.

Not all operators have chosen to outsource their water management needs; decisions are condition specific. Some operators find on-property disposal easier to arrange, especially those who own their own disposal wells. Larger companies, with expansive contiguous acreage, may have the manpower to deal with R&R and the financial resources to build their own pipeline infrastructure that enables additional ways, other than disposal, to handle water. Matador Resources has established a water management subsidiary, called San Mateo Midstream. San Mateo reportedly has a water disposal capacity of 170,000 barrels of water per day as of the time of writing this report and plans to increase this capacity to 220,000 barrels of water per day.

Pioneer has pursued public-private management model. Under the agreement, Pioneer will pay to upgrade the city of Midland's wastewater plant and receive the treated water in return for use in its completions. This represents a savings of $174 million in Midland city taxpayer-supported debt to fund the upgrades and higher fees. Pioneer also has a contract for water from the City of Odessa and is currently buying water under that contract.

Going forward, operators will have a choice, keeping water management in house or contracting with a commercial midstream water company. The scales may be tipped toward midstream water management by the dual advantages that the operator does not have to invest in infrastructure and the treated water may be less expensive than purchased fresh or brackish water.

Future Trends

Treatment Comes of Age and Takes Off

Data on current PW recycling volumes in Texas are not compiled and reported publicly; up-to-date data are hard to come by. It was reported at a February 2019 industry conference that in the Permian Basin, several companies use over 10 percent treated water in their fracturing fluids including Pioneer at 15 percent, EOG at 20 percent and Apache at 30 percent. Both XTO and Concho reportedly are using 10 percent.[160] In a recent *Shale Play and Water Management* article, Michael Dunkel stated: "Of the largest companies operating in Permian, all report that they are now reusing PW. This increase is substantial compared to recent years when only a few companies were reusing."[161]

While this white paper did not undertake a systematic analysis of all of the operators' strategies, the information gleaned in the interviews provides insight into what's happening today in the Permian Basin:

- One interviewee pointed to recycle reaching 10-15 percent of the total volume of PW in today's Permian Basin.
- Another interviewee estimated the Permian Basin operators are recycling on the order of 450,000 barrels of water daily, representing about 7-9 percent, mostly using oxidation-based processes and simple filtration.
- Yet another Permian Basin operator that currently recycles about 20 percent of its water forecasts their recycle rate will rise to 75 percent in the next five years.
- Some interviewees pointed out that there is so much PW that companies have almost stopped drilling fresh source water wells.
- Another operator estimates it uses 100 percent recycled PW on most of the fracture treatments pumped in Loving County, Texas and intends to use 100 percent recycled PW in Loving County, whenever possible.

Regardless of the exact percentage, PW R&R is likely to increase as the midstream industry matures and injection capacity is unable to keep pace with production. Individual operators' stories point to consistent, significant and growing uses of treated PW in oil and gas operations.

Midstream Consolidation Likely

Currently there are up to 50 companies providing water services in the Permian Basin, an area that may be ripe for consolidation.[162] This consolidation would likely be facilitated by the private equity-based companies targeting companies with large continuous acreage and pipeline miles. One interviewee predicted the industry consolidation will resemble either a "Pacman" (with companies gobbling each other up to form large, full cycle, water management firms) or a "Tetris" (with companies finding their niche and fitting together cooperatively) scenario. Scale typically improves competitiveness and if two companies have assets that are relatively adjacent to each other, but serve different customers, that could make a strong case for consolidation. Likewise, if a firm has large acreage dedications but has not yet built the infrastructure to serve them, another firm seeking to serve that customer, or which may already be serving them nearby could again find strong logical support for a mergers and acquisition type transaction.

Trans-basin Water Management

Some predict that trans-basin pipelines, some crossing state borders, especially for areas with disposal well/seismicity concerns, will increase.[163] Such an export inter-basin type of network is most likely for the Delaware Basin which will have large amounts of PW and not enough disposal capacity. Over time, all Texas basins may need to recycle on the largest scale possible and then rely on pipelines to take away the rest.

Recommendations

A key objective of the 2019 white paper is to make recommendations for the sustainable use of PW. The goal is to offer suggestions to improve the handling of PW in Texas today as well as encourage changes to Texas's policy and regulatory framework that encourage the safe and economic use of treated PW outside the oil and gas fields in the coming years.

The 2014 white paper made the following nine recommendations: 1) voluntary water recycling reporting; 2) consideration of recycling tax incentives; 3) preservation of the RCRA exemption; 4) review of federal NPDES discharge permitting requirements; 5) evaluation of the PBR; 6) review of civil liability laws; 7) industry support for recycling activities; 8) balance the population's and industry's water needs; and 9) expand oil and gas clean up funds to recycling activities.

The 2019 white paper offers the following ten recommendations:

- **Delegate oil field NPDES authority to Texas:** Increasing federal delegations to Texas was highlighted by the SCR 26, passed by the Texas 85th legislature and signed into law by Governor Abbot in 2017. Since then national groups have also called for increased federal delegations to states, highlighted by the 2018 IOGCC RESOLUTION 18.054 "Pertaining to the Delegation of Federal Regulatory Authority to State Government Agencies." Recently passed Texas legislation (HB 2771) will lead to the consolidation of state authority for discharge permitting, including oil field in the Texas Commission of Environmental Quality (TCEQ). The new law also calls on the TCEQ to seek federal delegation from the EPA for oil field NPDES. Federal and state support for this delegation will streamline permitting and enhance R&R opportunities in Texas.
- **Update or eliminate the role of the 98th Meridian in policy:** Policy and procedures for Federal NPDES permits differ to the east and west of the 98 Meridian, which bisects Texas. The elimination or modification of this federal regulatory contrivance will encourage discharge application be considered on a site specific and case by case basis, honoring the technological advances in PW recycling that have recently developed. It should be noted that the EPA has recently released a study of "Oil and Gas Extraction Wastewater Extraction Management" which is intended to take a holistic and national look at how the agency regulates wastewater from the oil and gas industry.
- **Preserve the RCRA exemption:** Maintaining the existing RCRA regulatory framework is the foundation for almost all oil field waste management practices. It remains as critical today as it was in 2014. It should be noted that the April 23, 2019 release of the EPA's Office of Land and Emergency Management (OLEM) RCRA Determination for Oil and Gas E&P Wastes was an important event. EPA formally determined that revisions to existing federal solid waste regulations for the management of crude oil, natural gas and geothermal energy wastes from exploration, development and production (E&P) activities are not necessary at this time - i.e., that the existing state frameworks are handling these wastes effectively. This EPA determination is required to be conducted on a regular three-year basis and it should be noted that the current review was prompted by a 2016 federal lawsuit filed by a non-profit in Washington DC.

- **Maintain state jurisdiction over produced water pipelines:** The State of Texas regulates PW transportation by pipelines, not federal agencies like the Pipeline and Hazardous Material Safety Administration (PHMSA). Any encroachment on the state oversight by federal agencies could be a disruptive and costly burden for the recycling industry to bear.

- **Increase coordination among energy producing states, state and national associations and work groups:** Coordination remains important on the national level. The overarching objective is to share experience, expertise, lessons learned and eventually homogenize policy as much as practicable given the significant variations in state authority. There is an important role for national groups and associations, such as IPAA, a co-sponsor of this White Paper and API, a leading organization of industry experts, to play in policy and technical discussions and we urge industry support of these and other national associations. In addition, national organizations comprised of governmental representatives like the Groundwater Protection Council (GWPC) and IOGCC can play a crucial role in ensuring industry and regulators march to a similar drumbeat of progress and innovation. For example, the GWPC has authored a national white paper on PW which will aid the dialogue on hydrocarbon extraction management, regulations and overall energy security.

  One concrete political example of increased communication among different levels of government recently occurred on May 16, 2019, when a Congressional House subcommittee met in Washington DC to hear testimony regarding hydraulic fracturing and state regulation of PW. Invited testimony came from California, Ohio, South Dakota and Texas. The testimony clearly demonstrated that the impressive regulatory framework constructed in Texas is a model that could help other states address regulatory concerns.

- **Revise statutes and regulations on the handling of PW:** As technology evolves so must regulations. Over-regulation can stifle economic growth, while under regulation can threaten environmental safety. A regulator is tasked with getting it just right. The existing framework of sequentially permitted activities, from waste generation, through transportation, including recycling and to disposal, that currently regulates PW management is comprehensive and adequate. However, updated guidance may be welcomed by industry and the public to address specific issues, such as PW spill cleanup and notifications. Furthermore, the "PBR" concept implemented to encourage PW R&R within the Texas oil fields has done just that and this PBR model may be applicable to other operations in the oil field, such as facility permits, pit permits, or other water recycling activities that currently require a permit application.

- **Enhanced/institutionalized cooperation between Texas and federal agencies:** Texas leads the country in oil and gas production, technical innovations and regulatory oversight. However, in the recent spirit of cooperative federalism, some states (New Mexico as an example) have joined in MOU's with the EPA and participated in White Papers involving PW. Meanwhile the EPA has issued its own draft "Study of Oil and Gas Extraction Wastewater Management" in May of 2019. Efforts like these, or a similar scoped task force or any other endeavor that regularly joins the state and federal regulators, the public, the regulated community and science together in common study and constructive critique, are laudable and could benefit Texas.

- **Prepare a roadmap for the beneficial use of treated PW including an assessment of toxicology knowledge gaps:** Concerns regarding the chemical constituents in PW highlighted much of the opposition to recent beneficial reuse PW legislation. While many of these concerns should be addressed in technical reviews of site-specific permits, the need to encourage pilot studies and research would be an initial and helpful step to study this issue. Furthermore, a solid and repeatable funding mechanism to defray the cost of these academic and scientific studies would appear to be a benefit to all.

- **Develop incentive mechanisms to help lower the costs of treating PW:** Recycling technology might be considered expensive, but the opportunities inherent in this technology for water conservation and beneficial reuse could be significant. As Texas pursues its policy to conserve water and improve supplies, incentives for water recycling should be considered and studied. The need for an interim study of incentives for PW recycling has been mentioned by the Texas Legislature and this work could provide future opportunities to invest in Texas PW recycling and should be pursued.

- **<u>Collect and provide public access to PW data</u>:** Currently the reporting and permitting framework for PW does not encourage the compilation of PW production or R&R data. While the business model that supports and requires specific and detailed data tracking efforts is rock solid and cannot be replicated or replaced, general or statewide numbers disseminated annually to the public by regulators or others would be a valuable tool in helping the public understand the value and future of oil field recycling. Additionally, because R&R can currently mean any number of lifecycles for PW, it is difficult to ascertain exactly what the varied data represent. Recycled water data may refer to lightly treated PW used in the oilfield for a new fracturing operation, or in an EOR operation, or even to highly treated PW used outside of the oilfield. The lack of reporting in general and standardized reporting specifically on PW and R&R could be cause for confusion in the industry moving forward. Knowing that good, reliable data helps inform sound and useful regulation, it is recommended that the industry standardize PW terminology, reporting and disclosure. This has been one of the key goals of the current White Paper.

Concluding Thoughts

Although the Texas oil and gas industry does not use high volumes of water as compared to other key industries, it is expected to further increase its efforts to use water in a sustainable manner, embracing PW R&R. This is positive for Texas jobs, service companies, oil producers of all sizes and the local and state tax base. It extends well life and lowers induced seismic chances. The time is here for R&R to take center stage as the water management option for producers across the state.

Produced water management strategies have evolved dramatically over the past five years. Increasing albeit low levels of treatment are becoming more prevalent. Not only does R&R of treated PW offset the need for fresh water for fracturing operations, treated PW works better than fresh water. As treatment costs have come down and fresh water prices have gone up, operators are reducing their costs. Even if it were a break-even situation, it reduces trucking and associated environmental and infrastructure impacts. Concerns remain including current and future availability of disposal wells, changing state requirements for seepage/evaporation ponds and reduced ability to R&R PW in some basins as drilling and completion activities decline.

Looking at what Texas has done right but could do better, Texas took an early lead in recognizing the potential value of recycling PW and began revamping its regulatory framework as early as 2013. The benefits are now here to behold with the emergence of midstream water management and the increasing business opportunities in the recycling of PW. To improve, it is now time for the next generation of innovation, with careful consideration of incentives for recycling, infrastructure improvements, pilot projects to study potential impacts of PW reuse, improved data availability and updated metrics and federal delegation of key statutory authorities. Operators, investors, managers and regulators need to tie all the aspects of the full cycle water management world together.

Five plus years ago, the question was whether PW was an “asset” or “waste.”[164] This was answered - PW is both.

Now, the question is what it will take to move the needle. What’s needed for beneficial use of PW for non-food crop irrigation, industrial process water, cooling, and municipal uses outside the oil and gas industry? Produced water will become a truly valuable commodity when all American consumers use it in some fashion.

The Ground Water Protection Council published a thorough analysis of the drivers, barriers, opportunities and research needs surrounding such beneficial reuse. It concluded:

> Currently, the feasibility of reuse is significantly greater in unconventional oil and gas operations than in applications outside the oil and gas industry, where the costs of transporting and storing PW and, particularly, of treating it to a “fit for purpose” level can be limiting. Potential risks to health and the environment must be well understood and appropriately managed in order to prevent unintended consequences of reuse. Produced water is complex and in most cases further research and analysis is needed to better understand and define the “fit for purpose” quality goals for treatment and permitting programs. Environmental

considerations beyond direct health or ecosystem impacts include emissions from treatment, managing waste materials from treatment, cumulative ecosystem impacts, or other localized issues.[165]

During the white paper interviews, some expressed optimism that reuse outside the oil and gas industry will be achieved on a large scale; others less so due to the large expense of dealing with the solids from treated PW. While the authors trust beneficial reuse outside the industry is going to happen in the future and offer recommendations that will further move the needle, the verdict's not in as to when.

Emergence of the midstream companies is a first step in the development of a PW private sector market. The experiment using treated PW to irrigate cotton crops in Pecos, Texas, demonstrated that PW can be safely be used outside of the oil and gas fields in Texas.

Planning must take place now before disposal is constrained or the number of new wells needing treated PW for fracturing operations declines. In practical terms, gathering operations must be streamlined with larger diameter pipes and easier pipeline transport over lands fragmented by a myriad of owners. Economically, treatment costs must come down. If desalination costs can be lowered, especially for non-food crops, the economics will line up and it will be dam-breaking.

The legal and regulatory system must develop in a timely fashion its framework of rules and regulations about acceptable uses so the private sector is ready to deploy when the economics align with demands for new uses. The Texas government must get delegated rights from the federal government, clear up some laws and get reasonable federal oversight from EPA to allow Texas to approve PW for other uses. If the State builds a regulatory framework that encourages profitability through PW recycling, business will be attracted to invest in that area. The potential for Texas to have a competitive advantage through modernizing their regulatory framework can be an opportunity for business gains as well as water conservation.

Texas's neighbor has made strides in moving the needle. In 2019 New Mexico Governor Michelle Lujan Grisham signed the Fluid Oil and Gas Waste Act into law.[166] This law, which took effect in July 2019, gives New Mexico a statutory framework to address beneficial reuse of PW outside of the oil field. Rules and standards for discharge must be established by the New Mexico Water Quality Control Commission.

Water can be considered the life blood of our planet, our country, our economy and our Texas oil fields. As such, it has long been the practice of lawmakers and regulators to protect our water supplies from industrial activity and its byproducts. As policies and practices in managing oil field PW mature, the perception that PW is a problem is now giving way to the growing recognition that PW can be considered a solution. Nevertheless, the question remains: will we be able to embrace the technology and craft the regulatory framework that allows us to take advantage of the opportunities that PW may provide? The answer lies before us.

Contact Information

Supplemental materials are available upon request.
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Glossary of Terms

1. **Acre-foot-** unit of volume equal to volume of sheet of water one acre in area and one foot in depth; 43,560ft^3
2. **Barrel (bbl)-** 42-gallon barrel commonly used as measurement for petroleum production
3. **Beneficial Reuse-** refers a volume water applied to a non-wasteful use, including wildlife, agriculture, aquifer recharge and others
4. **Brackish Water-** slightly saline water (3,000-10,000 mg/L TDS or 1,000-10,000 mg/L TDS)
5. **Brine-** water containing more dissolved inorganic salt than typical seawater (>35,000 mg/L TDS); water containing salts in solution, such as sodium, calcium or bromides; brine is commonly produced along with oil
6. **CERCLA-** Comprehensive Environmental Response, Compensation and Liability Act (a.k.a. “Superfund”), outline responsibilities of operators for transportation, storage, treatment or disposal of regulated “hazardous substances,” which include certain oilfield materials
7. **Class II Injection Well-** used to inject fluids associated with oil and natural gas production; disposal wells, enhanced oil recovery wells, hydrocarbon storage wells
8. **Concentrate-** salt and contaminants removed from PW during treatment; currently regulated under RCRA
9. **Conventional Resource-** hydrocarbons trapped by overlying rock formations with lower permeability
10. **Crude Oil-** unrefined petroleum
11. **DOE-** U.S. Department of Energy
12. **DUC-** drilled but uncompleted well
13. **Earthquake-** the sudden release of accumulated stress in the Earth by movement or shaking. Earthquakes are caused by tectonic activity, volcanoes and human activity (such as explosions)
14. **EIA-** Energy Information Association
15. **Electrical Conductivity-** ability of a material to support the flow of an electrical current.; freshwater is not conductive, but the salt ions in salt water or brine are electrically conductive
16. **EPA-** U.S. Environmental Protection Agency
17. **Flowback Water-** water that returns to the surface during initial fracturing operations, typically thought of as the initial volume of water returning to the surface, followed by a drastic reduction in the volume of fluid returning to the surface, which is then referred to as PW
18. **Fracturing Fluid-** (fracturing fluid) a fluid injected into a well as part of a stimulation operation that typically contains water, proppant and a small amount of nonaqueous fluids designed to reduce friction pressure while pumping the fluid into the wellbore; fluids typically include gels, friction reducers, crosslinkers, breakers and surfactants
19. **Freshwater-** low salinity, low TDS, low chloride, high purity water; <1,000 mg/L TDS (or <3,000 mg/L TDS as defined by RRC)
20. **FP water-** flowback and PW
21. **Horizontal Well-** an oil or gas well that is dug at an angle of at least eighty degrees to a vertical bore; typically, hydraulically fractured
22. **Hydraulic Fracturing-** fracturing of rock at depth with fluid pressure, accomplished by pumping water into a well at very high pressures
23. **Hydrostatic Pressure-** the pressure exerted by a fluid at equilibrium at a given point within the fluid, due to the force of gravity; increases in proportion to depth measured from the surface because of the increasing weight of fluid exerting downward force from above
24. **Induced Seismic Event-** seismicity (earthquakes) induced by external anthropogenic forcing (e.g. water injection) rather than natural tectonic activity
25. **Injection Well-** a well in which fluids are injected rather than produced, the primary objective typically being to maintain reservoir pressure; two main types of injection are common: gas and water

26. **Midstream-** portion of the oil and gas and water industries that is primarily concerned with transportation (e.g., pipelines or trucking)
27. **Mcf-** thousand cubic feet
28. **Natural Gas-** a naturally occurring mixture of hydrocarbon gases that is highly compressible and expansible; methane [CH_4], ethane [C_2H_6], propane [C_3H_8], butane [C_4H_{10}] and pentane [C_5H_{12}] make up the typical suite of natural gas compounds
29. **NORM-** Naturally Occurring Radioactive Material is commonly present in producing formations and thus is also present in PW
30. **NPDES-** National Pollution Elimination Discharge System; Clean Water Act to control discharges of contaminants; discharges are allowed in to US water only by NPDES permits
31. **Oil and Grease-** not an individual chemical or typical group of chemicals, rather a common test method that measures many types of organic chemicals that collectively lend an "oily" property to the water.
32. **OPEC-** Oil Producing and Exporting Countries;
33. **Permeability-** a rock's ability to transmit fluids, where rocks like sandstones typically have a series of large well-connected pores and are "permeable," and shales have smaller, less interconnected pores and are "impermeable"
34. **Porosity-** percentage of pore volume or void space, or a volume within rock that can contain fluids; can be generated by the development of fractures; "effective porosity" is the interconnected pore volume in a rock that contributes to fluid flow in a reservoir
35. **PW-** A term used to describe water produced from a wellbore that is not a treatment fluid and is typically thought to be the water brought to surface after the initial flowback fluid, most studies do not distinguish between PW and flowback fluid; characteristics of PW vary and use of the term often implies an inexact or unknown composition
36. **RCRA-** Resource Conservation and Recovery Act; law that creates the framework for the proper management of hazardous and non-hazardous solid waste; both *flowback* and *PW* are exempt under RCRA
37. **Recycle-** to convert waste into reusable material (e.g., PW into usable water)
38. **RRC-** Railroad Commission of Texas; the state agency of Texas that regulates the oil and gas industry, gas utilities, pipeline safety, the LNG industry and surface coal and uranium mining
39. **Salt Content-** a primary constituent of PW and a main area of concern for water treatment; can be represented as salinity, TDS, or electrical conductivity
40. **Saltwater-** saline water with >10,000 mg/L TDS
41. **Seismicity-** frequency, magnitude, mechanisms and distribution of earthquakes (seismic activity)
42. **Sustainable-** the physical development and institutional operating practices that meet the needs of present users without compromising the ability of future generations to meet their own needs, particularly with regard to use and waste of natural resources
43. **SWD Well-** saltwater disposal well;
44. **TDS-** Total Dissolved Solids; the total volume of minerals, metals, organic material, salts, cations or anions dissolved in water; typically used to characterize PW
45. **Unconventional Resource-** petroleum reservoirs whose permeability/viscosity ratio requires use of technology to alter either the rock permeability or the fluid viscosity in order to produce the petroleum at commercially competitive rates
46. **UIC-** underground injection control program; EPA well classification of underground injection wells; Classes I through VI
47. **USGS-** United States Geological Survey; governmental scientific agency that studies the nature, resources and hazards of the natural world
48. **Vertical Well-** conventional drilling method that employs only a vertically drilled borehole
49. **WOR-** water to oil ratio, also known as water cut, the ratio of barrels of water to barrels of oil produced for a well

Notes

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IdeaSmiths, LLC is a consulting firm that offers expertise in energy systems. The firm provides modeling expertise, due diligence and expert testimony for clients ranging from early-stage investors to Fortune 100 companies. Our team of professionals works with clients to understand the impact of a rapidly changing energy landscape by delivering insight on opportunities to improve the way energy is produced, managed and consumed. For more information, please visit us at www.ideasmiths.net.

Website Website www.ideasmiths.net

Miller Consulting, Inc.

Miller Consulting, Inc. is based in Austin, Texas and has represented oil and gas operators and related energy entities before the Railroad Commission of Texas as well as other state agencies for all types of compliance requirements since 1984. Miller offers assistance with all types of data research as well as filings for all necessary organization, permitting, completion, production, plugging, hearing applications and many other necessary filings. For more information please visit our website at www.milconinc.com.

Website www.milconinc.com

Sourcewater

Sourcewater, Inc. is based in Houston, Texas and founded from the Massachusetts Institute of Technology's Energy Ventures program in 2014 -- is the leading oilfield water intelligence platform. Sourcewater gathers, analyzes and maps water, disposal, oil and gas permits, capacity, production and pricing data from our exclusive water and disposal marketplace, which includes over 1,000 registered users and over 1 billion barrels of listed water sourcing, recycling and disposal capacity; from our proprietary satellite imagery analytics of every frac pond and well pad in the Permian Basin; from over 50 state government data sets updated daily, weekly or monthly; and from continuous market research of water market participants. Sourcewater shows where every barrel of oilfield water is located, comes from and goes in Texas, New Mexico, North Dakota and Pennsylvania. Our new dirt work detection technology scans weekly satellite imagery of the Permian Basin with computer vision and machine learning algorithms to predict drilling permit and rig activity six months ahead of permit filings. Visit www.Sourcewater.com for more insights

Website www.Sourcewater.com

Texas Alliance of Energy Producers

The Texas Alliance of Energy Producers has a long, rich, and commanding history of fighting for the Texas independent oil and gas industry.

A statewide organization with more than 2,900 members, the Texas Alliance serves our independent energy producers and associated service industries through advocacy in front of all levels of government; federal, state, and local.

Our highly experienced staff and supporting consultants provide renowned expertise on virtually every regulation from any government entity. No issue is too big and no membership is too small for the Alliance. Come and join us.

Website: www.texasalliance.org

Independent Petroleum Association of America

The Independent Petroleum Association of America (IPAA) is a national upstream trade association representing thousands of independent oil and natural gas producers and service companies across the United States. Independent producers develop 91 percent of the nation's oil and natural gas wells. These companies account for 83 percent of America's oil production, 90 percent of its natural gas and natural gas liquids (NGL) production and support over 4.5 million American jobs. Learn more about IPAA by visiting www.ipaa.org and following @IPAAaccess on Twitter.

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