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Reuse of produced water from the onshore oil and gas industry

Evaluating opportunities and challenges

INTRODUCTION

Produced water is the water that is brought to the surface during the production of crude oil and natural gas, and includes formation water, flow-back water and condensation water (IPIECA, API, IOGP, 2020). Produced water varies in composition and volume from one formation to another and has often been managed as a waste material requiring disposal. In recent years, the increased demand for, and regional variability of, available water resources, along with sustainable water supply planning, have driven interest in the reuse of produced water. Such reuse includes the beneficial utilization of produced water to meet the requirements for use within the oil and gas industry or by external users.

Reuse of produced water can provide important economic, social and environmental benefits, particularly in water-scarce regions. For oilfield operations, produced water can be used for well stimulation (e.g. hydraulic fracturing), water flooding and enhanced oil recovery, thereby decreasing the demand for other sources of water. However, the reuse of produced water for off-site, non-oilfield applications, such as crop irrigation, wildlife and livestock consumption, industrial processes and power generation, is subject to a variety of constraints. Practical considerations for off-site reuse include, but are not limited to, supply and demand, regulatory (e.g. permits, water quality standards), infrastructure (e.g. transportation, storage, treatment technology), economic (e.g. cost), legal (e.g. ownership), social (e.g. public perception) and environmental factors (e.g. brine management).

This fact sheet, in conjunction with other IPIECA water management guidance, is intended as a resource for oil and gas operators and contractors, policymakers and other interested parties for investigating opportunities to reuse produced water for a variety of purposes. The document focuses on sources of produced water from conventional onshore oil and gas operations (e.g. high mobility/permeability formations) and unconventional operations (e.g. low mobility/permeability formations such as oil sands, and shale/tight oil and gas) and addresses the challenges and opportunities for the reuse of produced water. Although published information regarding produced water composition and management practices is limited, summary information is provided where available.

SOURCES, CHEMICAL PROPERTIES AND MANAGEMENT OF PRODUCED WATER

The composition and flow of produced water can differ dramatically from one source to another. General information on the sources of produced water, the volumes at which it is produced, and its composition are summarized below.

Sources and volume of produced water

In conventional oil and gas production, oil and/or gas exist in relatively permeable geologic formations, and the natural pressures in the formation conditions, often stimulated by pumping, push or draw the oil, gas and formation water towards a well for surface extraction. These pressure and formation conditions may be manipulated by secondary (e.g. water flooding) or tertiary (e.g. steam flooding) recovery methods to help bring oil to the surface (IPIECA, 2014a). Over the lifespan of a conventional oil and gas well, the volume of produced water generated may increase with time as the hydrocarbon reservoir depletes, resulting in larger water-to-hydrocarbon ratios over time (Clark and Veil, 2009).

Unconventional production occurs when oil and/or gas have low mobility or exist in geological formations with low permeability (IPIECA, 2014a), such as shale beds or 'tight' sands. In an unconventional well, the flow rate of produced water often diminishes over time, as the return of flowback water diminishes and the well yields relatively low volumes of formation water (GWPC, 2019). The various sources of produced water from conventional and unconventional wells are shown in Figure 1.

Figure 1 Sources of produced water

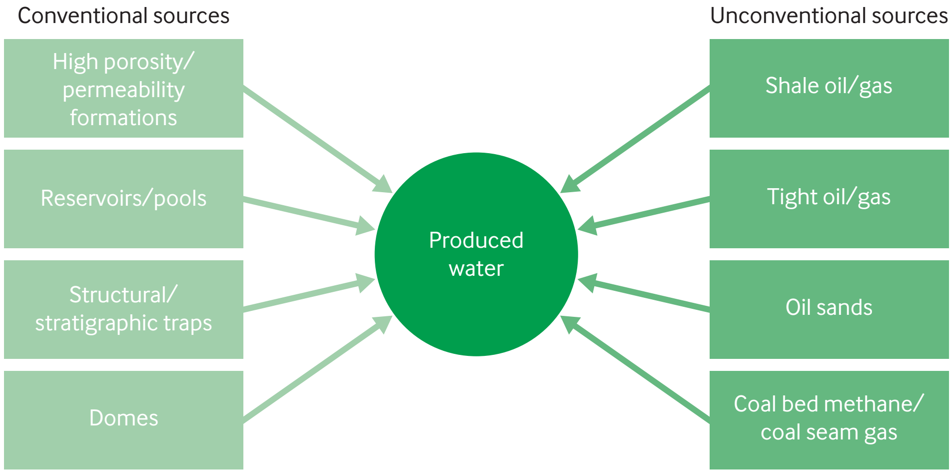
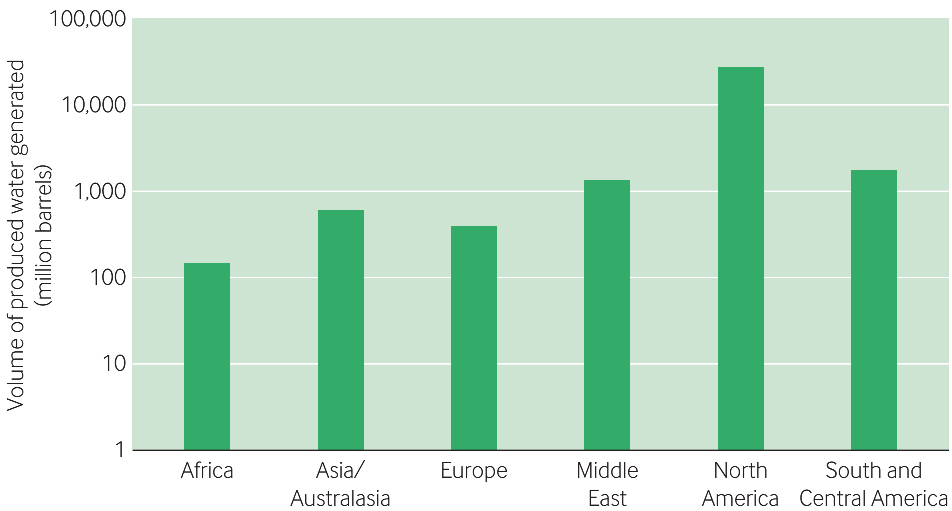


Figure 2 The volume of produced water generated onshore in 2017 in various regions around the world, as reported by IOGP members (data from IOGP, 2018)



The onshore oil and gas industry generates millions of barrels per day of produced water worldwide (IOGP, 2018). Quantities of produced water generated can vary across regions. For example, Figure 2 presents the volume of onshore produced water reported by 44 of the 56 International Association of Oil and Gas Producers (IOGP) member companies operating in various regions worldwide during the 2017 reporting period. These data represent approximately 27% of 2017 world production, and as such do not encompass all operations in these regions, but provide a general sense of the magnitude of the produced water volumes generated in each case.

Produced water constituents

The composition of produced water varies considerably depending on a number of factors, such as the geographic location of the oil and gas field, the geologic formation producing the water, and the process used to extract the hydrocarbon product (IPIECA, 2018). Predominant constituents include total dissolved solids (TDS), such as natural salts and minerals, as well as dissolved and volatile organic compounds, oil and grease, heavy metals, dissolved gases, bacteria, naturally occurring radionuclides (e.g. radium) and the additives used in hydrocarbon production (IPIECA, 2018).

Elevated salinity (i.e. high TDS and chloride (Cl) concentrations) renders the water unfit for many industrial and agricultural purposes, and the costly and energy-intensive desalination needed for high-salinity water also limits the feasibility of reuse (PTAC, 2007; GWPC, 2019). TDS and Cl concentrations measured in produced water from North America range from as low as 40 mg/l to greater than 450,000 mg/l, and chloride concentrations range from 1 mg/l to more than 300,000 mg/l. On an international scale, detailed information on produced water composition is limited; however, the variability likely spans the same range of TDS and Cl concentrations seen in North America.

Common methods for management of produced water

Decisions regarding produced water management practices are influenced by a number of factors, principal among those being regulatory requirements, and the technical and economic feasibility of alternatives. In general, effective management of produced water begins with minimizing the volumes of produced water generated at the oil and gas field, by preferentially pumping wells with lower water volumes, adjusting the depths from which oil is pumped from the reservoir, employing downhole separation techniques, or other methods. The produced water that is generated during the production of oil and gas is commonly managed by operators via one or more of the following methods (in order from the most common to the least common):

- Disposal in appropriate underground formations via injection wells.
- Reuse within oil and gas operations (mainly reinjection).
- Reuse for agricultural and industrial operations after appropriate treatment.
- Discharge of treated water to the environment, subject to applicable environmental regulations.

To the degree that is feasible at each location, oil and gas operators recognize the benefits of reusing produced water in their own operations so as to minimize the use of other water resources. Given the relatively stringent water quality criteria required for direct discharge of the treated water to the environment or for use in irrigation, produced water treatment and reuse can prove economically infeasible in many cases (GAO, 2012). Consequently, where geologic conditions are appropriate for reinjection, underground disposal of produced water is often selected as the most practical management option, and is often necessary to prevent subsidence. Additional factors are the high cost of water testing and treatment, and the potential liabilities associated with uses outside the oil and gas operation (GWPC, 2019)

Treatment of produced water for reuse

Produced water containing higher levels of dissolved salts, suspended solids and other constituents require treatment prior to reuse or even disposal. The degree of treatment required depends on the feed water composition and the proposed end use.

Reuse in oilfield operations may require only limited treatment so as to meet the needs of water flooding, drilling and completions, including hydraulic fracturing. However, reuse of produced water for non-oilfield operations typically poses a much greater treatment challenge depending on the salinity of the produced water. The salinity of produced water must be reduced to the required levels for uses such as crop irrigation, livestock consumption and industrial processes.

The evaluation of produced water treatment options begins with identifying the water quality needs for the end use and other environmental regulations that may apply, followed by addressing the technical and economic factors involved with achieving the desired level of water quality. Treatment commonly involves some combination of physical, chemical and biological processes to remove oil, gas, suspended solids, mineral salts, heavy metals, organics and radionuclides, as needed. Technologies to reduce water salinity can have their challenges, and can also be costly, entail significant energy consumption, and produce wastes such as concentrated brines, mineral solids, etc. which, in turn, require disposal (GWPC, 2019).

CHALLENGES AND OPPORTUNITIES FOR THE REUSE OF PRODUCED WATER

The reuse of produced water for on-site oilfield operations is a common practice and is subject to the specific technical and economic considerations for a given oil and gas field. In contrast, the reuse of produced water for off-site, non-oilfield operations can entail many technical, regulatory, economic, environmental and social considerations, as described below.

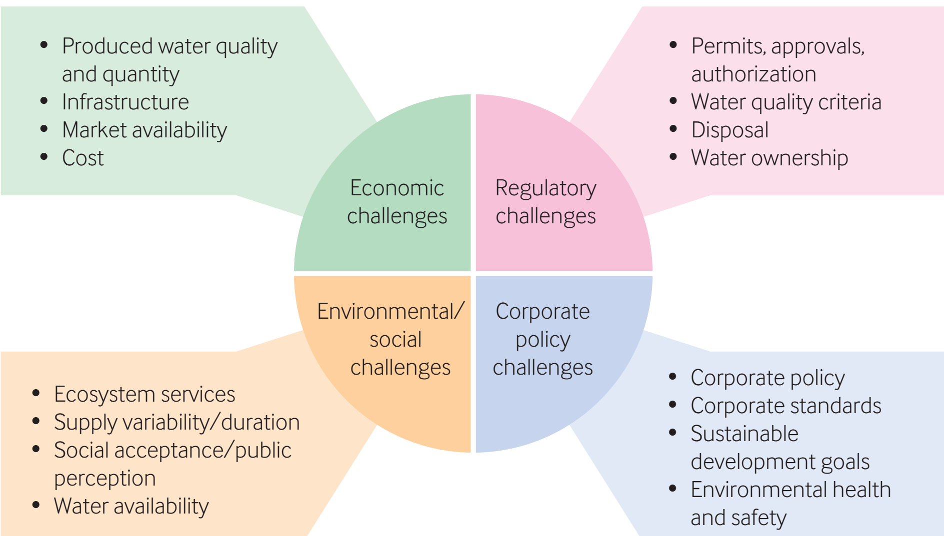
Challenges to produced water reuse

Produced water that meets quality requirements is used in a variety of applications within oilfield operations, such as water/steam flooding, drilling and completion, and hydraulic fracturing operations. Reuse for non-oilfield uses such as crop irrigation, wildlife and livestock consumption, aquifer storage and recharge, and power generation face a number of challenges that may restrict these beneficial uses, as indicated in Figure 3.

Understanding the nature and composition of the produced water source is a first step in assessing the environmental, health and regulatory issues associated with reuse outside oil and gas operations, as well as the feasibility of rendering the water suitable for the proposed use. The technical and economic feasibility of rendering the water suitable and safe for the proposed use will commonly dictate whether the opportunity warrants further consideration. In addition, regulatory challenges to the reuse of produced water for off-site, non-oilfield applications include restrictions on storage and transport, and on water ownership, as the rights of ownership, diversion and use of the water may belong to the government, landowners or other parties and not the oil and gas operator. Additional potential issues associated with non-oilfield reuse also need to be considered, such as accidental releases, overflows, leaching or run-off. (GWPC, 2019).

Infrastructure costs, financing and planning may hinder the use of produced water for off-site purposes. There may be a lack of existing economically viable users in geographic proximity. Treatment technology to achieve a suitable end use may not exist or the cost may be prohibitive. Physical limitations to the installation of equipment, lack of storage capacity or conveyance pipelines, and compatibility with existing infrastructure may also hinder reuse options.

Figure 3 Challenges to the reuse of produced water in non-oilfield operations



Economic constraints to non-oilfield reuse of produced water include the cost of treating the water for an appropriate use, market availability for reuse, and the value of treated water in the context of sustainability. Fluctuations in value on the oil and gas market and on the water market can also affect the feasibility of a water reuse project.

Social factors and public perception may also play an important role when considering options for off-site, non-oilfield use. In addition, the ability of a possible short-term produced water supply to meet long-term community water needs and expectations should be considered.

When deciding whether to reuse produced water, companies will need to weigh the benefits of making use of this resource against the risk of potential liability. The reuse of produced water beyond the project fence line may have the potential for liability associated with service agreements to provide an agreed volume and quality of water to an end user. As produced water volumes and quality are variable during oil and gas operations, this could be a key risk requiring mitigation.

The feasibility of produced water reuse at any given site is a site-specific determination, considering the various factors identified above. Some examples of the successful reuse of produced water for oilfield and non-oilfield applications are presented below. These examples represent only a small set of potential applications for produced water reuse, and may not be appropriate in other geographic locations or for other produced water sources.

Examples of produced water reuse within the oil and gas industry

The greatest opportunity for produced water reuse is within oil and gas operations. On-site water reuse technologies allow the oil and gas industry to reduce water demand and supplement limited water supplies (Dahm, 2014). Examples of reuse applications for specific locations and operations are highlighted below.

- Reuse for drilling and completion in the US: Produced water is commonly treated to remove suspended solids and hydrocarbons, and reused for drilling operations. By recycling produced water in drilling operations and completions in the Permian Basin, the Apache Corporation reduced its operating costs associated with water management and disposal (US EIA, 2016). As of 2016, Apache had built six water recycling systems in the Alpine High oil and gas play in West Texas to recycle approximately 90% of produced and non-potable water for drilling and completions (Apache, 2018).
- Reuse for hydraulic fracturing in Canada: Tourmaline Oil Corp. received regulatory approval to construct and store produced water in a large-scale engineered containment pond for future use in hydraulic fracturing activities. Tourmaline reports recycling more than 95% of flowback from its gas operations (Tourmaline, 2017).
- Reuse for mining of oil sands in Canada: Many oil sands operators, including members of the Canada Oil Sands Innovation Alliance (COSIA), have developed new treatment technologies to enable the reuse of produced water for in-situ oil sand production in response to new recycle targets imposed by regulators. For example, the steam-assisted gravity drainage (SAGD) pilot plant recycles 90% of the water it uses to generate steam and soften the bitumen to facilitate its flow to extraction wells (COSIA, 2017).

Examples of produced water reuse outside the oil and gas industry

Constraints to non-oilfield use of produced water include site-specific considerations of timing, reliability, quantity, the variable water quality of produced water, and the cost of treating the water to ensure that it meets the requirements of other users (CDR, 2014). Some examples of the successful reuse of produced water outside the oil and gas industry are presented below.

- Irrigation in Australia: Produced water may be used as irrigation water when treatment is feasible. Produced water from coal bed methane (CBM) operations in Australia has been treated by reverse osmosis and reused in large-scale forestry operations and legume plantations in Queensland's Bowen Basin, and for irrigating pasture crops, tree timber plantations, and oilseed-bearing legume tree plantations (Mallants *et al.*, 2017).
- Agriculture and reduced power consumption in Oman: Following oil-water separation, produced water treated to appropriate standards for this end use may be placed in constructed wetlands to undergo natural treatment and enhance the wildlife habitat. The constructed wetlands are also used to remove constituents from produced water and have the potential to make water available for use by local communities. Since 2010, BAUER Nimr LLC has implemented the commercial water treatment plant on a 32-year design, build, own, operate and transfer concession agreement on behalf of Petroleum Development Oman and Shell. The facility uses native wetland plants for treating residual oil in produced water from the Nimr oilfield in south Oman. This project has allowed produced water to be reused for bio-saline agriculture in an area where freshwater supply is scarce, and has eliminated the power consumption and carbon dioxide emissions associated with deep well disposal (Breuer, 2019).

- Livestock and wildlife watering in the US: Produced water that has been appropriately treated has been used for wildlife and livestock watering. In the US, the State of Wyoming allows produced water treated to salinity levels of <5,000 mg/l TDS and <2,000 mg/l Cl from CBM operations to be discharged into surface waters for beneficial use by livestock and wildlife, subject to permit requirements, and for wetland habitat development (US FWS, 2002).
- Electrical power industry in Australia: Treated produced water may supplement cooling water feed or other power industry uses, depending on the specific water quality needs of each facility. Raw produced water from coal seam gas (CSG) operations in Australia's Surat Basin is drawn and treated on-site for cooling and steam production at a power station located near Chinchilla (ANWC, 2011).
- Other industrial/commercial uses in Australia: Produced water can be used for a variety of purposes, such as vehicle washing, firefighting, road dust control, or equipment de-icing, subject to the proper control of run-off and the protection of water bodies. For example, Arrow Energy in Australia provides untreated produced water from CSG operations to the Wilkie Creek coal mine for removing soil, rock and other impurities from coal to help reduce carbon dioxide emissions during coal combustion (ANWC, 2011).

CONCLUSIONS

The onshore oil and gas industry is continually investigating new and improved ways to manage the supply and disposal of produced water. Under certain conditions, the reuse of produced water can be part of a potential solution to diminishing water supplies. Within oil and gas operations, produced water is increasingly being recycled and reused for enhanced oil recovery, drilling and well stimulation activities. The increased demand for water resources in many regions around the world is also creating more interest in the reuse of produced water outside oil and gas operations, which requires careful consideration of the potential challenges and benefits on a case-by-case basis.

Natural reed bed water treatment project in Oman. Photograph courtesy of BAUER Nimr LLC. https://bauer.de/bre

GLOSSARY

Coal bed methane	Production of gas from coal seams. Termed coal seam gas (CSG) in Australia (IPIECA, 2014a).
Conventional gas production	Gas contained in reservoirs under natural pressure that expands when pressure is released (e.g. well drilling) and flows naturally up the production well without additional stimulus (IPIECA, 2014a).
Conventional oil production	Extraction of hydrocarbon from a reservoir in which oil initially moves by natural mechanisms (e.g. formation pressure) to the extraction point as it is forced to the surface (IPIECA, 2014a).
Enhanced oil recovery	Techniques to prolong the productive life of reservoirs (IPIECA, 2014a).
Flowback	The fracture fluids that return to surface after a hydraulic fracture is completed and prior to the well being brought into production (IPIECA, 2014b).
Formation water	Water that occurs naturally within the pores of rock (IPIECA, 2018).
Hydraulic fracturing	Well completion operation involving the injection of fluids and proppant into the target formation to induce and maintain fractures in the rock through which oil or natural gas can flow to the wellbore.
Produced water	Water that is brought to the surface during the production of hydrocarbons, including formation water, flowback water and condensation water (IPIECA, API, IOGP, 2020).
Recycled water	Used water/waste water employed through another process cycle after treatment (IPIECA, 2014b).
Reused water	Treated water/wastewater that is used more than once before it passes back into the water cycle (WateReuse, 2020).
Unconventional production	Extraction of hydrocarbon resources with low mobility and/or which are present in low permeability geological formations. Includes oil sands, shale/tight oil and gas, and coal bed methane (IPIECA, 2014a).
Water flooding	A secondary recovery method involving the injection of gas and/or water into the pore space of the reservoir production zone (IPIECA, 2014a).

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