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Reuse of Produced Water in the Oil and Gas Industry

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Abstract

Oil and gas operations handle and manage large volumes of produced water. In recent years, the increased demand for and natural variability of water resources have driven interest by policy makers, regulators and society in the potential opportunities for its reuse. Such reuse may include the beneficial utilization of produced water with or without treatment to meet the requirements for use within oil and gas operations, or by external users. In recognition of the need to gain a full understanding of produced water management and the potential for reuse, IPIECA conducted an internal survey of 14 IPIECA member companies, interviews with selected external stakeholders covering a range of sectors and geographic regions and a literature review of readily available information regarding this subject. The external stakeholders were identified from the membership survey as well as from IPIECA and consultant's experience with the aim to learn from, and build on, existing work on produced water reuse. Numerous factors can influence the practicability of implementing the reuse of produced water either within the oil and gas industry or by external users. Based on the local circumstances of an operation, the same factors can provide either opportunities and/or constraints, with associated risks. Four main aspects have been identified for considering the reuse of produced water: Economic, Regulatory – Permits, Social and Corporate Policy and Infrastructure.

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, 2015). 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 reuse of produced water. Such "reuse" includes the beneficial utilization of produced water with or without treatment 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 offsite, non-oilfield applications, such as crop irrigation, wildlife and livestock consumption, industrial process and power generation, is subject to a variety of constraints and risks. Practical considerations for offsite 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 factors (e.g., public perception), and environmental factors (e.g., brine management and the impact of produced water on the environment).

This paper, in conjunction with other IPIECA water management guidance, is intended as a resource for oil and gas operators, policy makers, and other interested parties for investigating opportunities to reuse produced water for a variety of purposes. This 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, shale/tight oil and gas) and addresses the challenges and opportunities for reuse of produced water. Although published information regarding produced water composition and management practices is limited, summary information is provided when 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 facilitated by pumping, push or draw the oil, gas, and formation water towards a well for surface extraction. These pressure and formation conditions may be facilitated 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 low permeability geological formations (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 on Figure 1.

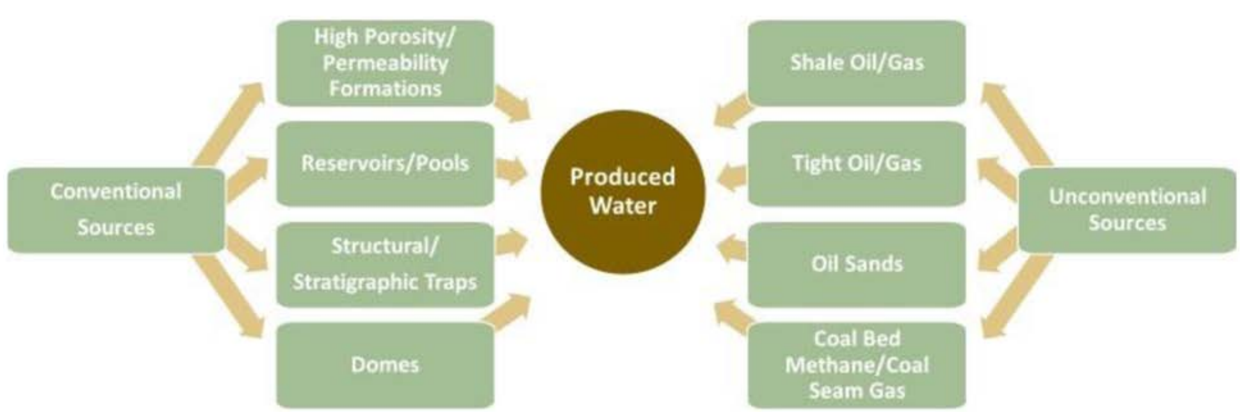

Figure 1—Sources of produced water.

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.

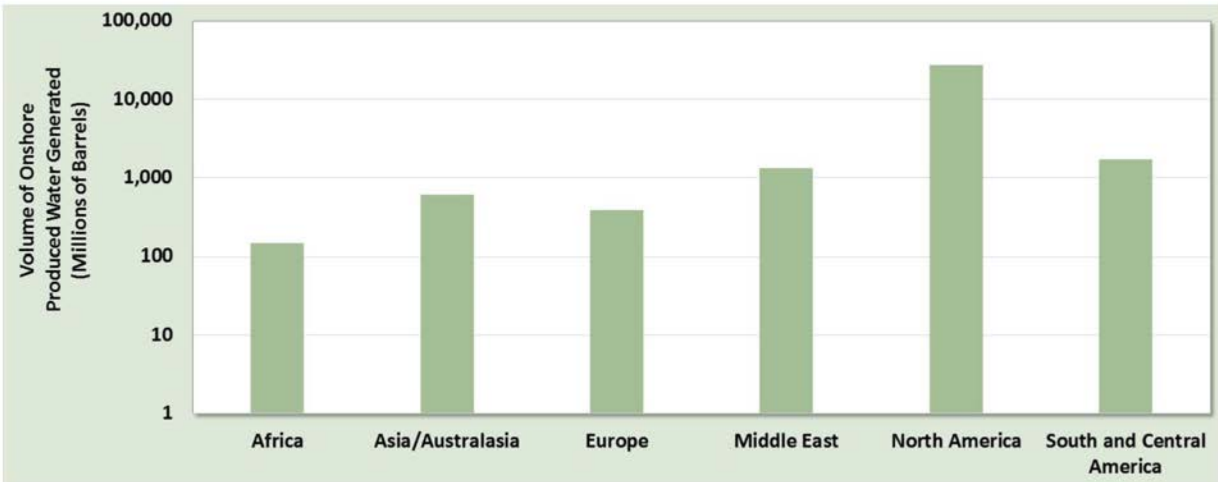

Figure 2—Volume of produced water generated onshore in 2017 in various regions around the world as reported by IOGP members (Data extracted from; IOGP, 2018).

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 (NORM) (e.g., radium), and the additives used in hydrocarbon production (IPIECA, 2018).

Elevated salinity (i.e., high TDS and chloride 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 chloride concentration 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. Figure 3 provides example information on produced water TDS from several North American oilfields. This figure shows the huge range in produced water TDS from different sources. On an international scale, detailed information on produced water composition is limited; however, it is thought to be similarly variable as seen in North America.

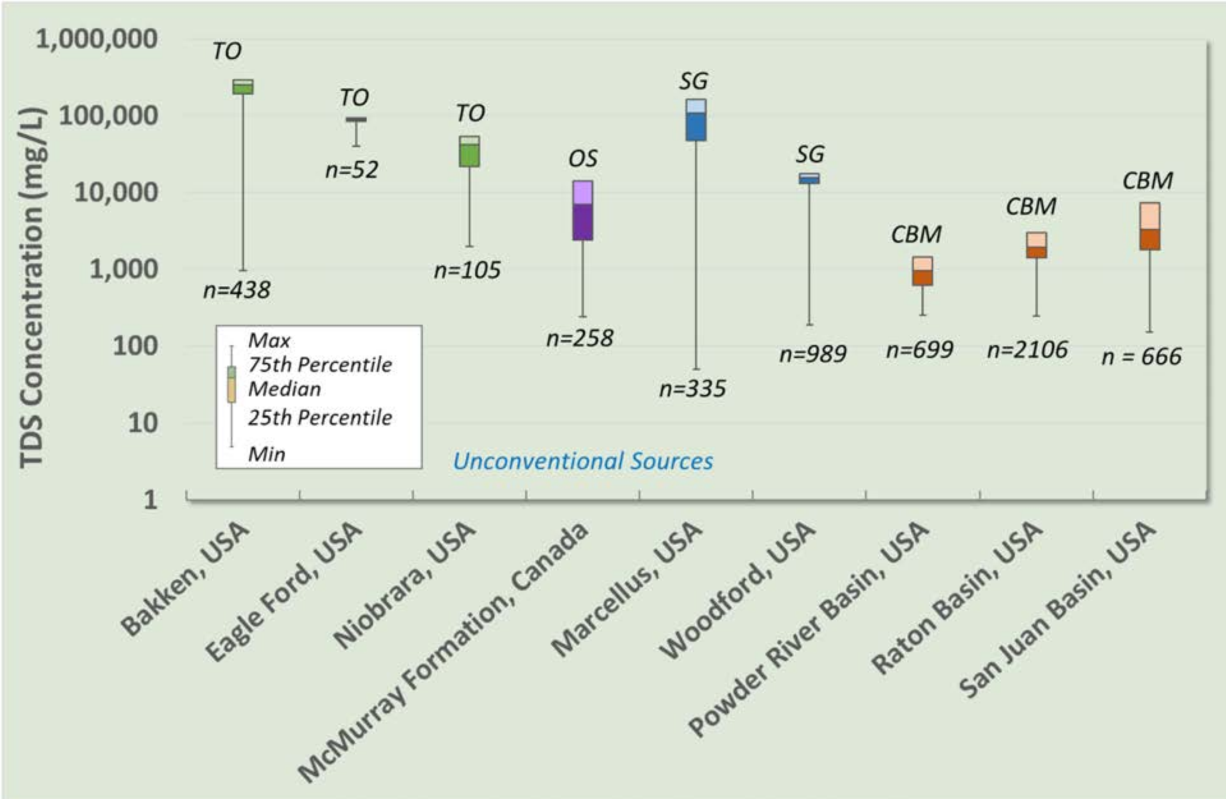

Figure 3—Range of TDS concentrations found in different oil and gas formations.
Notes: TO = Tight Oil, OS = Oil Sands, CH = Conventional Hydrocarbon, SG = Shale Gas, CBM = Coal Bed Methane. (Sources: USA – USGS, 2018; Columbia - Aranguren-Campos et al., 2017; Canada = PTAC, 2007.)

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, environmental impact, water risk, and the technical and economic feasibility of alternatives. In general, effective management of produced water begins with minimizing the volumes of produced water generated from the oil and gas field, by preferentially pumping wells with lower water volumes, adjusting the depths from which oil is pumped in the reservoir, employing downhole separation techniques, or other methods. For the produced water that is nevertheless generated along with oil and gas production, operators commonly manage produced water by one or more of the following methods, in order from 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, or
- Discharge of treated water to the environment, subject to applicable environmental regulations.

To the degree feasible at each location, oil and gas operators recognize the benefits of reusing produced water in their own operations so as to minimize 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. Additional factors are the high cost of water testing and treatment and the potential liabilities associated with uses outside of the oil and gas operation (PTAC, 2007).

Treatment of Produced Water for Reuse

Produced water containing higher levels of dissolved salts, suspended solids, and other constituents may require treatment prior to reuse or even disposal. Treatment technologies applicable to produced water include ion exchange, reverse osmosis, and distillation. 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 waterflooding, drilling, and completions, including hydraulic fracturing. However, reuse of produced water for non-oilfield operations poses a much greater treatment challenge. This is in part due to the naturally elevated salinity of the produced water, which must be reduced to the much lower levels required for uses such as crop irrigation, livestock consumption, and industrial processes.

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 this 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 be costly, entail significant energy consumption, and produce wastes, such as concentrated brines, mineral solids, etc., that in turn require disposal.

Challenges and Opportunities for Reuse of Produced Water

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 may potentially be used in a variety of applications within the oilfield operation, such as water / steam flooding, drilling and completion, including hydraulic fracturing operations or outside the oilfield operations, such as crop irrigation, wildlife and livestock consumption, aquifer storage and recharge, and power generation. However, these non-oilfield uses face a number of challenges that may restrict these beneficial uses, as indicated in Figure 4.

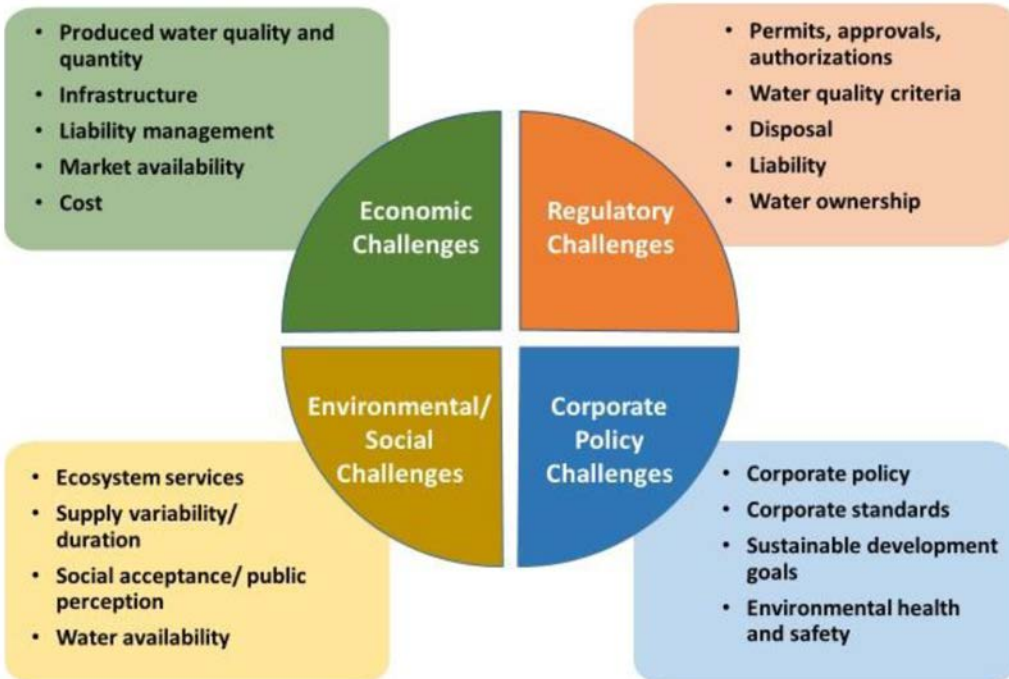

Figure 4—Challenges to reuse of produced water outside of oilfield operations.

Understanding the nature and composition of the produced water source is a first step for assessing the environmental, health, and regulatory issues associated with reuse outside of the 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 reuse of produced water for off-site, non-oilfield applications include restrictions on storage and transport, water quality criteria endpoints and the need to obtain permits, approvals or authorizations from local, regional, and/or national governing authorities. Water ownership can also pose an impediment to reuse for off-site non-oilfield applications 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 must also be considered, such as accidental releases, overflows, leaching or runoff that may pose risks to ecosystems, contamination of industrial or commercial water supplies, problems with respect to water quantity or quality (PTAC, 2007).

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 may be cost 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.

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. Value fluctuations in the oil and gas market and 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 some cases, even when the produced water is treated to meet the applicable water quality standards, the public may have concerns about the reuse of produced water. In addition, the ability of a possible short-term produced water supply to meet long-term community water needs and expectations must be considered.

The feasibility of produced water reuse at any given site is a site-specific determination, considering the various factors identified above. Examples of the successful reuse of produced water for oilfield and non-oilfield applications include those highlighted below. These examples represent only a small set of the many 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 the oil and gas operation. Onsite water reuse technologies allow the oil and gas industry to reduce water demand and supplement limited water supplies (Dahm, 2014). Improvements to the state and local permitting process can encourage greater reuse, as well as water sharing among operators (CDR, 2014). Examples of successful reuse applications for specific locations and operations are highlighted below.

1. Reuse for Drilling and Completion, USA: 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 operating costs associated with water management and disposal (USEIA, 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).
2. Reuse for Hydraulic Fracturing, Canada: Tourmaline Oil Corp. received regulatory approval to construct and store produced water in an 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).
3. Reuse for Mining of Oil Sands, Canada: Many oil sands operators, including members of the Canada Oil Sands Innovation Alliance (COSIA), have developed new treatment technologies to reuse 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 (Alberta Innovates, 2017).

Examples of Produced Water Reuse Outside of the Oil and Gas Industry. Constraints to non-oilfield use of produced water include those identified in Figure 4 as well as site-specific considerations of timing, reliability, quantity, variable water quality of produced water, and costs required to treat the water to levels required by other users (CDR, 2014). Some examples of successful reuse of produced water outside of the oil and gas industry are presented below.

1. Irrigation Use, Australia and USA: For oil and gas formations that contain water with exceptionally low salinity, the treated produced water may be used as irrigation water after appropriate treatment, particularly for salt-tolerant crops.

   Irrigation Reuse, USA: appropriately treated produced water from certain fields in Kern County California, which has low-salinity (TDS ~750mg/L), is blended with other fresh water sources and is used as irrigation water by local water districts.

   Irrigation Reuse, Australia: Moderately saline (TDS: 5,000 mg/L) produced water from CBM operations was 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).
2. Agriculture and Reduced Power Consumption, Oman: Following oil-water separation, produced water with moderate salinity (TDS: 7,000-8,000 mg/L) may be placed in constructed wetlands to undergo natural treatment and enhance wildlife habitat. Similar to constructed wetlands, reed beds are

also used to remove pollutants from produced water and have the potential to make water available for use by local communities. Since 2010, Petroleum Development Oman and Shell have operated a commercial water treatment plant that uses salt-tolerant reed beds for treating residual oil in produced water from the Nimr oilfield in Oman. This project has allowed produced water to be reused for agriculture in an area where freshwater supply is scarce, and has reduced the power consumption and carbon dioxide emissions associated with deep well disposal equipment (IUCN/IWA, 2015;.

3. Livestock and Wildlife Watering, USA: Produced water with low concentrations of salt and hydrocarbons, such as water from coal bed methane (CBM) or coal seam gas (CSG) operations, has been used for wildlife and livestock watering. Salinity tolerance varies among animal species. In the USA, the State of Wyoming allows low-salinity produced water (TDS < 5,000 mg/L and Cl < 2,000 mg/L) from CBM operations to be discharged into surface waters for beneficial use by livestock and wildlife, subject to permit requirements, and wetland habitat development (USFWS, 2002).
4. Electrical Power Industry, Australia: Treated produced water may supplement cooling water feed or other power industry uses, depending on specific water quality needs of each facility. Raw produced water from CSG operations in Australia's Surat Basin is drawn and treated onsite for cooling and steam production at a power station located near Chinchilla (ANWC, 2011).
5. Other Industrial / Commercial Uses, Australia: Produced water can be used for a variety of purposes, such as vehicle washing, firefighting, road dust control, or equipment deicing, subject to proper control of runoff and protection of water bodies. For example, Arrow Energy in Australia provides untreated CSG produced water 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 produced water supply and disposal. In certain conditions, 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 interest in reuse of produced water outside of oil and gas operations which will require careful consideration of the potential challenges and benefits on a case-by-case basis.

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, 2015).
Recycled water	Used water / waste water employed through another process cycle after treatment (IPIECA, 2014b).
Reuse	Water that has been employed through another process cycle with no or minimal treatment, before discharge for final treatment and/or discharge to the environment (IPIECA, 2014b).
Unconventional	Extraction of hydrocarbon resources with low mobility and/or present in low permeability geological formations. Includes oil sands, shale / tight oil and gas, and coal bed methane (IPIECA, 2014a).
Water Flood	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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