

# World Petroleum Council Guide

---

## Water Management

---



[www.world-petroleum.org](http://www.world-petroleum.org)



# Proceedings of the 21st World Petroleum Congress

15 - 19 June 2014, Moscow, Russia



## *Responsibly energising a growing world*

Published in an easy to reference, easy to search electronic format on a handy USB stick, the official 21st WPC proceedings includes content from the 100+ sessions held as part of the WPC event in Moscow. The 21st WPC Proceedings provides an extensive record of the event, including papers and presentations from:

- Plenaries and special addresses
- Best practice keynote sessions
- Forum papers and posters
- Round tables
- Special sessions
- Opening and closing ceremonies

Photos, videos and official publications produced for the Congress are also included.

Jan 2015 ISBN 978 0 85293 698 6

**Full price £750.00\***

\*UK VAT rates will apply to this item



World Petroleum Council

## Order

Online at  
[www.energypublishing.org](http://www.energypublishing.org)

**By email, phone or post**, contact  
Turpin Distribution  
Pegasus Drive, Stratton Business Park  
Biggleswade  
Bedfordshire  
SG18 8TQ, UK  
t: +44 (0)1767 604 951  
e: [energyinst@turpin-distribution.com](mailto:energyinst@turpin-distribution.com)

Published by



# World Petroleum Council Guide

---

## Water Management

---

Published by International Systems and Communications Limited (ISC)  
in conjunction with the World Petroleum Council (WPC).

Copyright © 2015. The entire content of this publication is protected by copyright, full details of which are available from the publisher. All rights reserved. No part of this publication may be reproduced, stored in retrieval systems or transmitted in any form or by any means – electronic, mechanical, photocopying, recording or otherwise – without the prior permission of the copyright owner.



World Petroleum Council  
Fourth Floor, Suite 1  
1 Duchess Street  
London W1W 6AN  
England

Telephone: + 44 20 7637 4958  
Facsimile: + 44 20 7637 4973  
E-mail: [info@world-petroleum.org](mailto:info@world-petroleum.org)  
Website: [www.world-petroleum.org](http://www.world-petroleum.org)



International Systems and  
Communications Limited  
140 Tachbrook Street  
London SW1V 2NE  
England

Telephone: + 44 20 7901 3830  
Facsimile: + 44 20 7901 3838  
E-mail: [general@isiscom.com](mailto:general@isiscom.com)  
Website: [www.isiscom.com](http://www.isiscom.com)

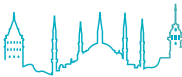
www  
**22WPC**  
com



**istanbul**  
22<sup>nd</sup> WORLD  
PETROLEUM  
CONGRESS

09 - 13 July **2017**

**BRIDGES**  
to our  
**ENERGY**  
*Future*



HOST SPONSOR



**TURKISH PETROLEUM**

60 YEARS OF EXPERIENCE

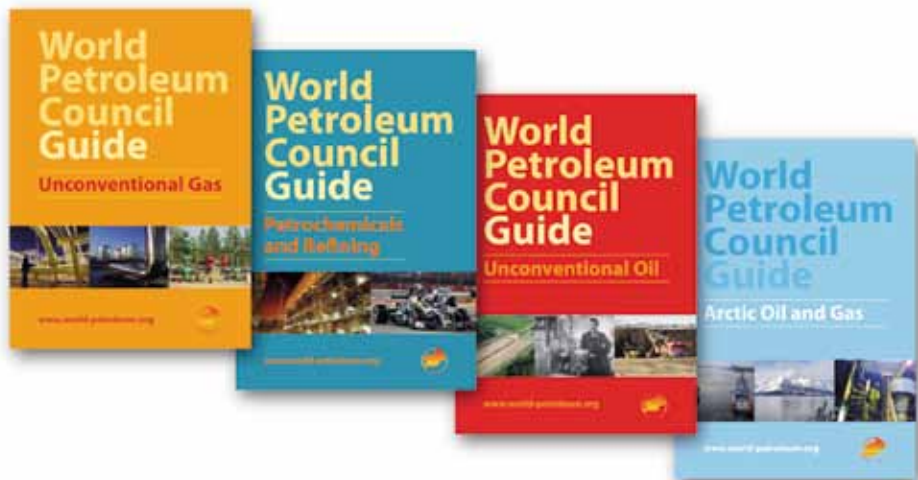


# Contents

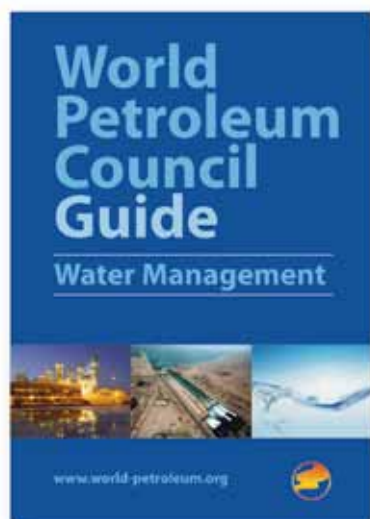
|  |           |   |           |
|--|-----------|---|-----------|
| <b>Message from the Director General</b>                           | <b>5</b>  |   |           |
| <b>WPC Vision, Mission and Values</b>                              | <b>6</b>  |   |           |
| <b>WPC overview</b>  | <b>8</b>  |   |           |
| <b>Introduction to water management for oil and gas operations</b> | <b>14</b> |   |           |
| <i>By Ruth Romer and Jennifer Yau, IPIECA</i>                      |           |   |           |
| <b>Efficient use of water for oil and gas operators</b>            | <b>18</b> |   |           |
| Water management for petroleum refineries                          | 22        |   |           |
| <i>By Mudumbai Venkatesh and Rob Cox</i>                           |           |   |           |
| Case study: Waterflooding and oil recovery                         | 27        |   |           |
| <i>By Dr Ali Yousef, Salah Al Saleh and Mohammed Al-Jawfi</i>      |           |   |           |
| Case study: National Iranian Oil Company                           | 28        |   |           |
| <i>By Mrs Samaneh Ashoori</i>                                      |           |   |           |
| <b>Advanced technologies for water management</b>                  | <b>30</b> |   |           |
| <i>By Georgia Lewis</i>  |           |   |           |
| <b>Water management for unconventional</b>                         | <b>36</b> |   |           |
| Water management for unconventional oil and gas                    | 36        |   |           |
| <i>By Marcus Oliver Gay and Andrew Slaughter</i>                   |           |   |           |
| Water use in shale gas development                                 | 40        |   |           |
| <i>By Melissa Stark</i>  |           |   |           |
|  |           | Water management technology for hydraulic fracturing projects | 46        |
|  |           | <i>By Dr Katharina Gruenberg</i>                              |           |
|  |           | <b>Water management for LNG, FLNG and GTL projects</b>        | <b>48</b> |
|  |           | Water management for LNG projects                             | 48        |
|  |           | <i>By Georg Oftedal</i>                                       |           |
|  |           | CSG-to-LNG water management case study                        | 50        |
|  |           | Water management for FLNG                                     | 51        |
|  |           | <i>By Vijay Anne</i>  |           |
|  |           | GTL water management case study                               | 55        |
|  |           | <b>Produced water, storage, treatment and disposal</b>        | <b>56</b> |
|  |           | <i>By Dr Abdulkareem M AlSofi</i>                             |           |
|  |           | <b>Water management for Arctic operators</b>                  | <b>62</b> |
|  |           | <i>By Georgia Lewis</i>                                       |           |
|  |           | <b>Environmentally responsible water management</b>           | <b>70</b> |
|  |           | <i>By Tamar Gomez</i>   |           |
|  |           | Glossary of terms   | 76        |
|  |           | Acknowledgements  | 80        |

The opinions and views expressed by the authors in this book are not necessarily those of WPC, its members or the publisher. While every care has been taken in the preparation of this book, they are not responsible for the opinions or any inaccuracies in the articles.

Unless otherwise stated, the dollar (\$) values given in the book refer to the US dollar.



## A GROWING SOURCE OF REFERENCE



*The World Petroleum Council Guide to Water Management* is the latest in a special series of twice yearly publications being produced by WPC to act as a definitive source of reference on the most pressing matters affecting global energy markets.

Building on the four previous titles looking at unconventional gas, petrochemicals and refining, unconventional oil and Arctic oil and gas, WPC is fulfilling its mission to raise awareness and enhance the understanding of the issues and challenges facing the industry in the years ahead.

Published by award-winning International Systems and Communications in both print and digital formats, all titles in the series can be viewed online via the following link:

[is.gd/wpcguides](https://is.gd/wpcguides).



# Message from the Director General

This WPC guide examines the water management challenges facing oil and gas operators around the world.



Dr Pierce Riemer, Director General, World Petroleum Council.

This is the fifth guidebook in the World Petroleum Council's Education Series on the energy industry and we are very proud of what we have achieved so far – the books have met with a great response and demand has been high for both the printed and online versions. We are confident this will continue with this latest book on water management for oil and gas operations.

In a world where oil and gas activities are under pressure to ensure all activities are conducted sustainably and responsibly as well as being economically viable, it is essential that water management is a top priority. Achieving best practice in water management is a challenge, but one that we are confident can be met with the right investment, skills, information and support from all stakeholders.

Along with an increased awareness of the importance of water management for oil and gas projects, the technologies that help achieve this have improved. The oil and gas industries have been leaders in this field and this book outlines the technological advances that are helping us go from strength to strength with reusing and recycling water, minimising wastage, and protecting the environment.

We have gathered global experts to contribute to this book, sharing their expertise. This book covers different uses of water in hydrocarbon projects, discusses how water can be used as efficiently as possible, and examines important environmental and social considerations needed for responsible, sustainable development that benefits communities and companies. Additionally, we examine the unique water management challenges for operators working in the tough conditions of areas such as the arctic.

Once again, we are proud to include case studies from major companies to show how excellent water management is achievable, cost-effective and an important part of responsible operations. The Education Series is committed to providing practical information in a clear, easy-to-read format and the case studies play an important role in achieving this and demonstrating best practice for our readers.

We are confident this latest guidebook in our Education Series continues the fine work of the previous editions. Water management is a big issue for the oil and gas industry and we hope you find this book to be a useful resource that will join the other books in this growing and popular collection.





# WPC Vision, Mission and Values

The World Petroleum Council (WPC) is a non-advocacy, non-political organisation with charitable status in the UK and has accreditation as a Non-Governmental Organisation (NGO) from the United Nations (UN). WPC is dedicated to the promotion of sustainable management and use of the world's petroleum resources for the benefit for all.

WPC conducts the triennial World Petroleum Congress, covering all aspects of the industry, including management of the industry and its social, economic and environmental impact.

## Vision

An enhanced understanding and image of the oil and gas sector's contribution to sustainable development.

## Mission

The World Petroleum Council is the only

organisation representing the global oil and gas community. WPC's core value and purpose centres on sustaining and improving the lives of people around the world through:

- Enhanced understanding of issues and challenges
- Networking opportunities in a global forum
- Cooperation (partnerships) with other organisations
- An opportunity to showcase the industry and demonstrate best practice
- A forum for developing business opportunities
- Information dissemination via congresses, reports, regional meetings and workshops
- Initiatives for recruiting and retaining expertise and skills to the industry
- Awareness of environmental issues, conservation of energy and sustainable solutions

## Values

WPC values strongly:

- Respect for individuals and cultures worldwide
- Unbiased and objective views
- Integrity
- Transparency
- Good governance
- A positive perception of energy from petroleum







- Science and technology
- The views of all stakeholders
- The management of the world's petroleum resources for the benefit of all

### Key strategic areas

- **World Class Congress** to deliver a quality, premier oil and gas congress.
- **Inter-congress activities** to organise forums for cooperation and other activities on specific topics; and to organise regional events of relevance to WPC members and all stakeholders.
- **Cooperation with other stakeholders** to add value by cooperating with other organisations to seek synergies and promote best practice.
- **Communication** to increase awareness of WPC's activities, through enhanced communication, both internally and externally.
- **Global representation** to attract and retain worldwide involvement in WPC.
- **Youth and gender** engagement to increase the participation of young people and women in oil and gas issues, including the establishment of a dedicated Youth Committee for the development of active networking opportunities with young people.
- **Legacy** to manage a central WPC legacy fund to benefit communities and individuals around the world based on WPC's mission.

### World Petroleum Congresses

#### 2017 22nd WPC Istanbul

|      |          |              |      |          |             |
|------|----------|--------------|------|----------|-------------|
| 2014 | 21st WPC | Moscow       | 1979 | 10th WPC | Bucharest   |
| 2011 | 20th WPC | Doha         | 1975 | 9th WPC  | Tokyo       |
| 2008 | 19th WPC | Madrid       | 1971 | 8th WPC  | Moscow      |
| 2005 | 18th WPC | Johannesburg | 1967 | 7th WPC  | Mexico City |
| 2002 | 17th WPC | Rio          | 1963 | 6th WPC  | Frankfurt   |
| 2000 | 16th WPC | Calgary      | 1959 | 5th WPC  | New York    |
| 1997 | 15th WPC | Beijing      | 1955 | 4th WPC  | Rome        |
| 1994 | 14th WPC | Stavanger    | 1951 | 3rd WPC  | The Hague   |
| 1991 | 13th WPC | Buenos Aires | 1937 | 2nd WPC  | Paris       |
| 1987 | 12th WPC | Houston      | 1933 | 1st WPC  | London      |
| 1983 | 11th WPC | London       |      |          |             |



## WPC overview

Since 1933, the World Petroleum Council (WPC) has been the world's premier oil and gas forum and is the only international organisation representing all aspects of the petroleum sector.

World Petroleum Council was established in 1933 to promote the management of the world's petroleum resources for the benefit of all. It is a non-advocacy, non-political organisation and has received accreditation as a non-governmental organisation (NGO) from the UN. WPC's prime function is to catalyse and facilitate dialogue among stakeholders, both internal and external to the petroleum industry, on key technical, social, environmental and management issues in order to contribute towards finding solutions to those issues.

Headquartered in London, WPC includes 70 member countries from around the world representing more than 95% of global oil and gas production and consumption. WPC membership is unique, as it includes both OPEC and non-OPEC countries with high-level representation from National Oil Companies (NOCs) as well as International Oil Companies (IOCs). Each country has a national committee made up of representatives of the oil and gas industry, the service sector, academia, research institutions and government departments. The governing body of WPC is the Council consisting of representation from each of the national committees. Its global

membership elects the President and an Executive Committee every three years to develop and execute its strategy. The Council also selects the host country for the next World Petroleum Congress from the candidate countries.

Every three years, the Council organises the World Petroleum Congress hosted by one of its member countries. The triennial Congress is also known as the "Olympics of the petroleum industry". It covers all aspects of oil and gas from technological advances in conventional and unconventional upstream and downstream operations to the role of natural gas and renewables, management of the industry and its social, economic and environmental impact. In addition to industry leaders and experts, outside stakeholders such as governments, other industry sectors, NGOs and international institutions also join the dialogue. To ensure the scientific and topical quality of the event, the WPC Council elects a Congress Programme Committee whose members are responsible for delivering the high-level content for these events.

Istanbul will be the host of the 22nd World Petroleum Congress in 2017 ([www.22wpc.com](http://www.22wpc.com)).

Beyond the triennial Congress, the World Petroleum Council is regularly involved with a number of other meetings such as the WPC Youth Forum, the WPC-UN Global Compact Best Practice Forum, joint WPC/OPEC workshops and other regional and topical events on important industry issues. For 2015 a new event has been added to the WPC programme and the Norwegian National Committee will host the first WPC Leadership Conference on Responsibility, Cooperation & Sustainability in Tromsø.

### Legacy

As a not-for-profit organisation, WPC ensures that any surpluses from the triennial Congresses and other meetings are directed into educational or charitable activities, thereby leaving a legacy. The World Petroleum Council has set up a dedicated

WPC Legacy Fund to spread the benefits beyond the host countries and its members and alleviate energy poverty through carefully selected projects.

The concept of leaving a legacy in the host country started in 1994 with the 14th World Petroleum Congress in Stavanger, Norway. After this Congress, the surplus funds were put towards the creation and building of a state-of-the-art Petroleum Museum in Stavanger.

The 15th World Petroleum Congress in Beijing adopted the issue of young people as a key aspect of its theme: "Technology and Globalisation – Leading the Petroleum Industry into the 21st Century". To support the education and future involvement of young people in the petroleum industry, the Chinese National Committee donated all computer and video equipment used for the Congress to its Petroleum University.

Profits from the 16th Congress in Calgary were used to endow a fund that gives scholarships to post-secondary students in several petroleum-

related fields. The Canadian Government Millennium Scholarship Foundation matched the amount dollar-for-dollar, creating an endowment which supported more than 2,000 students until its conclusion in 2010.

The 17th World Petroleum Congress was the first to integrate the concept of sustainability throughout its event, taking responsibility for all waste it generated. The Congress and the Rio Oil & Gas Expo 2002 generated 16 tonnes of recyclable waste – plastic, aluminium, paper and glass. All proceeds of the recycling activities were passed on to a residents' cooperative with 6,000 inhabitants located in the port area of Rio de Janeiro.

But the sustainability efforts did not stop there – an army of 250 volunteers collected 36 tonnes of rubbish in 10 days in a special community effort to clean up the Corcovado area before the Congress, donating all proceeds to the rubbish collectors, some of the poorest inhabitants of Rio. The Finlândia Public School also received a new



Social Responsibility Global Village at the recent 21st World Petroleum Congress in Moscow: Interactive World CSR Map



The WPC legacy initiative started in 1994 when surplus funds from the 14th World Petroleum Congress were put towards the building of Stavanger's Petroleum Museum.

lick of paint from our volunteers. The surplus funds for the Congress were used to set up the WPC Educational Fund in Brazil, which was further increased in 2005 with tax initiatives added by the Brazilian government.

The 18th World Petroleum Congress also chose a sustainability focus for the first-ever WPC to be held in Africa: "Shaping the Energy Future: Partners in Sustainable Solutions". Education was the focus of the 18th World Petroleum Congress Legacy Trust, set up by the South African National Committee to provide financial assistance to needy young South Africans who wish to pursue a qualification in petroleum studies.

In 2008, with the 19th Congress in Madrid, the trend continued and the organisers selected a number of projects and foundations to receive the surplus from the event for charitable and educational programmes in Spain and around the globe. The 19th Congress was the first one to offset all its carbon emissions and receive a certification as a sustainable event.

Qatar's 20th Congress also offset all of its carbon emissions and is establishing a gallery devoted exclusively to the country's oil and gas industry as an integral part of the future National Museum of Qatar (NMoQ). This gallery dedicated to the story of oil and gas in Qatar, will educate



WPC's first Youth Forum was held in Beijing in 2004.

Qataris and residents about the history of Qatar and the way the oil discovery shaped the nation since 1940, and in accordance with the legacy policy of the Congress will provide a project that serves the community.

Additionally the recent 21st Congress held in Moscow will develop a legacy trust which focuses on assisting with educational opportunities for students and young professionals, with a special interest in the petroleum sector.

### Youth outreach

Youth is a critical factor in the sustainability of the oil and gas industry. Addressing and involving young people in the design of future energy solutions is therefore one of the major issues for WPC's 70 member countries. WPC recognises their significance to the future of the petroleum industry and the importance of giving the young

generation scope to develop their own ideas, talents and competencies to create viable solutions for the future of our world.

As part of its outreach to recruit and retain the next generation, WPC created its Youth Committee in 2006 to provide a channel through which young people have a direct involvement and say in the strategy and activities of the organisation. It aims to create and nurture a collaborative, global forum for young people to be heard, to champion new ideas within the petroleum industry, to promote a realistic image of the petroleum industry, its challenges and opportunities and to bridge the generation gap through mentorship networks.

In 2011, WPC launched a pilot Mentorship Programme to provide a bridge between international experts and the next generation of our industry. This programme is now in its third successful cycle and has already created 150 matches.









# Introduction to water management for oil and gas operations

*By Ruth Romer and Jennifer Yau*

Water plays an important role across oil and gas operations globally.

Water sustains life on earth. It is essential to the healthy functioning of all ecosystems and the services they provide. For the oil and gas industry, fresh and saline water are used throughout the project lifecycle in many of the core activities from production to manufacturing. Therefore, the oil and gas industry can be a significant user of water



Water management must encompass environmental and social impacts as well as the needs of industry.

at the local and regional scale and may require access to significant quantities of water. The demand for water is likely to increase from global and local pressures such as climate change and population growth. As such, the ability of upstream and downstream sectors to efficiently manage this water usage via good practice management and efficiency is a priority.

Effective water management requires the identification, assessment and subsequent management of potential water risks, continuous improvement within local areas such as river catchments and aquifer basins, whilst also understanding the needs of other water users within a river basin. IPIECA's water management framework (see *break out box*), developed for oil and gas companies, recognises other important considerations to cover when working toward effective water management. These include the principles of water stewardship from the Alliance for Water Stewardship ([www.allianceforwaterstewardship.org](http://www.allianceforwaterstewardship.org)), integrated water resources management by the Global Water Partnership and stakeholder engagement.

## Water sources and efficiency

There are a number of water sources available, ranging from freshwater and brackish aquifers to marine desalination plants, wastewater and produced water. Unlike typical water sources, produced water occurs when trapped water within pore spaces is collected alongside hydrocarbons during the extraction process. This is a useful water source, which may be saturated with hydrocarbons and other chemical substances and therefore requires treatment before it is discharged to the environment, recycled back into the operations or disposed of into deep, non-fresh water formations.

With many sources available, identifying what quality and quantity of water is required is an important feasibility aspect during project initiation. Identification helps to define the information required to determine the viability of the water





source options, as well as developing a clearer scope for the project.

To provide an initial high-level understanding, general physical, social and legislative knowledge and concerns of the area, along with local data and experience, are all required. Additionally, to help identify, analyse and prioritise social concerns linked to water use impacts on river basins, it is good practice to consider stakeholder and regulatory engagement and consultation through the entire operation's lifecycle.

The oil and gas industry can sometimes play a dual role in water resource management by reducing the impact of its operations, and contributing to the communities where it operates. To this end, encouraging collective action through developing relationships, communicating plans and acting on stakeholder concerns could help to manage catchments and local areas, whilst sharing common risks, strategies and solutions.

To encourage a more systematic way of managing water usage efficiently, hence reducing the impacts of operations and protecting the environment, the conceptual "waste hierarchy" attempts to identify activities and processes in which water used can be reduced, reused and/or recycled. The water efficiency hierarchy is summarised as follows:

- **Reduce** Lowering the consumptive use of a process or activity.
- **Replace** Removal of the need for, or partial or full substitution of, fresh water by a different resource.
- **Re-use** Use of water for the same or alternative process without treatment, or with minimal treatment.
- **Recycle** Bringing water back into use through treatment to improve water quality.

To help develop a clearer way of defining water requirements and usage in projects, the quantity used can be calculated using withdrawal, consumption and discharge flows in operations. When water is withdrawn from a source for oil and gas

operations, it is only classed as consumption when the withdrawn water is not returned back to the environment in which it was sourced, as shown in *Figure 1*. Water withdrawals and discharges are undertaken according to local regulations.

### Common water uses and returns

To help identify viable and suitable water sources, it is important to understand the quality and quantity of water required for the various processes. Although there are many processes involved in the extraction of different fossil fuel sources, there are a number of common water uses that are common across the industry. This is elaborated on further in the "Efficient use of water" chapter.

In summary, personnel, construction and commissioning, drilling and well completion, process and operations, and produced water are the most common uses for water in hydrocarbons operations.

Potable water is required for personnel usage, such as drinking, laundry, cleaning and heating. For construction and commissioning, the quality and quantity of water required varies according to the activity. Often, water is lost to the environment in these activities but there is scope for recapture in many instances. Responsible treatment and disposal is an important consideration for operators across the whole process.

The drilling and well completion process typically requires fresh water, although appropriately treated water can be used in many instances. Treat-

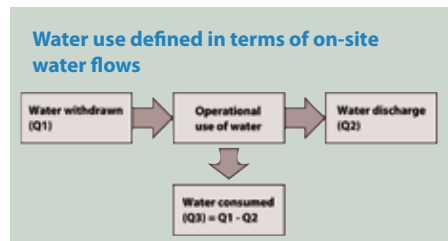


Figure 1.





ment and/or containment of contaminated water are additional requirements for many operators.

At the process and operations stage, the majority of water usage occurs in the refining process. Steam generation and machinery cooling are two processes in particular that consume large quantities of water. There is scope for further treatment for water reuse or safe discharge in many projects too.

### Water use for conventional and unconventional sources

Factors including the type and size of the hydrocarbon resource, the existing infrastructure and geological conditions will affect the volumes of water required and the measures needed to improve water use. For example, water uses depend on the extraction process, which can typically be separated into conventional and unconventional sources. Conventional sources are those reservoirs, either onshore or offshore, where resources can flow relatively easily to the extraction point. However, unconventional sources cannot be exploited economically by conventional means because the resources are more difficult to extract, requiring more advanced extraction technologies such as horizontal drilling and hydraulic fracturing.

#### Conventional

During the primary production stages, the pressures and formation conditions within conventional reservoirs mean that hydrocarbons flow freely to the surface.

Gas in reservoirs naturally expands and flows up the production well with very little water recovered. Water is mainly used for gas processing to remove impurities and to liquefy for export. The quantity of water required may increase as the production matures from the increasing number of impurities. A mixture of fresh and saline water is utilised for various processes.

For oil, however, when the recovery process matures, additional pressures from the injection

of extra fluids or gases are required to sustain economic rates of hydrocarbon recovery. Although some of the injected water can be reused to maintain the pressure after the resource is recovered, additional water may still be needed to stabilise the well pressure. Typically saline water and produced water can be used, provided that they have been sufficiently treated. To prolong the life of a reservoir or maximise product recovery, tertiary recovery or enhanced oil recovery methods are used to alter the fluid properties. This helps displace or dislodge the hydrocarbon from the formation. Techniques commonly employed include: thermal recovery, chemical flooding and miscible injection, with the former two often requiring fresh water.

Throughout primary, secondary and tertiary stages, the volume of produced water rises. This water is treated for re-use as a reinjection fluid for pressure maintenance, reinjected into saline water formations for disposal, or discharged to surface water under appropriate permits.

#### Unconventional

Unconventional resources are typically hydrocarbons with low mobility and/or present in low permeable geological formations and are drilled with a horizontal and vertical component, with typical sources being oil sands and shale oil (also known as tight oil) and gas.

Oil sands can be extracted through open-pit mining or in-situ recovery. Both forms of extraction require water to be used in separating the bitumen by mixing or steam stimulation, cooling of equipment and other processes to enable easier extraction of oil. Mining operations typically require water of slightly brackish quality, whereas steam generation for in-situ recovery requires water to be treated to specific requirements.

Shale oil and gas operations require the use of hydraulic fracturing systems that use fluids such as water or oil in a combination with other gases

or liquids to stimulate the resource to the extraction point. The quantity and quality of water required depends on the subsurface conditions, the type of well (vertical or horizontal) and the type of hydraulic fracturing liquid employed. Flowback water, which returns following hydraulic fracturing, is typically mixed with produced water and other fracturing fluids. This is then treated for either disposal via injection wells,

recycling for drilling and hydraulic fracturing or for discharge back to the environment, again under appropriate permits.

*Ruth Romer is Senior Manager, Biodiversity and Ecosystem Services and Water with IPIECA in the United Kingdom.*

*Jennifer Yau is Coordinator Environment with IPIECA in the United Kingdom.*

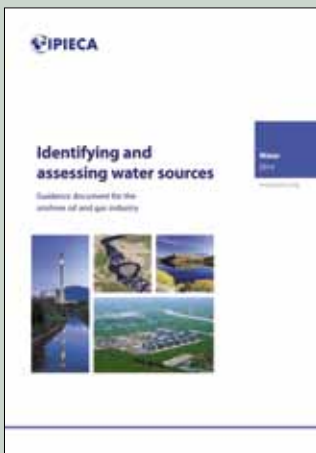
### Further reading

To encourage proactive and collective management of issues related to the risks and opportunities of water use, IPIECA has developed a Water Management Framework for onshore oil and gas activities. This was developed by oil and gas member companies to provide high level guidance to help companies develop their own company-specific water strategies, enhance the industry's efforts to achieve sustainable water use and respond to broader global concerns about water availability, quality and management. Two complimentary documents have also been published: "Identifying and Assessing Water Sources" and "Efficiency in Water Use". IPIECA has developed customised oil and gas risk assessment

tools, such as the IPIECA Global Water Tool, to help companies map their water uses and assess risks for their overall global portfolio of sites.

IPIECA will continue to facilitate the development of useful tools and guidance documents to encourage efficient and sustainable management of water through workshops and member-lead tasks forces within the association. As many of the water risks are common across industries, IPIECA will also continue to encourage collective action and participation in the development of a long-term vision for water stewardship. Case-studies of good practices can be found on the IPIECA website.

[www.IPIECA.org](http://www.IPIECA.org)



# Efficient use of water for oil and gas operators

Water management is an ongoing challenge for hydrocarbons facilities at every stage of the process.

Before identifying water efficiency opportunities, an operation's water uses and return flows (water that has either been used and is returned to the system, effluent, or a by-product of the process) should be understood. The type of hydrocarbon resource being developed and the maturity of the development will determine how water is used and managed, the requirements for water quality, and the scope for water efficiency within the operation.

## Common water uses for hydrocarbons operations

● **Personnel** The workforces involved in exploration, construction, drilling and operating a facility require water for drinking, cooking, personal hygiene, laundry, toilet-flushing, cleaning facilities, air-conditioning, ventilation and heating. The quantity of water required to fulfil these functions varies according to the environmental setting, but is typically between 180 and 300 litres per person per day. Potable water is generally required to meet these functions due to the consumptive element.

The return water associated with personnel supply are wastewaters, such as sewage effluent

(black water) and grey water from hand basins, showers, baths, laundries and kitchens. The composition, and hence the quality, of the black or grey water can vary according to the environmental setting, which may alter due to different diets and chemical usage. The quantity of return water will also vary in different environmental settings.

● **Construction and commissioning** The typical uses of water in the construction phase of a hydrocarbons project include dust suppression, vehicle-washing, road preparation, concrete mixing, hydrotesting of pipelines and pipework and, for some operations in extremely cold climates, the creation of snow and ice for roads, bridges and well pads (See Arctic, from p62). The quantity of water required depends on the size of the operation's facilities and the scale of the resource. The quality of the water needed varies from slightly brackish to fresh water, depending on the task.

Water used in construction is often lost to the environment or bound within the product, such as water used for concrete. This limits the generation of return water. Water used for hydrotesting becomes return water once it has passed through pipework because the quality is altered by chemicals and other contaminants.

● **Drilling and well completion** Drilling and completing an exploration or production well requires water for drilling mud, well-development, well completions and rig maintenance. The quality and quantity of water needed depends on the length of drilling and shallow geological conditions. These requirements can change within a single well at different stages of the drilling process, although typically fresh water is required.

Mud, including return water, from the drilling process is captured in mudpits or tanks. It contains additives to aid the drilling process, as well as drill cuttings which come to the surface in the return



water. Once cuttings are removed, the mud is usually recirculated until the well has reached its target depth.

● **Process and operations** Water is used for upstream processing of produced hydrocarbon streams before export. For example, it is used in desalters to strip out soluble contaminants from the product stream, within process pump seals, for cooling water, and for steam generation in turbines. At many sites, a large volume of water is used for steam generation and cooling, as well as utility water, such as fire water.

Return water flows commonly encountered from the processing stages include hydrocarbon dew-

point condensation, blow-down water and condenser water from boilers, along with cooling water, which can be recirculated.

● **Produced water** Water trapped within the pore spaces of rocks when they are formed is referred to as connate water. Produced water is the term used to describe this water when it is extracted at the same time as the oil or gas.

Produced water is normally saline and of a high temperature because of its long residence time in the rocks, and its depth. This water may be saturated with hydrocarbons in either free or dissolved phase, and may contain chemicals used in the extraction process.



A foam pig being sent down a pipeline as part of hydrotesting.





Water has a many uses in conventional gas processing operations.

### Conventional oil and gas production

A conventional hydrocarbon reservoir undergoes several phases of recovery. In the primary production stage, natural mechanisms, such as formation pressure, result in the movement of the resource within a reservoir to the extraction point as it is forced to the surface. This requires minimal extra production support and minimal water use beyond that used for well drilling and support of the workforce.

As the recovery process matures, the formation pressure decreases and it becomes insufficient for hydrocarbon recovery. Additional methods, known as secondary or tertiary recovery, are required with reservoir pressures and fluid mobility being manipulated to bring oil or gas to the surface.

● **Conventional oil production** There is usually enough natural pressure at the primary recovery

stage for conventional oil but the reservoir pressure lowers as a result of production, so the secondary stages require the injection of external fluids to maintain the pressure and displace the oil so it moves towards the production well.

Secondary recovery methods involve the injection of gas into the pore space of the reservoir and/or water, usually into the production zone, known as waterflood. As the production process matures, greater injection rates are required to recover the oil and, particularly in the case of waterflood, the amount of water produced at the production well increases.

The ratio of water to resource recovered, known as the water cut, may range from 1:1 in the early stages of waterflood to 11:1 or higher as the production matures. Eventually, considerable volumes



of injected fluid are recovered at production wells and it becomes uneconomic to continue production. This is the stage when secondary recovery reaches its limit.

Water mixed with the produced oil stream can be separated and used as injection fluid. An additional water source may also be required to replace the resource recovered from the reservoir.

Saline water can be used for pressure maintenance or waterflood. A low-level treatment is usually required to remove the suspended, dissolved and biological components that could create a risk of blocking pore spaces in the reservoir during injection.

Management of produced water is important in conventional oil production. Depending on reservoir formation conditions, the produced water may be strongly mineralised and/or elevated in temperature, and may contain some oil. The quality of produced water can deteriorate as production matures.

● **Enhanced oil recovery (EOR)** EOR uses techniques to alter the fluid properties, displace or dislodge the oil and prolong the productive life of the reservoirs. The technique is dependent on the characteristics of the reservoir, such as the temperature, pressure, depth, permeability and fluid properties, and the residual oil and water saturations. EOR was originally employed to extend the productive life of a reservoir but it is now often used at the start of a development to maximise recovery.

Water plays a prominent role in the techniques commonly employed in EOR.

Thermal recovery, such as steamflood or in situ combustion techniques, both require water. Steamflood involves boilers at the surface heating water to generate steam for injection in the reservoir. This lowers the viscosity of the oil, promoting its movement to extraction points.

In situ combustion involves the ignition of hydrocarbons within the reservoir to volatilise

lighter fractions of the oil as well as water. This promotes mobility and allows the resource to be collected at extraction points. Miscible injection uses carbon dioxide or hydrocarbon injection to lighten the oil while chemical flooding uses water mixed with polymers and gels.

Steam generation and chemical flooding can require the use of fresh water to prevent scale and corrosion of equipment and to allow chemical solutions to operate effectively.

As with primary and secondary recovery, management of produced water is an important component of EOR. The chemical properties of the produced water are similar, but may also include any chemicals used as part of the EOR production process.

● **Conventional gas production** Beyond well-drilling, water is mainly used in conventional gas production for gas processing. During this stage, water forms the basis of chemical solutions used to strip impurities, such as water vapour, hydrogen sulphide and carbon dioxide from the gas. It is also used for cooling and steam generation, particularly when the gas is liquefied for export.

As gas field production matures, the proportion of impurities in the gas may rise which, in turn, requires more processing to remove them. The quality of water required for gas processing varies depending on the end use. For example, fresh water is used for steam generation while saline is required for cooling.

Water vapour, a type of produced water, is present with gas with small amounts of water also recovered as part of gas processing. This water is not saline but may contain hydrocarbon contaminants.

*This is an edited extract from Efficiency In Water Use, a publication by IPIECA. The complete publication can be found at [www.ipeica.org/publication/petroleum-refining-water-wastewater-use-and-management](http://www.ipeica.org/publication/petroleum-refining-water-wastewater-use-and-management).*



## Water management for petroleum refineries

*By Mudumbai Venkatesh and Rob Cox*

Improved water management in a petroleum refinery can potentially reduce the volume and cost of raw water used in operations. Additionally, efficient water management results in reduced wastewater flow and contaminant load – and this, in turn, reduces operating and maintenance costs for wastewater treatment.

With critical shortages of fresh water in most areas of the world, and a requirement for relatively high volumes of raw water in a refinery, the pressure to recycle and reuse water is increasing. In evaluating recycling and reuse issues in a refinery, potential uses of water should be investigated along with recycling and reuse of refinery wastewater, external sources of wastewater, and opportunities and risks of water exchange.

There are important areas in a refinery where water can be reused or substituted, where water minimisation practices can be employed and where opportunities for implementing internal and external water exchange practices exist. Also, there are technologies available for upgrading large volumes of water. The “holy grail” of water management for refineries is Zero Liquid Discharge (ZLD) from a refinery, but there can also be a trade-off between reducing effluent discharges and increased energy use and emissions.

Compared to other industries, refineries are large users of raw water. Especially in areas where there are water shortages, refineries are restricted on the quantities of raw water that can be imported from outside sources. This has led to many operators implementing water recycling and reuse practices while taking into account local site conditions.

### Raw water uses in a petroleum refinery

Raw water is used for various purposes in a refinery, such as boiler feed water, cooling, potable, fire water and utility water.

- **Process water** This is water used for washes in process equipment and for other purposes where the water comes into contact with the hydrocarbons.

- **Boiler feed water (BFW)** Also known as demineralised water, BFW is used for the generation of steam and it needs to be treated prior to use. Usually, to produce BFW, water is treated by a lime-soda process and further purified by an ion exchange or a hot phosphate treatment. Reverse osmosis can also be used to demineralise the water.

- **Cooling water** Water-cooled condensers, product coolers and other heat exchangers can use a large amount of water in a refinery. Most refineries also use air coolers, where the process stream is exchanged with air before being sent to a cooling water heat exchanger. In cooling tower systems, build-up of salt concentration is unavoidable since water is evaporated in the cooling tower. Make-up water is needed to replace these and other losses. Some refineries use a once-through system where the incoming water is exchanged against the process fluid and the warmer cooling water is then returned to the source of the water. Some water treatment is necessary to prevent scale formation, corrosion, algae and slime.

- **Potable water** Potable water is needed for use in kitchens, wash areas and bathrooms at refineries. City water or treated ground water can be used for this purpose. A portion of the treated water from the plant softening unit may be diverted for potable water use.

- **Fire water** The requirements for fire water are intermittent but can constitute a very large flow. Often refineries collect storm water from non-process areas and store it in a reservoir dedicated to the fire water system in the plant.

- **Utility water** This is used for miscellaneous washing operations, such as cleaning operating areas. It should be free from sediment but does not require any additional treatment.







Efficient water management in all areas of refinery operation reduces costs and contaminant loads.

### Supplying water to the refinery

Raw water can be supplied to refineries from different surface water sources, such as rivers or lakes, or from groundwater in the local area. In some cases, it can be supplied from the sea or other brackish water sources. Raw water can include varying amounts of solids and salts, referred to as total suspended solids (TSS), total dissolved solids (TDS) and turbidity. Raw water can also be supplied from municipalities, which generally offer potable water (drinking water) but may also be able to offer treated effluent from local wastewater treatment plants.

When crude oil arrives at a refinery, it often carries water that remains from the extraction process. This water is typically removed as storage tank bottom sediment and water (BS&W) or in the desalter, which is part of the crude unit in the refinery, and is typically sent to wastewater treatment.

Rain is another source of water to a refinery. Rain that falls within the refinery battery limits typically requires treatment before discharge. Rain

that falls in non-process areas, such as parking lots, green areas or on offices, may be discharged without treatment depending on local regulations. Storm water harvesting can be employed to capture uncontaminated storm water and this can be used for certain processes, such as equipment washing, with the proper storage and treatment.

### Water out of the refinery

Refineries produce significant quantities of wastewater that has been in contact with hydrocarbons. Other sources of wastewater include water that has been rejected from the boiler feed water pre-treatment processes, cooling tower blow down or cooling water that has left the refinery. Typically, wastewater is sent to either a treatment plant at the refinery or it can be pre-treated to remove oil and grease before being sent to a municipality treatment works for further treatment.

Excess low pressure steam that is produced in the refinery is vented to the atmosphere when it is impractical to recover the condensate.



Significant water loss occurs in refineries as a result of evaporation in cooling towers. Some of the water in the cooling tower is also entrained by the large quantities of air passing through the tower and gets lost to the atmosphere. These entrainment losses are also known as cooling tower drift.

### Management of wastewater produced in refineries

There are different types of process water from petroleum refineries and these need to be managed in different ways.

● **Desalter effluent** Inorganic salts, predominantly sodium chloride, are present in crude oil, generally in the form of naturally occurring brine. The quantity of this water in oil varies, but is usually between 0.1% and 2% of volume. Typically, the first operation in a crude oil refinery is a desalter to wash out the salts present in the crude. This helps prevent corrosion of downstream equipment.

Some of the drilling muds that come in with the crude can accumulate in the desalter and need to be removed periodically. The more advanced desalters are fitted with continuous mud washing systems so mud does not accumulate.

The wash water used in desalters is typically 5-8% of the crude throughput. Different sorts of wash water can be used in desalters, depending on the refinery. Fresh water is good because it requires minimal treatment but it increases overall water usage, wastewater generation and costs for operators. Alternative sources of wash water include recycled crude tower overhead water and recycled vacuum tower overhead water, both of which save fresh water use but have pH levels that can be hard to control. Recycled stripped sour water can also be used – it has more manageable pH levels although routing all sour water that is produced results in more capacity in the sour water stripper being required.

● **Sour water** Steam is used in many processes in a refinery, mainly as a stripping medium and a diluent. Since this steam condenses in the presence of hydrocarbons, which contain hydrogen sulphide ( $H_2S$ ) and ammonia ( $NH_3$ ), these compounds are absorbed into the water at levels that typically require treatment. The usual treatment for sour water is to send it to a steam stripper for removal of  $H_2S$  and  $NH_3$ . Steam is used to inject heat into the strippers and the resulting stripped sour water is an ideal candidate for recycling and reuse in the refinery. Strippers that use direct steam injection as the stripping medium create more wastewater in the refinery than strippers that use reboilers to inject heat into the strippers.

Refineries that include process units, such as catalytic crackers and delayed cokers, produce more sour water than a less complex refinery. The sour water from these sources also contains phenols and cyanides and should be segregated from the remaining sour water. Dedicated sour water strippers may be used to process this water and the stripped sour water from this stripper should ideally be used as wash water for the desalters. This will result in the extraction of up to 90% of the phenol contained in the sour water and a lowering of the load of phenol to the wastewater treatment system.

● **Tank bottom draws** Crude tanks, gasoline tanks and slop tanks may require water draws in refineries. The incoming crude to refineries usually contains water and mud that gets picked up when the oil is extracted from wells. This is referred to as bottom sediment and water (BS&W). When crude is stored in large tanks, BS&W settles to the bottom and must be periodically removed to prevent a build-up. If BS&W is allowed to build up, storage capacity is reduced. Water draws are normally sent to either the wastewater treatment or to a separate tank where the solids can be separated from the oil and water.

Tanks that store gasoline also tend to collect water. These tanks should be equipped with

drainage systems similar to that of crude tanks to ensure that hydrocarbon product is not inadvertently drained from the tanks. It should be noted that the amount of water drained from gasoline tanks is relatively small compared to the amount of water from crude tanks.

● **Spent caustic** Spent caustic is formed when acidic components are extracted from hydrocarbon streams. It is important that this does not end up contaminating water. Traditionally, spent caustic has been disposed of in a number of different ways. Discharge to the sewer system is common but not necessarily best practice. An alternative option is offsite disposal of spent caustic where recovery of contained organic compounds can take place. Offsite disposal of sulfidic spent caustic, which often makes up the largest proportion of refinery spent caustic, is more difficult because there are few reprocessing options for this stream.

### Refinery wastewater treatment

Typical refinery wastewater treatment plants consist of primary and secondary oil/water separation, followed by biological treatment and, if required, tertiary treatment.

In a refinery wastewater treatment system, two steps of oil removal are typically required to achieve the necessary removal of free oil from the collected wastewater prior to feeding it to a biological system. This oil removal is achieved by using an API Separator (developed by the American Petroleum Institute and the Rex Chain Belt Company, now Siemens Water) followed by a Dissolved Air Flotation (DAF) or Induced Air Flotation (IAF) unit.

The wastewater from the secondary oil/water separation unit is sent to the equalisation system that is used to dampen out variations in flow and concentration in the refinery wastewater. The wastewater is then routed to the aeration tank/clarifier, which constitutes the biological system.

The effluent from the clarifier is then sent to tertiary treatment, if necessary, before being discharged.

### Water reuse

With the shortage of fresh water in most areas of the world, together with the relatively high requirements for raw water in refineries, the press to recycle and reuse water is increasing. In evaluating recycling and reuse issues in a refinery, the potential users of water should be evaluated along with recycle/reuse of refinery wastewater and external sources of wastewater, such as municipalities.

Desalter makeup water, coke quench water and coke cutting water can be reused as stripped sour water. Additionally, desalter makeup water can be used for vacuum tower overhead water or crude tower overhead water. Boiler feed water and cool-



Siemens' Zimpro wet air oxidation system destroys odorous sulfide pollutants and generates a biodegradable effluent that can be discharged to conventional biological wastewater treatment.



ing tower makeup water can be treated and upgraded for reuse in refineries.

Storm water can also be reused by hydrocarbon operators. If it is non-contaminated, it can be used for fire water in drills and actual fire events; as well as cooling tower makeup water and boiler feed water.

● **Utility water** Refinery utility water systems use non-potable, non-contaminated water. Utility water may be used for any purpose in a refinery where water is needed, such as washing down process units and cleaning up spills. Storm water may be collected and pumped from storage into the plant utility water supply header. As with any water reuse system, the source of the water, its quality and potential contaminants must be monitored and deemed acceptable for all designated uses.

### Upgrading water for reuse

Treated refinery wastewater and treated municipal wastewater from outside sources can be considered for reuse as long as the water is treated to remove residual contaminants. Different technologies can be used for upgrading water and the choice is made by operators based on factors such as prior application of upgrading technology, previous results from upgrading activities, capital and operating costs, operability, flexibility, and plot space requirements.

The main contaminant that needs to be removed as part of the treatment process is dissolved solids, although in some cases, residual hydrocarbons and other compounds will also need to be removed. There are three main TDS removal technologies.

● **Ion exchange** In a refinery, ion exchange is typically used to remove calcium and magnesium from raw water so it can be reused. In this system, feed water is passed through cationic and anionic beds where the cations and anions in the water are exchanged with ions that are present on the resins. After a period of time, the adsorption capa-

city of the resin is exhausted and needs to be regenerated. The regenerant water is rejected from the system during this process.

It is usually economical to use ion exchange when the TDS concentration in the feed water is lower than 400mg/L. At higher concentrations, the resin gets exhausted frequently and regeneration is required, thus increasing operating costs.

● **UF/RO** Ultrafiltration followed by reverse osmosis (UF/RO) is a system where by refinery wastewater has first undergone sand filtration to remove residual solids. The wastewater is then sent to an activated carbon filter where residual chemical oxygen demand/biochemical oxygen demand (COD/BOD) is removed to protect downstream filtration membranes from fouling. The water then goes on to the ultrafiltration modules where residual fine particles are removed. Ultrafiltration membranes are periodically backwashed to remove collected solids.

The pH is then increased before being sent to the RO system. The reject from the RO system is discharged and the pH is adjusted back to around seven before being sent to be recycled. The permeate produced from a UF/RO system typically can have a TDS concentration of less than 20mg/L and can be used for cooling tower makeup water or demineralised water makeup.

● **EDR** The electro-dialysis reversal (EDR) system is very similar to UF/RO. The ultrafiltration process remains the same but the RO process is replaced by EDR modules. These modules use electric current to separate the cations and anions in the wastewater. Like water treated by UF/RO, EDR-treated water can be used for cooling tower makeup water or demineralised water makeup.

● **ZLD** Zero Liquid Discharge (ZLD) can be used when there are restrictions on the disposal of liquid wastes in place. ZLD is achieved by taking the reject streams out and sending it to an evaporation/crystallisation system. A ZLD unit requires significant energy input in the form of steam.





SmartWater Flood increases oil recovery through tuning of the ionic composition of seawater at Saudi Aramco's Qurayyah Seawater Treatment Plant.

In a ZLD system, the treated wastewater from the refinery is processed through a UF/RO or EDR system. Typically, the recovery of water is about 70-80% of the feed. Some of the water is lost in the backwash but this can be recovered by recycling it back to the biological unit in the refinery. The remainder is lost as reject from the RO or EDR system and this reject stream is sent to an evaporator/crystalliser for further recovery. The recovered water is then recycled back to the refinery along with permeate from the RO system and the salt crystals from the crystalliser are sent to be disposed.

*Mudumbai Venkatesh is Vice President with AECOM in the USA, and Robert Cox is Technical Director with IPIECA in the United Kingdom.*

*This is an edited version of a paper from the 20th World Petroleum Congress, Doha 2011. For the full version please see [www.ipieca.org/publication/petroleum-refining-water-wastewater-use-and-management](http://www.ipieca.org/publication/petroleum-refining-water-wastewater-use-and-management).*

### Case study: Waterflooding and oil recovery

*By Dr Ali Yousef, Salah Al Saleh and Mohammed Al-Jawfi*

Waterflooding has been the most successful method for recovering oil from reservoirs. In the past, the salinity and ion composition of injection water have not been considered as important parameters in oil recovery from waterflooded reservoirs. However, evidence from laboratory studies, verified by field tests mainly involving sandstone, has shown that injecting low-salinity water has a significant impact on oil recovery.

Saudi Aramco, through its upstream research arm, has initiated a programme called Smart-WaterFlood to explore the potential of increasing oil recovery by adjusting the injection water properties. Three years of research have taken place to conclude that substantial oil recovery can be achieved by altering the salinity and ionic content of field injection water.





The main grounds for successful waterflooding include water being an effective injectant for displacing oil of light-to-medium gravity; water is relatively easy to inject into oil-bearing formations; water is available and inexpensive; and waterflooding involves much lower capital investment and operating costs, leading to favourable economics compared to EOR methods.

Maximising ultimate oil recovery is the target of any waterflood reservoir. Because waterflooding has been viewed as a physical process to maintain reservoir pressure and drive oil towards producing wells, less attention has been given to the role of chemistry in the injection water and its role in oil recovery. But extensive research has since found that adjusting salinity and ionic composition of injected water can favourably affect oil/brine/rock interactions, alter rock wettability and eventually improve waterflood oil recovery. One trend that has emerged in sandstone reservoirs is the use of low-salinity water to significantly improve oil recovery. Initial results from trials of using low-salinity water have proved promising.

The studies undertaken by Saudi Aramco were broad-ranging. Different brines were used, including connate water, injection seawater and different salinity slugs of injection seawater. Reservoir oil samples were used in the study. Crude oil filtration was conducted to remove solids and contaminants to reduce any experimental difficulties during coreflood experiments. Live oil was used so the experimental conditions closely resembled reservoir conditions.

The impact of each diluted version of brine on carbonated rock samples was investigated. This determined the impact of injecting chemically optimised versions of brine on porous rock. In experiments, rocks were also injected with deionised water. Varying the salinity of the seawater led to a substantial increase in oil recovery, up to approximately 18% beyond conventional waterflooding. Reducing the salinity and altering the

ionic content of injected brine yielded the best results but there is some variation in results with different types of rock.

*Dr Ali Yousef is a Petroleum Engineering Consultant at Saudi Aramco.*

*Salah Al-Saleh is a Petroleum Scientist at Saudi Aramco.*

*Mohammed Al-Jawfi is a Laboratory Technology Specialist at Saudi Aramco.*

*This is an edited version of a paper presented at the 20th World Petroleum Congress, Doha 2011.*

## Case study: National Iranian Oil Company

*By Mrs Samaneh Ashoori*

Two National Iranian Oil Company (NIOC) offshore oilfields are served by two seawater injection plants. A step-by-step review of one of the plant's 40km of pipelines, three-stage filtrations, de-aeration tower, and treatment chemicals has taken place to optimise the water treatment cycle. The focus of the review was corrosion and chemical management.

The seawater injection system works by pumping water up from 20m below the surface and treating it with sodium hypochlorite, which is normally generated by electrolysis of the seawater at the pump intake. This allows for bacterial control and water is then filtered and pumped a distance of 2km to the plant via a 24-inch carbon steel pipeline that has been internally coated with cement. Despite this internal coating, there have been issues with pipeline corrosion. At the plant, the water is then filtered through a further four filters and deoxygenated by being passed through a de-aeration tower. Ammonium bisulfite is then injected to reduce oxygen concentration. The water is then pressurised and transferred to injection pumps. This flow is then treated by corrosion- and scale-inhibitors, and bactericides and filtered again





before injection. This treated, pressurised water is then transported 33km to the offshore platform via a 20-inch carbon steel pipeline with internal cement coating on the seafloor.

Contamination by solids, mineral scale deposition and corrosion were impacting on the quality of produced water. Additionally, problems with chemical treatment stemmed from aged water injection plants caused injectivity loss and added to operational costs. The plants treat seawater for injection into the two oilfields and have been in operation since 1985. In this time, systems have been damaged and suffered from a lack of corrosion monitoring and inspection.

Field data and laboratory tests indicated that one of the major problems associated with seawater injection at the oilfields resulted from inadequate filtration and the presence of sulphate salts, as well as sulphate-reducing bacteria.

The offshore oilfields have been in production since 1979 and they include four platforms and a shared oilfield between Iran and the UAE. A drop in reservoir pressure led to a water injection strategy being implemented.

Water injection commenced in 1983 but was stopped in 1989 because of high injectivity loss caused by multiple formation damage. In 1992, water injection recommenced for a year and then resumed again in 1994. Two plants serve these fields – they are on the island closest to the fields, located 72km from the southern coast of Iran.

The older of the two plants, and the focus of this case study, was built in 1977 and provides 75,000 bpd of water for injection into two oil fields. The second plant was constructed in 2001. Remedial action to maintain and stabilise ageing pipelines and facilities became urgent.

An inspection procedure was set up with 12 sampling points selected – seven water sample points, two filter sediment sample points and three injected-chemicals points. The water sampling points were at the input and output of the factory,

upstream and downstream of the deaeration tower, after the chemical injection point and on the 2km pipeline. To examine storage and weather effects on the performance of chemicals, two groups of samples were taken, one from the stock and one from the batch that had been brought to the plant for injection into the line. The chemical containers remain in the plant and are usually exposed to sunlight for between one day and two weeks in a humid environment with an ambient temperature of more than 40°C for most of the year.

Water and sediment samples were analysed in a laboratory, including the concentration of ions and elements as well as TDS, TSS and pH. The corrosiveness or scale-forming of water was determined according to this analysis. The chemical's performance and residual concentration were also analysed and a corrosion monitoring system applied.

The investigation into corrosion monitoring showed that with the installation of a proper corrosion monitoring system, approximately \$70,000 would be saved annually. Other conclusions and recommendations were also made as a result of the investigation. It was found that the optimum concentration of the scale inhibitor for this plant is 30ppm and the chemical injection point should be moved downstream of the filters to prevent chemical trapping. To prevent the adverse effect of biocides on other chemicals and to prevent bacteria resistance to the biocide, batch injection is recommended. The corrosion monitoring system will enhance the plant's efficiency by avoiding system failure due to corrosion and help evaluate the chemicals' effectiveness.

*This is an edited version of a paper presented by Mrs Samaneh Ashoori on behalf of the NIOC-IOR Research Institute, Iran, at the 20th World Petroleum Congress, Doha 2011. Mrs Ashoori is now an advisor for the technology department of Suncor Energy, Canada.*

# Advanced technologies for water management

*By Georgia Lewis*

Water management technologies have come a long way since the 1990s to help operators be more efficient and meet regulatory requirements.

New technologies for water management make it easier for operators around the world to meet this important challenge. These technologies achieved the multiple aims of water management in the hydrocarbons sector, such as efficiency, cost-effectiveness, meeting regulatory requirements, and being responsible operators.

Oil and gas operations produce different types of effluent and these should be treated responsibly. The main aims of treating water from oil and gas operations include removal of suspended particles, dispersed oil and grease, dissolved gases, soluble organics and naturally occurring radioactive materials. Other aims include the softening of water and disinfection. All effluent needs to be treated for discharge, reinjection, or reuse.

In particular, concentrated effluent streams are highly toxic and can contain carcinogenic components. Alternatively, there are instances where it can be turned into biogas. Other effluents that need to be treated include produced water, spent caustic from refineries and petrochemical plants,

gas-processing effluents, effluents with low concentrations of contaminants and higher flow rates, and shale gas flowback.

Water management technology should be fully tested before it is used by oil and gas operators. An example of this is Pell Frischmann Process Technology's pilot plant, test rig and full-scale plant facilities which were derived originally from the former British Gas Technology Division. Acquired in 2000 following a joint development programme, it is used to test generic and advanced technologies. The plant now includes new technologies and the test and design capability is based on 25 years of research and commercial plant development.

## An overview of water management technologies

Operators use a combination of physical, biological and chemical treatment processes for water management purposes.

● **Membrane filtration technology** Membranes provide a physical barrier to remove solids, bacteria and other unwanted molecules from water. There are different types of membranes which can be used for processes such as water-softening, disinfection, desalination and organic removal. Membrane filtration units can be used for small and large operations and can be automated. This means staff do not have to constantly watch the filtration process and can be deployed elsewhere for more cost-effective staffing.

Installing membrane filtration units can be an affordable approach for water management because the systems do not need large buildings or tracts of land, as well as being an energy-efficient way to remove impurities.

The pore size varies with the type of membrane used. Microfiltration membranes have the largest pore size and ultrafiltration is the next smallest size, followed by nanofiltration. Microfiltration and ultrafiltration membranes can be used as a pretreatment to desalination but cannot remove salt from water.



Chemicals are not required for these processes except for the cleaning of the membranes.

While low pressure is used for microfiltration and ultrafiltration, the processes of reverse osmosis and nanofiltration use hydraulic pressure to force clean water to diffuse through thick membranes. Reverse osmosis membrane filtration systems generally last around three to seven years. Nanofiltration systems are considered highly suitable for removing metals from water, water softening and the removal of extremely small particles.

● **Thermal technologies** These technologies are most effective in regions where energy costs are low. Before membrane technologies had advanced, thermal technologies were far more commonly used by operators for water treatment. The main thermal processes are multistage flash (MSF), multieffect distillation (MED), vapour compression distillation (VCD) and a hybrid of MED and VCD.

MSF is used for brackish water distillation and desalination of sea water. It works on the principle of water evaporation by reducing the pressure instead of raising the temperature. Feed water is pre-heated, flows into a low pressure chamber and immediately turns to steam. The MSF process can experience problems with scale formation but it is generally cost-effective for operations with a long lifespan.

MED involves applying thermal energy to saline water so it turns to steam. This steam is then condensed and recovered as pure water. Like MSF, scale formation is a problem with MED units but it is also a system with a long lifespan. Operators can use acids and scale inhibitors to help prevent scaling.

VCD is used primarily for desalination, but can also be used for produced water treatment. An evaporation chamber is used to generate steam



QCLNG's reverse osmosis plants can convert almost 97% of produced water into treated water suitable for beneficial use.

which is then heated and pressurised. Scale formation problems are reduced because it can work at temperatures below 70°C. VCD processes also use far less energy than MSF or MED.

MED-VCD hybrid technologies are a new way to treat produced water in a way that is energy-efficient. In coming years, MSF plants that have reached the end of their useful life could increasingly be replaced by MED-VCD hybrid units, which have a lifespan of around 30 years. These units use mechanical vapour compression to remove impurities from produced water. There are numerous advantages to MED-VCD hybrid units such as cost-effectiveness and a reduction in chemical use and waste.

● **Reverse osmosis** Reverse osmosis (RO) is a water purification process that uses a semi-permeable membrane to remove large particles. In RO, applied pressure is used to overcome osmotic pressure. The process can remove many types of molecules, ions and bacteria, to produce potable water.

Solute is retained on the pressurised side of the membrane and solvent passes through to the other side. The membrane should not allow ions or large molecules through the pores. The application of external pressure reverses the natural flow of pure solvent and the process is similar to other membrane technologies. However, there are differences between RO and other filtration methods. In particular, RO involves a diffusive mechanism which makes separation efficiency dependent on pressure, water flow rate and solute concentration.

● **Hydrocyclones** A physical method of separating solids from liquids in the treatment of produced water, based on the density of the solids. A hydrocyclone is made from either ceramic, metal or plastic and it usually has a conical base and a cylindrical top. It has no moving parts and relies instead on inlet pressure and the geometry of the hydrocyclone to separate the liquids from the solids. Larger particles are transported to the wall

of the unit and they exit at the reject side with a limited quantity of liquid. Finer particles remain in the liquid and exit the hydrocyclone via a tube that extends slightly into the body of the unit at the centre.

Hydrocyclones have a long lifespan but they generate a large slurry of concentrated solid waste which then needs to be managed responsibly.

● **Biological aerated filters** A biological aerated filter (BAF) has a bed that is generally 2-3m deep. This bed is made of a filter medium of a relatively small size to provide a surface area for growing a biomass. The filter bed is submerged and wastewater is either pumped upwards or downwards through the filter. Next, a blower sends air through a diffuser at the bottom of the bed to generate bubbles. These bubbles then rise through the filter providing a steady stream of oxygen so the biomass can support the oxidation process. Trapped solids and the biomass growing over time will block the filter pathways. This is cleared occasionally by air-scouring or back-washing with treated effluent. Waste backwash water is held in a well and gradually returned to the BAF plant inlet or to a primary sedimentation tank.

● **Gas flotation** Flotation technology is commonly used for treating produced water from conventional oilfields. The two types of gas flotation technology are dissolved gas flotation (DGF) and induced gas flotation (IGF). In DGF, gas is introduced into the chamber by a vacuum or by creating a pressure drop. In IGF units, bubbles are created by either propellers or mechanical shears.

Gas flotation uses fine gas bubbles to separate suspended particles, such as grease, oil and organic matter, that are not easily separated using sedimentation. When gas is injected into produced water, oil droplets and particles attach to the bubbles as they rise. This creates foam on the surface which is then skimmed off. This process is most effective when bubble size is less than the oil droplet size and it works better at low temper-



atures. Similar to hydrocyclones, gas flotation units generate sludge which needs to be disposed of responsibly.

● **Adsorption** Rather than being a stand-alone technology for water treatment, adsorption is generally used as a polishing step in the treatment process. Put simply, adsorption is the adhesion of a chemical species onto the surface of particles. Adsorption differs from absorption, which is where a substance diffuses into a liquid or solid to form a solution,

A variety of materials can be used as an adsorbent including organoclays, activated alumina, activated carbon and zeolites. These can be used to remove iron, total organic carbon (TOC), benzene, toluene, ethylbenzene, and xylenes (BTEX), oil and manganese from water. When a solution that contains adsorbable solute comes into contact with a solid with a porous surface structure, some of the solute can attach to the solid surface. The solute retained on the solid surface is called adsorbate and the solid on which it is attached is called an adsorbent. The accumulation of adsorbate on an adsorbent is called adsorption.

The media used for adsorption may have to be replaced or regenerated depending on the media type and the feed water quality. Chemicals can be used to regenerate the media which can result in liquid waste disposal and media replacement leads to operators having to find solid waste management solutions.

● **Media filtration** Produced water can be filtered using different types of media. These include anthracite, gravel, sand and walnut shells. Walnut shell filters are common for produced water. Water salinity is not an issue and this process can be applied to any type of water. In particular media filtration technology is highly effective at removing oil and grease. If coagulants are added to the feed water before filtration, efficiency can be further improved. However, like adsorption, this process does create the need for solid waste disposal.



A variety of materials can be used as an adsorbent including activated carbon.

● **Evaporation pond** An evaporation pond is an artificial pond which efficiently evaporates water using solar energy. These ponds either prevent subsurface infiltration of water or downward migration of water, depending on the quality of the produced water. Evaporation ponds tend to work better in warm, dry climates where the evaporation rates are generally higher. While these ponds may take up relatively large areas, they are usually economical and can be used onsite or offsite to treat produced water. Net coverings are often used to prevent migratory water birds from coming into contact with contaminated water. However, the main drawback is that all water is lost to the environment with evaporation ponds so operators cannot use them to meet the water management objective of reuse, recovery or recycling.

● **Freeze thaw evaporation** Freeze thaw evaporation (FTE®) was developed by B.C. Technologies Ltd and Energy & Environmental Research Centre in 1992. The process is used for treating and disposing of produced water. As the name suggests, it is a process of freezing, thawing and evaporation using evaporation ponds. When produced water with a freezing point lower than 0°C is cooled below 0°, but not below its freezing point, ice crystals and an unfrozen solution form. The dis-



solved constituents in the unfrozen solution portion of water can be drained away. The ice crystals, which are relatively pure, can be collected and thawed to obtain clean water for reuse.

In winter, around half the produced water can be collected as clean water but in warmer seasons,

no water is recovered. However, FTE® can remove more than 90% of TDS, TSS, heavy metals, total recoverable petroleum hydrocarbons, and volatile and semi-volatile organics. While a drawback of FTE® is that it is best suited to colder climates, it does have the advantage of not requiring chemi-



Veolia's MPPE unit for Shell's Prelude FLNG facility conforms to best environmental practices.



cals or extensive infrastructure. It is also easy to operate and monitor and the evaporation ponds have a lifespan of around 20 years.

● **Dewvaporation: The AltelaRain® process** This is a desalination process developed by Altela Inc. It is a process based on counter current heat exchange which produces distilled water. In one chamber, feed water is evaporated and then condenses in a chamber with a heat transfer wall as distilled water. It is effective on produced water with a high salt concentration. Energy requirements are low because it operates at ambient pressures and low temperatures.

● **Macro-porous polymer extraction technology** Used primarily for produced water management on offshore oil and gas platforms, macro-porous polymer extraction technology (MPPE) is known for its best environmental practices. It is a liquid-liquid extraction process in which extraction liquid is immobilised in polymer particles with large pores. These polymer particles are developed for absorbing dissolved and dispersed hydrocarbons from water. Since 1991, they have been applied to the treatment of produced water, industrial waste water and in groundwater remediation.

In an MPPE unit, produced water passes through a column packed with the polymer particles which contain an extraction liquid. The immobilised extraction liquid removes hydrocarbons from the water. The MPPE process means that almost all toxic dissolved and dispersed hydrocarbons present in the water can be recovered. Stripped hydrocarbons are separated from the water by gravity and then either disposed of or recycled. The treated water is then either discharged or reused.

MPPE is an effective treatment system for produced water containing methanol, salt, corrosion inhibitors, scale inhibitors, glycols, defoamers, demulsifiers, dissolved heavy metals, and  $H_2S$  scavengers. Before produced water is passed through an MPPE unit, no specific pre-treatment is required. Recently, structural removal of

mercury has been observed at 80-99% levels on various gas platforms and is currently under further investigation.

● **Ion exchange technology** In the ion exchange process, water is percolated through bead-like, spherical resin materials known as ion exchange resins. Ions in the water are exchanged for other ions which are attached to the beads. Primarily, this method is used for softening water and deionisation as a pre-treatment before reverse osmosis processing.

● **Chemical oxidation** Chemical oxidation technology removes colour, odour, and organic and inorganic matter. Oxidants commonly used for this process include peroxide, ozone, permanganate, oxygen and chlorine. The oxidant combines with the contaminants in the water, causing them to break down. It can be a high-cost process but it requires minimal equipment and units have a lifespan of at least 10 years. Sometimes solid separation post-treatment is required to remove oxidised particles.

● **Electrodialysis and electrodialysis reversal** Electrodialysis (ED) and ED reversal (EDR) are electrochemically driven technologies used for desalination. Both processes involve the separation of dissolved ions from produced water through ion exchange membranes which contain electrically charged functional sites. Only anions pass through a positively charged membrane while cations can only pass through a negatively charged membrane. EDR uses occasional reversal of polarity to optimise its operation.

ED and EDR have only been tested for the treatment of produced water and it works best on produced water with a relatively low saline level. High costs, a relatively short lifespan (around five years) and ongoing issues with membrane fouling are the main drawbacks to these methods.

*Georgia Lewis is Managing Editor for International Systems and Communications.*







# Water management for unconventional

## Water management for unconventional oil and gas

By Marcus Oliver Gay and Andrew Slaughter

*The ongoing development of unconventional hydrocarbons has led to new water management challenges.* Unconventional oil and gas exploration and production involves vast amounts of water, elevating effective water management to a major strategic concern.

Water is especially vital in oil exploration and production (E&P) operations. Once reliant on conventional vertical drilling and completion techniques, E&P companies have moved to unconventional drilling and completion processes – specifically, horizontal drilling and hydraulic fracturing – to access previously inaccessible resources. Water is a significant part of unconventional production processes, and managing its use and disposal throughout the value chain is complex. Specific water management strategies vary not just among plays but by individual well, depending on where it is in the production cycle.

For E&P operators in North America, water management is not only about managing direct line-item costs but about mitigating risk. Operators

must assess the operational risk and impacts on capital expenditures (CapEx) and operating expenses (OpEx) and manage challenges from increased regulatory oversight and public scrutiny. Operators that effectively prioritise water management can better mitigate risk, improve operational excellence, and protect millions of dollars in potential earnings.

### The water management value chain

- **Water source** Water for hydraulic fracturing operations is typically sourced from surface water or freshwater aquifers, but increasingly, operators are turning to brackish or wastewater sources to reduce local stress and minimise the risk of supply-chain interruptions.

- **Water transportation** The most common methods for water transportation in hydraulic fracturing operations are water hauling (moving water via tanker trucks) and water transfer (transportation via pipe and pump). Water transfer is more economical for moving water up to 8km. Trucks are more expensive but provide increased range and flexibility.

- **Water storage** Earthen impoundments, commonly known as pits, are the most economical way to store volumes of water, up to several hundred thousand barrels in one impoundment. Overground storage tanks offer more flexibility and superior environmental stewardship.

- **Water treatment** Wastewater drill fluid, flow-back fluid, and produced fluid treatment can serve to meet different water quality goals. This can be accomplished through discrete water-treatment steps that depend on effluent quality specifications. Treating to yield fit-for-purpose fluids is best practice, ranging from minimum effective treatment for reuse to full desalination for discharge.

- **Wastewater disposal** The most common method for disposing of oilfield wastewater is underground injection. Permitted in the US by the Environ-



mental Protection Agency but often managed with oversight from regional regulators, these wells inject wastewater into deep geologic formations removing it from the hydrological cycle.

### Water's role in unconventional E&P operations

The majority of new wells drilled and completed onshore in the United States use horizontal drilling and water-based hydraulic fracturing programmes, which are far more water-intensive and pose different management challenges than conventional E&P. The hydraulic fracturing process calls for large volumes of water for use in a fluid that is injected under pressure to create fractures that enable the flow of oil and gas. The fluid also contains small sand or ceramic particles, called proppant, that lodge within the fractures to keep the fracture sites open once the hydraulic pressure is released and the fluid flows out of the well bore. Today, hydraulic fracturing is a common practice in conventional E&P, where it is used to extend the useful life of old wells, and in unconventional E&P. A typical hydraulic fracturing programme involving a conventional well requires approximately 25,000 barrels of water. An unconventional well can require up to 250,000 barrels of fluid during the completion process and generate large volumes of wastewater.

That wastewater is categorised as “flowback fluid” or “produced fluid”. “Flowback fluid” is the waste that returns up the well bore during the initial stages of fracturing and production. The volume of flowback fluid is high in the first few weeks and months of operation, when as much as 40% of the initial fracture fluid volume can make its way back up the well bore. “Produced fluid” is the wastewater generated once the well begins producing hydrocarbons in volume. It dwindles to a trickle over the remaining life of the well. For example, a typical well in the Marcellus shale play in Pennsylvania may generate 1,200 to 1,500 barrels per day of flowback fluid for a few weeks

after the drilling and completion process and then decline to only seven barrels per day of produced fluid for the duration of the well's life.

US production from conventional E&P historically generates three to nine barrels of oilfield wastewater for each barrel of hydrocarbon, according to the Argonne National Laboratory. Conventional E&P has well-established management practices and a mature market of products and services for the transportation, treatment, and disposal needs of wastewater. But the larger water volumes involved in hydraulic fracturing, and rapid industry development, creates new challenges for operators and a growing marketing opportunity for water-management companies and oilfield service providers.

### Managing water for a sustainable advantage

The value of an effective water management strategy more than offsets the relatively insignificant costs of water acquisition and wastewater transport, storage, treatment, and disposal. Although those costs can add up to hundreds of thousands of dollars over the life of a well, the cost of lost business is much higher. And the danger of losing business rises sharply when an operator fails to make water management a strategic priority. Without effective water management, operators risk lower production rates, production halts, regulatory penalties, and a breach in stakeholder faith. Wells can be damaged. Drilling and completion programmes can be stalled or compromised. And millions of dollars in potential earnings can be washed away.

In contrast, business leaders who regard water as an important part of their operations can create true business advantage. By managing water in an integrated, cross-enterprise way, executives can improve efficiencies, reduce production and operational costs, and enhance credibility with local stakeholders. Taking the time to understand and build effective water-management strategies, de-



ploy demonstrated best practices, and invest in innovative technical solutions can help companies convert water-management challenges into opportunities for business success.

The increasing use of hydraulic fracturing has drawn many new stakeholders into local and regional water management discussions and increased scrutiny for operators. Regulators, shareholders, and community members track and sometimes object to the industry's water consumption and environmental practices. The American Petroleum Institute highlights alternative best practices that require less freshwater and use water recycling technologies. These technologies and tactics are often costly so operators must use them effectively and efficiently to remain financially viable.

Water acquisition and wastewater disposal constraints can create tremendous economic and management pressures that vary by geography, geology, operational conditions, and phase of play development. Thus, water management strategies must be developed locally, with a sensitivity to budget constraints and regional drivers such as regulatory culture, water resource availability, and wastewater disposal capacity.

Accounting issues also create management challenges. Generally, all expenses generated before a well begins producing, such as the costs of hydraulic fracturing and flowback fluid management, are considered CapEx. Costs incurred after oil or gas is flowing, including the costs of handling produced fluid, are attributed to OpEx. In areas where water is scarce or disposal is costly, water-management costs are high and growing – they account for 10% of the CapEx budget and as much as 50% of OpEx. Operators must balance the cost of drilling and completion with effectiveness of production operations to assess whether the well generates attractive returns.

Regulatory oversight and public scrutiny are another challenge. In the US, oil and gas activity on private land is regulated at the state level, not

by federal agencies. In some states, local commissions and boards are responsible for issuing water withdrawal permits. In other areas, representatives from the public sector and community groups work in consortia to ensure an equitable allocation of water among operators, residents and businesses.

### New operational strategies

To reduce the costs of water management, increase efficiencies, and maintain community goodwill, US operators are exploring new approaches. Changes include:

#### ● Increasing reuse of oilfield wastewater

Unconventional energy production generates large volumes of flowback fluid. Recognising this water as an asset creates opportunities to reduce freshwater consumption, cut costs, and increase sustainability. Physical and chemical characteristics of flowback and produced fluid vary, and the level of treatment (if any) applied to recycled wastewater is a unique operational decision dictated by the completion engineering programme.

#### ● Replacing freshwater with brackish water

Some operators are investigating the use of brackish water to offset freshwater use for hydraulic fracturing. Demand for brackish water is certain to escalate as regulators impose more restrictions on freshwater withdrawals and operators and service providers increase the tolerance levels of the chemical additives used to make fluids.

● **Reducing disposal volumes** Most flowback and produced fluid generated from unconventional activity is disposed of via wastewater disposal wells. Where available, disposal wells are the most economically viable option for wastewater management. Regulatory or geological considerations, though, can require other means of disposal, such as reusing water rather than trucking it to a disposal site.

● **Treating water locally** Mobile water-treatment technologies can increase the flexibility and mobility of wastewater recycling options. Additionally, semi-mobile modular systems are gain-





ing popularity. These systems offer economies of scale with increased process efficiency and simplified water transportation logistics. Careful analysis of water demand, wastewater production, and logistical considerations enables geographical optimisation to reduce transportation costs and increase the reuse of scarce water resources.

● **Vendors supporting multiple components of the value chain** The landscape of products and services for oilfield wastewater management is highly diverse and heavily disaggregated. Some large oilfield service providers offer components of water management to complement their other services. Most of the market is comprised of many smaller companies that provide individual services within the value chain. Many E&P operators prefer to work with vendors that bundle offerings across the value chain, hence the emergence of new oilfield water management companies with products, services, and capabilities tailored to unconventional E&P.

● **Improving transportation options** Water transportation by truck is costly. Each well may require thousands of truckloads of water and wastewater. Communities are often eager to keep these vehicles off local roads to reduce the degradation to local infrastructure and the creation of dust, noise, and congestion. Increased reuse of wastewater and mobile on-site treatment can help operators reduce the need to transport water. In addition, operators are experimenting with networks of pipes that can transport fluids to central locations for treatment. High-density polyethylene pipes are an option for this procedure, as are lay-flat hoses that can be quickly compressed and efficiently transported and deployed.

● **Transferring knowledge** In North America, operators have extensive experience in the exploration and production of unconventional energy and operators in other regions are drawing on lessons learned. Shared expertise aids decision-making on issues such as sourcing water, stake-

holder concerns, and optimising infrastructure for water transportation, treatment and disposal.

### **New growth opportunities in water management**

To reduce risk, capital and operating costs, and stakeholder concerns, operators are increasing the reuse of oilfield wastewater. This shift has evolved water-management strategies, varying among operators, and this dynamic optimisation challenge has created growth along the water management value chain.

No single water-management approach makes sense for all operators or plays. At this stage of the unconventional E&P industry's development, though, many operators lack a holistic view of water management challenges. Others have not developed the water-management expertise to accurately assess challenges, and they may need partners to help select optimal strategies and technologies.

Fragmented, localised water-management value chains add complexity. Unlike traditional oilfield services, where integrated oilfield service companies compete to handle the whole process, operators in the unconventional energy market often cannot use a single vendor to manage all aspects of oilfield water management. Thus multiple local specialists handle discrete stages of the water-management process, from trucking to treatment to disposal. If these companies are integrated, most economies of scale are out of reach. Valuable opportunities are waiting for vendors that can deliver a full suite of services to unconventional operators.

*Marcus Oliver Gay is Senior Principle Researcher at IHS. Andrew Slaughter is Executive Director, Deloitte Energy Solutions. This is an edited version of an article that was first published in the IHS Quarterly (Q1 2014) at [www.ihs.com/publication/q12014.html](http://www.ihs.com/publication/q12014.html) and is republished here with the kind permission of IHS.*





## Water use in shale gas development

By Melissa Stark

Water is vital to each stage of the shale gas well life cycle, from well development to production. The volumes of water required to fracture a well, the varied characteristics of wastewater produced from shale gas operations that drive treatment and disposal options and the high proportion of logistics movements make water management central to shale gas production.

The Accenture report, *Water and Shale Gas Development, Leveraging the US experience in New Shale Developments*, summarised the three main challenges in managing water for shale operators. They are: Sourcing sufficient volumes of water required for drilling and fracturing each well; effectively managing the volumes of wastewater generated; and managing the water movements for sourcing and disposal.

Shale gas operators are faced with a number of options regarding the sourcing of water and the disposal of wastewater. Local regulatory frameworks, the characteristics of the returned water, and cost-effectiveness are some of the drivers behind these choices. This landscape is evolving as the industry grows and matures, and players explore effective water management options that are available (see Figure 1).

### Sourcing water

Hydraulic fracturing water is sourced from surface waters (lakes and rivers), groundwater (wells and aquifers), municipal supplies, and wastewater from previous operations. Once collected, water is hauled or piped to the site where it is stored in lined impoundments or tanks until the drilling and fracturing stages.

The volumes of water required in shale gas production vary considerably from well to well. The FracFocus website, which details the water use of wells across the United States, shows the variety of volumes required across different wells.

According to “Trends In Flowback Water Management in Shale Gas Plays”, written by John Veil in *Water and Shale Gas Development, Leveraging the US experience in New Shale Developments*, the depth, length and number of horizontal segments fractured influence total water volume. The longer the segment, the more water is required for the fracturing process. There is a trend for longer horizontal segments. Two years ago, these would be approximately 914 metres long but with advances in technology, these can now cover up to 1,824 metres.

Geologically, shale plays differ widely, including depth, thickness and total porosity, resulting in different water requirements. US Department of Energy figures indicate the Haynesville Shale (3,200 to 4,110m in depth), for example, requires on average one million litres of water during the drilling phase compared to 227,000 litres for the Fayetteville Shale (300 to 2,100m in depth).

As an average, approximately 18.9 million litres of water are required to drill and fracture a well. This is the equivalent of 1,000 water truck movements, according to the State of New York Department of Environmental Conservation’s 2011 figures. The fracturing stage is the most water-intensive, using up to 90% of the total water use. Despite public perceptions to the contrary, these water requirements are low compared to other sectors like agriculture or industry, and when compared to the water intensity of other forms of energy. Nevertheless, access to water sources is likely to become more of a constraint for operators in arid regions facing growing depletion of water resources, and in areas where water flows and availability follow seasonal variations.

### Wastewater production and disposal

Following the fracturing, varying volumes of the injected fracture fluid will flow back to the surface (“flowback water”), mixed with “formation water” containing dissolved minerals from the formation.



Source: Accenture Report, Water and Shale Gas Development, Leveraging the US experience in new shale developments.

Figure 1: Water challenges: Regulation, usage and movement.

Although there is no formally agreed definition, flowback and produced water are jointly referred to in a review by the Royal Society and the Royal Academy of Engineering as “wastewater.” The water recovery rate, that is, the amount of wastewater recovered from the volume injected as part of the hydraulic fracturing process, both in the short term (flowback water) and in the long term (total produced) varies by well and by shale (Source: [www.netl.doe.gov](http://www.netl.doe.gov)). There are “dry” shales with lower water recovery rates with 15-25% of the injected water returning to the surface, such as the Marcellus, and “wet” shales with high water recovery rates of up to 75%, such as the Barnett, as reported by John Veil in *Water and Shale Gas Development, Leveraging the US experience in New Shale Developments*.

The flowback water constitutes the highest volumes of wastewater over the life cycle of a well and can represent 3.7 million litres of water or more over the course of weeks (Source: [www.npc.org](http://www.npc.org)) with the majority captured in the first several hours to several weeks (Source: [www.netl.doe.gov](http://www.netl.doe.gov)). It contains a number of constituents, depending on the fracturing fluid and the shale formation, and varies dramatically across shale plays.

Additives in flowback water from the drilling and fracturing fluids include biocides, scaling inhibitors, friction reducers, as well as salts, organic compounds, sulphates, and metals (e.g. calcium, magnesium, barium, etc.). Some are present in the formation, and some are Naturally Occurring Radioactive Materials (NORM). NORM is brought to the surface in the drill cuttings, in solution in

the produced water, or in scales or sludges. The levels found in wastewater are significantly lower than the safe limits of exposure. However, according to *Shale Gas Extraction in the UK: A Review of Hydraulic Fracturing* by the Royal Society and the Royal Academy of Engineering, these should be monitored carefully in case concentrations increase during waste treatment. At concentrations higher than regulatory limits allow, the material must be disposed of at licensed facilities. A further characteristic of this produced water is its salinity, measured in levels of Total Dissolved Solids (TDS). These levels vary between shales, depending on the rock strata and the geology, from brackish to saline to brine (Source: [www.npc.org](http://www.npc.org)).

Following this high initial flow, the levels of wastewater generated gradually decrease as production begins. Following field development, the returned water is produced in small quantities by a multitude of different wells over longer periods of time. The logistics challenges involved in managing these small volumes of water produced by multiple sources over longer periods of time will be different to those presented by field development. The opportunities to reuse the wastewater are also different.

### Wastewater treatment and disposal options

The options available to operators vary depending on the availability of underground injection wells, the volume of flowback, the characteristics of the water, and the local regulatory framework.

● **Underground injection** Operators can inject their wastewater into underground injection wells, or Class II wells or pay a third-party commercial disposal company to take their water and inject it into a disposal well. In the US, either type of well must be permitted by a state agency or the Environmental Protection Agency through the Underground Injection Control programme. These underground formations are situated in porous rock formations, thousands of feet underground.

As the cheapest disposal option for flowback and produced water, this is one of the most widely used, and cost-effective wastewater management options. Produced water is either hauled or piped to these sites.

● **Water reuse** Flowback water can be collected and reused in a closed-loop system. When considering water reuse as a water management option, two characteristics of the returned water will be examined: the water recovery rate and the water quality.

The water recovery rate (i.e. the volumes of returned water compared to initial water injected) is particularly important as this affects the volume of water required to supplement the returned waste water to meet the volumetric requirements of the drilling and fracturing stages, as well as the on-site water storage requirements. Water recovery rates vary between plays and there are considerable variations within the plays.

The large volumes of water required present an operating challenge when only a percentage of injected water returns to the surface, for instance, in dry shales such as the Marcellus, where the formation characteristics tend to trap and bind the water in the formation. This is known as “imbibition”.

Flowback water is the focus of reuse since this presents the highest volumes over short periods of time. During development, these volumes will need to be supplemented by freshwater to reach the volumes required. Later in the life of a field, these wells will start producing small amounts of water over longer periods of time, making reuse less attractive. The quality of the returned water will shape the decision on treatment required to reuse the water (simple filtration or dilution, or further treatment) without affecting productivity. Main concerns include:

● **Concentration of TDS and high salinity** Very high TDS increases friction in the hydraulic fracturing process, which is bad for fracturing.



● **Levels of Total Suspended Solids (TSS)** The returned water should be treated to a level where suspended solids will not cause scaling in the injection train or clogging of the pore space in the formation. High TSS could also reduce the effectiveness of biocide.

● **Concentrations of scale-forming chemicals** Levels of scale-forming chemicals (including barium, calcium and magnesium) should be limited as these can damage equipment and infrastructure.

● **Levels of microbial constituents** Biological growth should be controlled, as microbes can increase the likelihood of plugs being formed in the wells.

Some operators will choose a simple dilution and/or filtration of the flowback water. In some cases, this will meet the requirements of the fracturing fluid, but filtration only removes TSS, not metals, organics, or chemical constituents in the water, including high concentrations of TDS. Other treatments may be required to allow for reuse of fracturing fluid or drilling fluid quality to be met.

### Treatment to freshwater

Treating the water to produce clean freshwater is the most expensive management option, due to costly technologies and necessary pre-treatment. Evaporation and crystallisation technologies are costly but they present the best options for treatment of the brines, in particular for removing high levels of TDS.

● **Water movements** An important part of selecting water sourcing, use and treatment options is the cost of water movements. Water transportation can account for as much as 40% of total fracturing cost and 20% of total well completion cost. This is compounded by rising transport and commodity costs as the scale of operations increases. The remote location of many shale gas plays and the dynamic nature of the operations make transport by road the most commonly used

option. Use of pipelines is increasing in more mature plays, but even in these operations, road transport is still the de facto mode for the “last mile” movements to remote and ever-changing drill sites.

● **Regulatory compliance** Many US states require operators to report on the source, volume and disposal of all water used. This task is typically handled manually by truck drivers and back-office staff, resulting in a costly and often inaccurate end-to-end process. As regulatory requirements and the scale of operations grow, operators will need to find more efficient ways to comply.

### Road transport issues

● **Health and safety** Busy transport activity associated with moving water exposes operators to health and safety risks. Driving-related accidents are the largest cause of fatalities in exploration and production-related operations. The exposure within shale gas operations is even greater, with remote locations often suffering from poor roads and few skilled drivers.

● **Local community impact** Logistics activities during drilling and fracturing can have a significant impact on local communities. Increased traffic congestion, damage to roads, and noise and air pollution, are among the most commonly cited concerns. Local governments can restrict operator traffic from entering residential areas; implement weight limits on access roads and levy maintenance fees for heavy usage of public roads. Such measures can reduce flexibility and increase cost but failure to address community concerns can impact public relations, and potentially result in more intrusive restrictions.

● **Delivery assurance for dynamic, volatile operations** Operational techniques associated with hydraulic fracturing are still maturing so there is high volatility in daily activity plans. In some operations, the changes to planned water movements on day of execution are averaging approx-





imately 60%, based on Accenture interviews with shale gas operators in the Marcellus region. This is set against a backdrop of limited operational visibility, with metrics and data relating to the operations often difficult to ascertain. Providing delivery assurance is critical, but over-supply will result in congestion of vehicles at the well pad and on surrounding roads, leading to health and safety exposure, challenges in managing congestion and high lifting cost. Conversely, a shortage of water can stop the operation, causing considerable cost wastage in a cost-marginal operation.

● **Talent and organisation** The concentration of operators working within a shale gas basin and the often remote nature of the locations, away from traditional oil and gas recruitment areas, is creating an acute war for talent as operators seek to recruit skilled road transport personnel in execution and management roles. This situation is compounded by the lack of experience in road transport within many operators and the need for a flexible workforce as the operations expand and contract over time. Moreover, with a large local workforce, union relationships need to be handled delicately to reduce risk of disruption.

## Opportunities to reduce water movements

Depending on the shale play, there are a number of levers that can be used to reduce the number of water truck movements.

● **Pipelines** Pipelines are increasingly used in the more mature basins as alternatives to road transport, but often, the final movement to the well site will still require road transport.

● **Water reuse and recycling** Water reuse and recycling can significantly reduce the volume of water movements. In the Marcellus and Fayetteville shales, some operators reuse 80-100% of flowback water, but in most cases, the flowback volume only accounts for 10-25% of the total water needs.

● **On-site water treatment and disposal** The development of on-site wastewater treatment and disposal technology can reduce the requirement to transport water, but these options will not be available in all basins.

● **Non-potable water sources close to shale developments** In particular, closed loop water systems where non potable water is sourced, treated and reused can significantly reduce water transportation costs in addition to having environmental benefits, but these options will not be available in all basins.

● **Propane gel and nitrogen foam used instead of water** However, there will still be movements associated with these alternatives and the cost of treating these waste streams could be more expensive.

The primary short-term and possibly most effective lever to cut miles travelled by moving water is implementing the existing leading logistics practices. Streamlined efficient processes, targeted use of specialist software, deployment of skilled logistics experts, and better commercial management all help achieve significant reduction in truck miles for improved delivery assurance.

An example is targeted use of technology to provide real-time information on water inventory levels and vehicle locations. This information allows effective management of wait times and inventory levels of water across the basin, to reduce health and safety risks, congestion, cost and provide delivery assurance. The detailed metrics generated through improved data also allow the logistics team to drive targeted continuous improvement initiatives, measure carrier performance and confirm freight payment compliance to further improve operations.

Basin-wide collaboration in logistics infrastructure and the management of logistics could reduce the overall costs of operating in a basin. Many shale gas basins feature a number of oper-





ators working in close proximity and in the same regulatory environment.

Where there are basin-wide infrastructure challenges, such as a lack of heavy vehicle-suitable roads and limited central water storage locations, operators should consider developing infrastructure resources collaboratively. This approach provides a holistic view across the basin, enabling operators to design their supply chain network in an optimal way. Additional benefits include preventing duplication in infrastructure networks. This reduces investment cost and logistics impact on the environment and local community.

Operators could work together to develop local suppliers so they perform to an operational level in line with industry standards in areas such as water hauling and camp services. This helps reduce the supplier development effort, while maintaining control and competitive advantage.

Finally, carrier capacity sharing (operators selling their excess capacity to other operators) and a basin-wide logistics management platform allows more information to be available to all operators and may reduce wasted capacity and congestion.

### Opportunities for improvement

Depending on the shale's characteristics and regulatory requirements, operators are likely to use the lowest-cost option allowed by regulation, but with a preference for reducing water use or for water reuse or water treatment in cost-neutral situations. However, we have identified six areas for improvement:

- **Developing an ecosystem of suppliers** Building longer-term relationship with a suite of suppliers means a suite of technologies, operations and services can be supplied and tailored. It is common for operators to have different water treatment and disposal suppliers in every basin. This limits research and development and continuous improvement opportunities, "re-inventing the wheel" for every basin.

- **End-to-end chemical net balance** Water use and treatment is often broken up with different groups responsible for sourcing and disposal, depending on volume and water quality. In some instances, water could be pre-treated to remove corrosive or scalant properties, so corrosion inhibitors and anti-scalants would not be needed in fracturing fluid or removed during wastewater treatment.

- **Reducing water movements** Use of closed loop systems, pipelines, onsite treatment and disposal, best practice logistics processes and systems, and basin-wide logistic management solutions will help reduce water movements.

- **Implementing different operating models for flowback versus produced water** Flowback water has a diverse set of options given the volume and reuse opportunities. Produced water is better suited to sharing treatment and disposal across multiple operators given the small volumes per well and long-tail of production.

- **Blending and optimisation** In the same way that a refinery recognises that every octane point has value, so does water quality. Given the cost of treatment, water should only be treated to the quality needed for its intended use.

- **Technology research and development (R&D)** Given the availability of freshwater and the dominance of underground injection wells in the US, relatively modest progress has been made in R&D around alternatives to potable water for fracturing and the productive use opportunities for wastewater. There will be continuous improvement of existing technologies to lower costs. We expect new innovations to use alternative water sources (mine drainage or salty water) and disposal (industrial uses).

There are still many opportunities to improve water use, to not waste a drop of water. As the international development of shale gas, tight gas and tight oil grows, water use will continue to improve. In the markets where water is scarce, like







China and Saudi Arabia, we expect an increased emphasis on R&D in this area.

*Melissa Stark is the Global Managing Director of New Energy at Accenture..*

## Water management technology for hydraulic fracturing projects

*By Dr Katharina Gruenberg*

*Strict regulation adds to the technical challenges faced by operators.*

“Estimated shale oil and shale gas resources in the United States and in 137 shale formations in 41 other countries represent 10% of the world’s crude oil and 32% of the world’s natural gas technically recoverable resources, or those that can be produced using current technology without reference to economic profitability”, according to an EIA-sponsored study released in 2013.

As the shale oil and gas industry grows, so are the concerns around the impact of its operations in areas such as water, road and air quality, seismic impacts and greenhouse gas emissions. Hydraulic fracturing (fracking), the process used to produce shale gas and oil, requires significant volumes of water compared to wells producing from conventional reservoirs. In comparison to other sectors, such as agriculture and electricity production, the oil and gas industry withdraws much less freshwater as global figures show (UN, 2012; FAO AQUASTAT). Yet, the need for water in the shale industry comes with the backdrop that increasing quantities of freshwater withdrawal and water quality issues are two areas of global environmental concerns (UNEP, 2013).

This creates enormous technical challenges for oil and gas operators who use hydraulic fracturing as a means of extraction.

According to the national hydraulic fracturing chemical registry for the US, FracFocus, a typical well requires around 18.9 million litres of water to drill and fracture, depending on the basin and

geological formation. Most of the water is needed for the fracturing process. Large volumes of water mixed with sand and chemicals are pumped into the well to facilitate the extraction of gas and light oil. Water is also used, like in conventional oil and gas production, in the drilling stage, as water is the main component of the drilling fluids. Further, water in small quantities might be used on site for dust suppression and for cleaning and flushing drilling equipment. While the industry is increasingly recycling and reusing water, freshwater is still needed as brackish water is more likely to damage the equipment and result in formation damage that reduces the chance of a successful well. As the industry grows, so does the pressure to increase the efficient use of freshwater and decrease fresh water withdrawal (Accenture, 2012).

Water quality and water contamination with respect to shale gas and oil production has, just as freshwater withdrawal, raised concerns. The Massachusetts Institute of Technology gas report from 2011 highlighted a meta-study of publicly reported incidents: while approximately 20,000 shale gas wells were drilled and fracked between 2000 and 2010, there were only 43 “widely reported” water contamination incidents related to gas well drilling.

## Water management framework

The responsible use of water is a vital part of the shale gas industry. In 2013, IPIECA highlighted that the term “water stewardship” – the use of water that is socially equitable, environmentally sustainable and economically beneficial, achieved through a stakeholder-inclusive process that involves site and catchment-based actions (Alliance for Water Stewardship), is now a recognised concept in industrial water management. To help industry with water stewardship, IPIECA developed a water management framework. “The IPIECA Water Management Framework is a cyclical



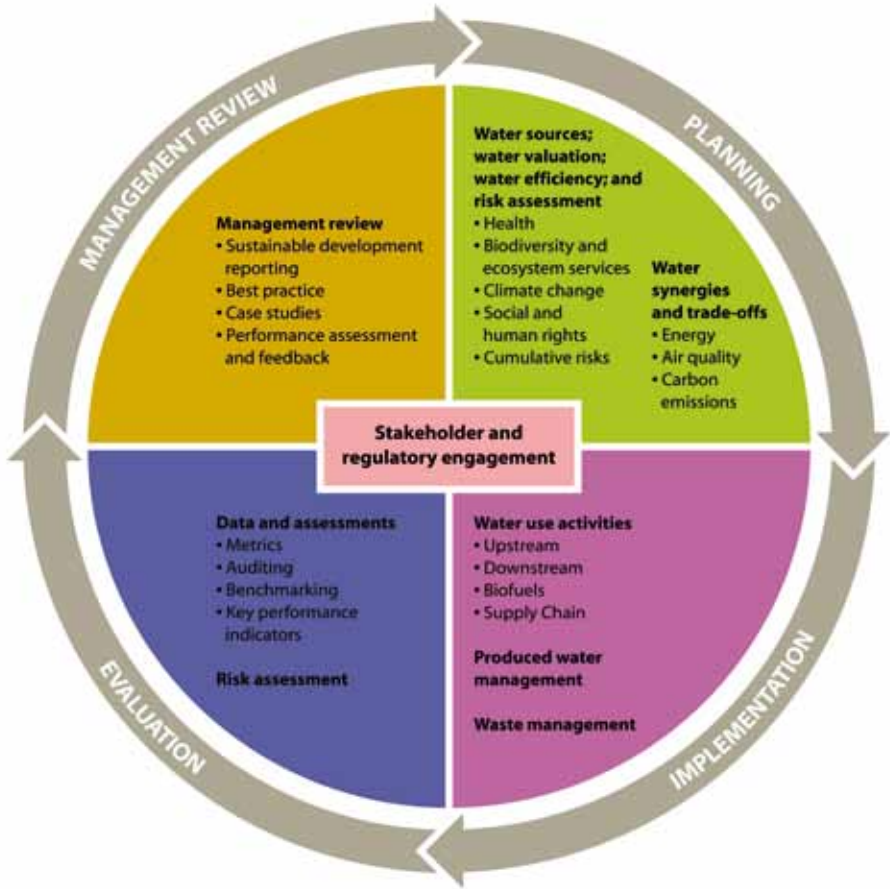


Figure 2: The IPIECA Water Management Framework.

process of planning, implementation, evaluation and review, focusing on water resources, water use and efficiency and wastewater management.” (IPIECA, 2013) *Figure 2* summarises the four core components of the Water Management Framework process.

Water resourcing for the fracturing process, as well as management of the produced water, are the main challenges for hydraulic fracturing projects. The amount of water needed can be reduced by further increasing the efficient use of water. Further, optimising water use across industries

and operations may also expose wider opportunities for efficient water use.

With regards to wastewater, the IPIECA Water Management Framework suggests that reuse and recycling potential “should be recognised and assessed, and where possible prioritised, by balancing technical, social and economic factors with the net environmental effects”, to avoid unintended consequences.

*Dr Katharina Gruenberg is the WPC UK Youth Representative.*



# Water management for LNG, FLNG and GTL projects

LNG, along with FLNG and GTL operations, require careful water management.

## Water management for LNG projects

*By Georg Oftedal*

Liquefied natural gas (LNG) is achieved by cooling gas to a temperature of  $-162^{\circ}\text{C}$  or lower. The volume of the gas being shifted into liquid is

reduced by a factor of roughly 600. Once the gas has been reduced to liquid, it is more easily transported. This form of energy is now a significant component for filling the needs of many countries. In 2014, global LNG production was up 5 million metric tonnes per annum (mmtpa) to 246 mmtpa.

The process of liquefying the natural gas is similar to that which is used in household refrigerators. The refrigerant gas, which refrigerates the feed gas, is cooled, compressed, and condensed. The temperature drops when valve pressure is reduced. The feed gas must reach a temperature of  $-162^{\circ}\text{C}$  or lower. Methane, one of the primary constituents of natural gas, liquefies at this temperature.

During the LNG process, methane, ethane, and propane are used as refrigerants. Many times, they are used as a mixture. The refrigerant component and the pre-treatment are usually included within the process at the liquefaction facility. The recovered by-products are liquefied petroleum gas (LPG) and its condensates.



LNG liquefaction facilities can consume significant amounts of water.





Prior to liquefaction, water management procedures depend on how the gas is extracted in the first instance. The technologies outlined from pages 30-35 and the water management strategies for unconventional hydrocarbon extraction outlined from pages 36-47 describe how operators can meet these challenges.

The use of water for process cooling at LNG liquefaction facilities and for revaporisation heating at LNG receiving terminals can consume significant quantities of water and may result in discharge streams. Other waste waters that can be generated at LNG facilities include process wastewater drainage, sewage waters, fire water, equipment and vehicle wash waters, oily waters and tank bottom water (which comes from condensation in LNG storage tanks). If biocides or chemical use is required, additives should be carefully selected in terms of concentration, biodegradability, toxicity, bioavailability and bioaccumulation potential. Strategies for operators to deal with produced water are outlined from pages 56-61.

### Replacing water cooling with air cooling

The three primary types of liquefaction used are expansion, mixed refrigerant, and cascade cycles. The vast majority of commercially available processes for the liquefaction of natural gas use one or more of these processes. Sometimes, the cycles are combined. The processes can include the integral incorporated cascade process, compact LNG technology, or mixed-fluid cascade process. Other processes include the single mixed-refrigerant cycle, dual mixed-refrigerant cycle, the dual mixed-return cycle and the propane-precooled mixed-return cycle.

One thing these cycles have in common is that they usually have water as one of the methods used for cooling. However, droughts have created demand for LNG plants using less water. This has led to the development of air-cooled LNG plants which use very little water.

Air-cooled plants are not without their challenges. These plants tend to be constrained by the local air temperature. Furthermore, the banks of



Air-cooled heat exchangers, like those used at SEGAS LNG in Egypt, greatly reduce a plant's water requirements.



heat exchangers will often raise the temperature surrounding the plants. This can be a problem if the plant is located in an ecologically sensitive area. Air-cooled heat exchangers (ACHE) usually take the form of large fans that are on top of the main pipe racks and cool the process fluids used by the LNG plant. When the air intake rises in temperature due to hot air recirculation (HAR), this creates a problem as the hotter air re-enters the system, decreasing its efficiency. This means that the performance level of the ACHE is highly dependent upon the air intake temperature at the turbine drivers. Even a single degree temperature increase can cost several million dollars in lost efficiency. Simulations done with plants that were air-cooled and located in Arctic regions have indicated that they can be as much as 80% more efficient than similar LNG facilities located in warmer regions.

When air cooling is not an option, cooling water should be discharged to surface waters in a

location that will allow maximum mixing and cooling of the thermal plume.

*Georg Oftedal is Business Strategy Manager for the Resources/Energy division of Accenture ([www.accenture.com](http://www.accenture.com)).*

### **CSG-to-LNG water management case study**

*Australia-Pacific LNG is setting a high water management standard for CSG-to-LNG projects*

Australia Pacific LNG has an industry-leading programme for dealing with produced water from its coal seam gas (CSG) activities, the first to use reverse osmosis to turn produced water into clean, pure water for re-use.

In CSG activities, water gets trapped in the gas in coal seams and it needs to be pumped to release the gas. This water is known as “associated water” and its quality varies from region to region and between well sites. Mostly, however, it’s brack-



The water treatment plant at Spring Gully processes 12 megalitres of water per day which is used to irrigate renewable crops.





ish and not suitable for consumption or agricultural reuse without treatment.

As well as varying quality, the quantity of water produced during CSG extraction differs between locations. The quantity of water tends to peak at the start of production before gradually decreasing over time.

Australia Pacific LNG has invested almost \$100 million in state-of-the-art reverse osmosis water treatment plants, and will continue to do so throughout the project. The water treatment facility in Australia Pacific LNG's Talinga gas fields, in the Australian state of Queensland, uses cutting edge water management and treatment technology to purify and desalinate up to 40 megalitres of water each day. A second facility in the Spring Gully fields, also in Queensland, treats 12 megalitres per day.

Water is a precious commodity in Australia so Australia Pacific LNG finds ways to put the produced water from CSG operations to beneficial use. At Spring Gully, treated water is used to irrigate a renewable crop of Pongamia trees. This particular tree was chosen because of its ability to be fully utilised and recycled, down to the last leaf. Its uses include creation of biofuel, protein meal for stock feed, electricity generation from its waste streams and as a plant fertiliser. In Talinga, treated water is used for crop irrigation.

Monitoring water quality and levels is another important aspect of Australia Pacific LNG's operations. Comprehensive monitoring of water levels and quality takes place in the most commonly used aquifers and geological layers not generally used for groundwater. In particular, pressure and water changes in the geological layers above and below the coal seams are closely monitored. This is an early detection process to allow time to implement mitigation of any impacts before effects are noticed at landholder bores. Water quality and water level test results from water storage facilities and monitoring bores are submitted to the government.

Australia Pacific LNG works with the local communities in which it operates to look at the other uses for this treated water. Options include agricultural irrigation, industrial uses, urban uses, discharge of clean water into local river systems and reinjection into suitable underground aquifers.

## Water management for FLNG

*By Vijay Anne*

*It is important to be responsible with water at all stages of the FLNG process.*

Water management is an important consideration for stakeholders involved in floating liquefied natural gas (FLNG) operations. How water is used in these facilities depends upon the type of the well drilled, be it a horizontal directional well or a vertical well.

Gas is liquefied for ease of transport in both LNG and FLNG projects. FLNG refers to liquefied natural gas (LNG) operations that use technologies that allow for the development of offshore natural gas resources. Cost-effectiveness is a major advantage of FLNG facilities. It means remote and very small fields can be developed with innovative process technologies.

The design and commissioning of FLNG ships are very similar to that of a floating, production, storage and offloading (FPSO) operation where the ship is built with all the process facilities and then towed to the production site. The energy required to run FLNG is mostly used from the natural gas produced and other energy generation processes in the field.

FLNG projects include a pre-commissioning/ commissioning phase, well development, process operations and, finally, decommissioning. Water management is important during all four phases.

Development drilling is one of the main elements where drilling is processed by mobile offshore drilling units under standard procedures. The number of production wells that are to be drilled depends on the hydrocarbon reservoir and available resources to run the process. Water is





The design and commissioning of FLNG vessels are very similar to that of a floating, production, storage and offloading (FPSO) operation.

primarily used to prepare water-based drilling fluids and for hydraulic fracturing.

#### Water-based muds

Water is cheap, readily available and good for dissolving things and allowing reactions to take place faster. Water can also be used to change the rate of reactions that occur with other chemicals.

Water-based muds are proposed based on well conditions, and are generally used when the well hole size is shallow and the well hole sections (usually 17.5", 26" and 36") are less technically challenging. These muds are of various types such as freshwater/bentonite, seawater gels, biopolymer/water and sea waters, prepared from pure water, barite, soda, ash, lime, caustic soda and bentonite with various properties.

Some of the important properties of drilling muds include controlling formation pressure and damage, allowing easy formation evaluation, releasing cuttings to the surface, and cooling the drill bit and the drill string.

#### Hydraulic fracturing

Water use in the process of fracturing to extract

gas from depleted wells can be described as a five-stage cycle initially from water acquisition to wastewater treatment and disposal.

● **Cycle 1: Water acquisition** Water from the sea is withdrawn and treated to meet specific requirements, so as not to damage any formations with the chemicals present in the sea water, and then used for hydraulic fracturing. Produced water from the well can then be recycled for further use in various operations in the facility.

● **Cycle 2: Chemical mixing** Once the water is removed from the sea, it is mixed with various proppants (granular substances used to keep the cracks open after the fracturing fluid from the well is withdrawn) and additives to prepare the fracturing fluid. The concentration and types of additives to be used are determined based on the well condition.

● **Cycle 3: Well injection** The pressurised fluid, once injected, creates cracks in the reservoir formation allowing oil and gas to flow to the surface. The amount of water used in the hydraulic fracturing depends on the type of well drilled. Horizontal wells typically require 3-5 million gallons of water depending on the length of the





Caribbean FLNG has one 0.5 MTPA water-cooled liquefaction train.

lateral position of the well drilled and the number of fractures. The horizontal directional and vertical wells require 0.1-1 million gallons of water.

● **Cycle 4: Produced water** Once the fracturing is processed, pressure from the reservoir is released, and the fluid flow direction is reversed. Water and excess proppant flow to the surface through the wellbore. The water that comes back to the surface from the hydraulic fracturing process is referred to as flowback. Natural gas and water is produced from the reservoir, where some of the water is returned with the fracturing fluid and some with formation waters, commonly referred to as produced waters. The produced waters contain chemical additives from the hydraulic fracturing process, various fluids and naturally occurring substances.

● **Cycle 5: Wastewater treatment** The produced water from the wells is treated in several ways for reuse or to meet environmental standards before being disposed of into the sea or injected into abandoned wells, if no longer useful.

These are the major areas where water is used in development drilling on FLNG facilities, including, but not limited to portable usage in the

facility, and various operations during construction. Water is also used in case of an emergency fire on the facility.

#### Water for cooling on FLNG operations

Water is used to cool down equipment used for processing gas, and to remove heat from FLNG facilities. A water cooling system is considered to be the most effective means of cooling, reducing energy consumption by the facility and producing less noise. Sea water is collected directly from the pipeline passing through the floating ship at a depth of around 30m beneath the surface. The heat released from the process equipment is absorbed in a closed loop system – this means the liquefaction refrigerants and the water are never in contact, but these fluids will leave back to the sea from another outlet.

If the water temperature is very high, it can be used for heat exchangers provided it is suitable and thus will avoid corrosion. The water that is pumped from the sea might contain organic materials which can clog the cooling systems. In such cases, chlorination would be used to avoid this and keep production running smoothly.





### Water use in gas treatment

Various unwanted components are found in gas extracted from the reservoir. As such, it is essential to treat gas before it is liquefied and transported in the pipelines. The feed gas, which contains mercury, CO<sub>2</sub>, SO<sub>2</sub> and water, is first directed to the slug catcher, where the unwanted slug (liquids that can damage the pipeline) is first removed. The feed gas is then sent to desalting and desulphurisation units where huge quantities of high-quality water (wash water) are required to run the process. The most efficient method to produce wash water is by processing seawater for further use.

Various purification processes are available to remove the acid gases from the feedstock. Of these, amine treatment under chemical absorption is the best process to remove these unwanted gases in two simple steps. The residue in the gas to be transported from the FLNG facility should be not more than 50 PPM of CO<sub>2</sub>/4 PPM H<sub>2</sub>S. Amine gas treating is also known as amine scrubbing, acid gas removal or gas sweetening and it refers to the processes that use aqueous solutions of alkylamines – which are usually referred to as amines – to remove hydrogen sulphide and carbon dioxide. Once acid gases are removed, feedstock is then sent to a dehydrating unit to remove water.

### Removing water from gas

Once the oil, CO<sub>2</sub>, SO<sub>2</sub>, inert gases and other condensates are removed, it is crucial to remove water from the liquid gas streams. Separation methods and complex treatments are used to remove water either at the wellhead or on the floating facility. Dehydration is one of the most common treatments to remove water vapour from LNG, which involves conventional methods such as absorption or adsorption. Dehydrating agents are used to remove water in the process of absorption and condensation for adsorption.

- **Absorption Technique** Glycol dehydration is one of the best techniques used for absorption, where liquid desiccant dehydrators eliminate water traces from the gas extracts. The glycol that is used in the process has a high affinity to water and hence when processed, the water is completely absorbed from the gas stream, the particles sink below the dehydrator and the gas stream leaves the unit, leaving no water behind. These units can very easily be installed in the restricted space of an FLNG unit.

- **Adsorption Technique** Adsorption is the process whereby water is removed from gas extracts by using solid desiccants such as granular silica gels or activated alumina. The liquid gas is passed through the desiccants in huge vertical adsorption towers from top to bottom. When the gas is passed through the beds in the towers, water present in the stream is retained on the desiccant particles and the dry gas is then sent for further processing to the bottom of the tower. The number of towers to be installed can be decided based on production levels and space availability on the facility.

Adsorption is more effective than glycol dehydration units, especially when large streams of gas are extracted under high pressure. Once the desiccants in the adsorption are saturated with water, high temperatures are used in the towers to heat the gas and allow the heated gas to pass through the beds. Water present on the desiccants is then vaporised, allowing further use for dehydrating the streams.

Research and development on implementing best practices from LNG plants and developing more emerging innovative solutions can help FLNG operators improve water management and convert this investment into a business success.

*Vijay Anne, has completed a Masters Degree in Petroleum Engineering at Robert Gordon University and is a WPC Writing Fellow.*



### GTL water management case study

***The Qatar-based Pearl project leads the way in innovation for GTL water management.***

North-east Qatar is the location for Shell's highly advanced Pearl GTL project. It comprises up-stream gas production facilities and an onshore Gas-to-Liquids (GTL) plant that produces 140,000 barrels per day (bpd) of GTL products. The GTL plant also produces approximately 120,000 bpd of associated condensate and LPG.

A Zero Liquid Discharge (ZLD) facility was required for the Pearl GTL plant. It had to be designed to deal with GTL effluent water as well as all other water streams, all of which had to stay inside the fence. In total, 12 different water streams were to be treated at the Effluent Treatment Plant (ETP) at eight different locations. Additionally, five different recycled water qualities were required.

Veolia was contracted for the design-build of the Pearl GTL ETP in a joint venture between Veolia, Saipem and Al Jaber, a local construction company.

The two main challenges were the sheer scale of the operation and the scarcity of water in Qatar. As such, Shell and Qatar Petroleum commissioned a ZLD option as the most sustainable solution. The plan would involve water produced in the transition from gas to liquids being sent to the ETP for treatment so it could be reused in the production process. The ETP can handle 45,000m<sup>3</sup>/day.

Wastewater is treated by ultrafiltration and reverse osmosis with the overall aim being complete reuse within the factory process. As a result, no liquid effluent is discharged into the natural environment. Reverse osmosis brine treatment is carried out by evaporation and crystallisation – this technology achieves ZLD where only salt crystals are produced. Other technologies include a controlled discharge facility, flocculation and flotation units, aerobic biological treatment, submerged ultrafiltration, three-pass reverse osmosis, UV treatment for irrigation water and sludge dewatering using a centrifuge.



Pearl GTL's choice of a ZLD water treatment system ensures no liquid effluent is discharged into the environment.





# Produced water storage, treatment and disposal

*By Dr Abdulkareem M AlSofi*

An overview of the challenges operators face when managing produced water.

Significant volumes of water are produced in association with hydrocarbon operations. This produced water consists of water that was injected into the reservoir and formation water that was initially residing in the reservoir. In conventional oil fields, the volumes of this associated water increase with time. Produced water represents the largest waste-stream in the oil and gas industry.

In many areas, operators on a daily basis handle more water volumes than oil. Obviously to meet sales specifications, this water – in addition to associated gas and solids – must be separated from the oil. This separation is achieved in the main hydrocarbon separation facilities.

After this main stage of separation, the processed produced water still contains between 100 to 2,000 mg/L of hydrocarbons. Such relatively high concentrations can be detrimental to the environment. Processing facilities often include secondary and auxiliary treatment stages to remove those remaining hydrocarbons and achieve levels that are acceptable for water disposal.

## Produced water storage

Pits and tanks are used for produced water storage. Generally due to volume considerations, pits are still the most common method for storing fluids in well operations. Different types of pits have been used in produced water storage and processing. Those pits are essentially similar but, according to their function, they can be classified as collecting, skimming, percolation, and evaporation pits.

Collecting pits are used for produced water storage before its disposal. Skimming pits are used for oil separation as oil is skimmed from the top. Often pits are used for both collecting and skimming and they can be either lined or unlined.

Depending upon the composition of produced water, the duration of its storage and the soil condition, including the soil permeability, pit lining might be necessary to prevent the seepage of produced water to the subsurface.

However, in many areas, operators are required to use liners for produced water pits. Guidelines and regulations for the construction of produced water pits exist but vary in different regions. For example, some regions require pits used for long-term storage to have a minimum distance from water bodies and for pits to not intersect the water table.

In general, pits should not be used for produced water disposal, but it can be a more practical option in areas where volumes of wastewater generated are minute, especially in arid climates. Pits with disposal functionality are either evaporation or percolation pits. Evaporation pits are lined pits in which water is left to evaporate leaving a solid residue that is then disposed of in landfill. Percolation pits are unlined, allowing water to seep through the soil where it eventually evaporates back into the atmosphere. However, the use of percolation pits for disposal has been phased out due to the lack of control over the ultimate fate of the produced water.





Tanks are also used for produced water storage, especially in situations where pit construction is not practical. A group of tanks used for produced water storage is referred to as a tank battery. In most places, this battery is contained within a dyke with a typical capacity of one day or a day-and-a-half's water production.

The purpose of these dykes is the containment of accidentally released fluids. Tanks used for the storage of oil and produced water vary in material, placement, and size depending on operational needs. In most places, there are no specific standards, regulations or guidelines. For instance, in the US only two states, Colorado and Wyoming, require tanks used for produced water to meet specific standards. The Underwriters Laboratories or American Petroleum Institute standards are used in Colorado, and the Federal Spill Prevention Control and Countermeasures Standard is used in Wyoming.

An overall lack of specific requirements across most regions allows a multitude of materials to be used such as steel, plastic and fibreglass. For re-injection, steel tank storage is preferred. This is to eliminate any contamination of the water supply by dust and other particles. However, in such cases, the corrosive nature of produced water must be taken into account to avoid any possible failure and resultant leakage.

### Produced water composition

Produced water contains a mixture of hydrocarbons, salts and solids. Hydrocarbons can be present in produced water in different forms: dissolved gases, dissolved oil, and dispersed oil. Dispersed oil is basically small oil droplets with diameters ranging from a fraction of a micron to a couple of hundred microns. The presence of dispersed oil droplets is the main produced water disposal challenge for oil operators.



Tanks are used for produced water storage.





An Environmental Auditor looks at some before and after samples of the dewatering process that were treated at the rig. The water is tested to establish the water recycling process during the drilling operations.

Dissolved oil is water-soluble hydrocarbons. The concentration of dissolved oil found in produced water depends on the properties and source of the hydrocarbon as well as operational factors, such as the type of artificial lift employed. Typically, dissolved oil concentrations are relatively small. However, the concentration of dissolved organics in some cases reaches the maximum limit allowed for offshore discharge.

As for dissolved gases, they are mainly natural gases, hydrogen sulphide and carbon dioxide. Corrosion and scaling are the main issues arising due to the presence of dissolved gases.

In addition to hydrocarbons, produced water contains dissolved and suspended solids. Dissolved solids are inorganic constituents. The concentration of total dissolved solids in produced water ranges from less than 100 to 300,000 mg/L. Waters with total dissolved solids between 10 and 30,000 mg/L are known as brackish water.

Suspended solids are mainly sands, clays, and chemical products that are added to water either pre-injection or post-production, such as fracturing proppants and corrosion inhibitors, respectively. The concentration of suspended solids is typically small, except when hydrocarbons are produced from an unconsolidated formation. In such cases, large volumes of sand can be produced depending on the use and efficiency of sand control measures.

Finally, produced water can contain naturally occurring radioactive materials (NORM). The concentration of those radionuclides is usually too low to present any ecological threat with respect to produced water disposal. However, in some instances, produced water contains sufficient radionuclides to result in radioactive precipitates in surface piping. Such pipes must be disposed of according to the relevant regulations governing the disposition of NORM materials and wastes.



### Produced water treatment

After primary gravity-based separation, produced water still contains concentrations of hydrocarbons ranging from 100 to 2,000 mg/L. Those hydrocarbons are predominantly dispersed oil droplets with diameters lower than a few hundred microns. Additional treatment of produced water is therefore necessary to abide by disposal regulations. The main objective in this secondary treatment is lowering the concentrations of dispersed oil. However, in some instances, removal of dissolved hydrocarbons might also be necessary. In addition, where inland disposal is permitted, a reduction in produced water salinity might be needed.

According to the type of pollutant it targets, secondary produced water treatment can be categorised as: de-oiling, removal of organics, and demineralisation. Three basic phenomena are used in the design of de-oiling equipment: gravity separation, coalescence, and flotation. Gravity separation is capable of removing droplets that are as small as 100 to 150 microns. Coalescence is capable of removing droplets that are as small as 30 to 50 microns. Flotation is capable of removing droplets that are as small as 10 to 20 microns.

In such de-oiling facilities, small amounts of solids might create problems. This will depend on the particle size and their relative attraction to oil droplets. Solid particles can attach to oil droplets preventing their separation. In such cases, chemicals are added to break the attraction between solid particles and oil droplets. Most operators are able to meet disposal regulations using the above de-oiling methods.

However, the removal of dissolved oil is sometimes necessary. In such cases, produced water streams with high concentrations of soluble oil can be recycled to a fuel separator. Other technologies are being developed and evaluated. Two of the most promising technologies for the removal of soluble hydrocarbons are bio-oxidation and carbon adsorption.

In bio-oxidation, produced water flows through a fluidised bed in which aerobic bacteria biodegrade the dissolved hydrocarbons. In carbon adsorption, produced water flows through a fixed bed containing activated carbon media to which the soluble hydrocarbons adsorb.

Where reduction in produced water salinities is necessary, demineralisation technologies include electrodialysis, reverse osmosis, forced evaporation, and vapour compression. In electrodialysis, a semi-permeable membrane with the application of electricity selectively separates ionic compounds. In reverse osmosis, a semi-permeable membrane with the application of pressures that are greater than the osmotic pressure retain the solute on the pressurised side of the membrane. Finally, in forced evaporation and vapour compression, water is converted to steam leaving behind the dissolved solids as a precipitate.

### Produced water management

There are three ways of dealing with any waste stream. We can reduce it, reuse it, or dispose of it.

The reduction of produced water volumes at the source has been practised widely. Various subsurface water management technologies have been developed. Most of those water management techniques were developed to improve the productivity and recovery of oil but they did include some environmental advantages. Those technologies include inflow control devices, water shut-offs, downhole oil/water separation and disposal, and downhole water sinks. We can even count horizontal drilling as a subsurface water management technique especially where it is used to combat water coning while depleting thin strata.

Secondly, the reuse of produced water is primarily limited to its re-injection in oil reservoirs for pressure maintenance and secondary recovery. This practice is widely employed in the industry. However, in limited instances, treated produced







Taking a water sample from a pipe on the production deck of an offshore platform.

water can be reused for irrigation, animal watering, and groundwater recharging.

Finally, the last and least preferred option to manage produced water is its disposal either via direct discharging or underground injection.

### Produced water disposal

The most common produced water disposal method is its injection into a subsurface formation. The main concern in this case is the potential for a well to offer contamination between the disposal formation and an overlying fresh water source. The main cause of this contamination is the failure of a well casing. For this reason, periodic mechanical integrity tests are usually required.

Offshore, this subsurface disposal option is problematic mainly due to the space and load

considerations of platforms. Therefore, in offshore fields, produced water is usually treated and discharged into the sea. The main concern here is the concentration of hydrocarbons in the discharged effluents. Although the concentration of dissolved solids is usually high enough to be considered toxic to marine life, the rapid mixing and dilution diminish environmental impact.

Conversely, in shallow near-shore waters, mixing is less effective. In those settings, a plume with high concentrations of dissolved solids can extend some distance away from the discharge point. For this reason, it is difficult to obtain permits for the discharge of saline produced water near shore, even if the produced water hydrocarbon content is very low.

Onshore, however, produced water discharge can be a viable disposal option. Firstly, discharge into lined evaporation pits is still allowed in some arid areas where evaporation rates are competitive with production rates. For instance, in the US state of Wyoming, surface discharge into dry stream beds is a common disposal scheme. In less arid areas, evaporation rates are limited. Additionally, when pits are not perfectly sealed, seepage of saline water is possible and domestic water wells can be contaminated. Secondly, in arid areas with little surface water, the discharge of produced water for beneficial purposes such as irrigation, animal watering, and ground water recharging might be allowed.

### Disposal regulations

Different countries have different guidelines for the discharge of produced water. Onshore, disposal is generally prohibited, except for limited cases related to produced water disposal in arid areas. In such cases, disposal might be allowed under limitations on produced water salinity being within a few thousand mg/L and its total hydrocarbon (oil and grease) content being below 30 mg/L.



Regulations for the overboard discharge of produced water into offshore waters focus on its total hydrocarbon content. The limitation on the total hydrocarbon content ranges from 15 to 50 mg/L depending on the jurisdiction.

For instance, the Canadian guidelines limit the total hydrocarbon content in discharged water to a monthly average of 40 mg/L and a daily average of 60 mg/L. The guidelines adopted by the US Environmental Protection Agency (EPA) are slightly stricter. The EPA limits the total hydrocarbon content in water discharged into federally regulated water to a daily maximum of 42 mg/L and a monthly average of 29 mg/L.

In various regions, including Australia, Brazil, Brunei, Columbia, Ecuador, Malaysia, Thailand, the Middle East, and the North Sea, the total hydrocarbon limitation is 30 mg/L. Finally, in some countries, regulations also specify the best available produced water treatment technology and the required reporting frequencies. For instance in the United Kingdom, monthly and annual reporting are required and gas flotation hydrocyclones are recommended as the best available technology.

*Dr Abdulkareem M AlSofi is a Reservoir Engineer for Saudi Aramco.*

### Case Study: Chesapeake

Chesapeake conserves water by reclaiming produced water through a water-recycling initiative called Aqua Renew, which has been in place since 2006. The project evolved from Chesapeake's involvement with the Barnett Shale Water Conservation and Management Committee in North Texas, as well as collaborating with the City of Fort Worth, Texas, which looked into recycling produced water from the Barnett Shale.

The water recycling initiative makes environmental and economic sense for Chesapeake. Reusing produced water cuts down on disposal transportation costs and the purchase of freshwater.

Generally, produced water contains a variety of salts, sand and silt found naturally in the Earth so freshwater is preferable for shale activities. Also, not all produced water can be recycled or reused because of quality issues and regulations. However, the company is experimenting with different additives and higher concentrations of salt in base fluids to expand the amount and quality of produced water that could potentially be considered for reuse. Chesapeake is also researching the use of brackish, non-potable aquifers as potential sources for fracturing fluids.

As of 2014, 97% of the wastewater produced by Chesapeake's Marcellus operations and 89% of the wastewater produced by the Utica operations is reused. In Marcellus North, 448.5 million litres of water per year are reused, which is enough water to complete approximately 30 Marcellus Shale wells a year without using any freshwater.

This is done by collecting and storing produced water in holding tanks before it is transferred to central locations. Here, suspended particles are removed through either gravitational separation or filtration. The water is then tested for salt and other minerals. This is to determine the rate at which it needs to be blended with freshwater so it is suitable for reuse. Once this ratio is determined, the water is transported to wells where hydraulic fracturing is scheduled to take place and mixed with fresh water during the completion phase.

Chesapeake is expanding its Aqua Renew programme across its operations. In the Mississippi Lime play in Oklahoma, more than 100 wells have been fractured using 100% produced water. This programme has been successful to date, but continues to be monitored for any long-term adverse production effects.



# Water management for Arctic operators

*By Georgia Lewis*

Arctic hydrocarbon development creates unique challenges for operators.

The harsh conditions faced by oil and gas operators in the Arctic create challenges not faced by operators in less hostile regions of the world. Water management is just one of these challenges and it is a challenge compounded by multiple factors. Harsh weather, particularly in winter, puts a strain on equipment; on Arctic land, poor soil conditions can

require additional site preparation; the Arctic icepack can damage offshore facilities; and access to Arctic hydrocarbon projects can be limited and difficult. Water quality overall is high in the Arctic and care needs to be taken to ensure this remains the case.

As well as harsh conditions, with winter temperatures ranging from  $-50^{\circ}\text{C}$  to  $0^{\circ}\text{C}$  over a nine-month period, the unique and highly sensitive biodiversity of the Arctic makes water management especially difficult. The variations on ice in the Arctic – permafrost, sea ice, glaciers, icebergs and lake ice – as well as seawater and fresh water; are all susceptible to pollution if careful water management practices are not in place. Arctic species, many of which live in water also need to be considered by oil and gas operators. These include Arctic whales, narwhals, seals, polar bears, 40 native seabird species, Arctic cod, Arctic char, capelin, pollock, salmon, herring and plankton.

## The main water management issues facing Arctic operators

For responsible operators in the Arctic, the protection of surface water and groundwater are im-



Preserving the rich flora and fauna of the Arctic, including protected species like the narwhal, must be taken into consideration by oil and gas operators.



portant priorities. Watercourses, topography and drainage patterns can be impacted by excavation and infill and this, in turn, can impact on wildlife and vegetation. Topographical changes can result in wetter, pond-dominated terrain while the use of fill material into surface water or permafrost can create higher, drier terrain

Arctic hydrocarbon operations can result in the contamination of groundwater and surface water with waste streams mainly coming from drilling activities, well treatment fluids, drilling muds, produced water, process water, wash and drainage water and sewage. Other causes of groundwater and surface water contamination include pipeline-related incidents, operational discharges, leakage, site drainage and accidental releases. Power generation, infrastructure development, and an influx of people to an area because of hydrocarbon development can also affect watercourses in the Arctic.

Operators also have to deal with challenges such as earthquake activity, seabed ice gouging, seabed permafrost thaw settlement, strudel scour and upheaval buckling when laying pipelines.

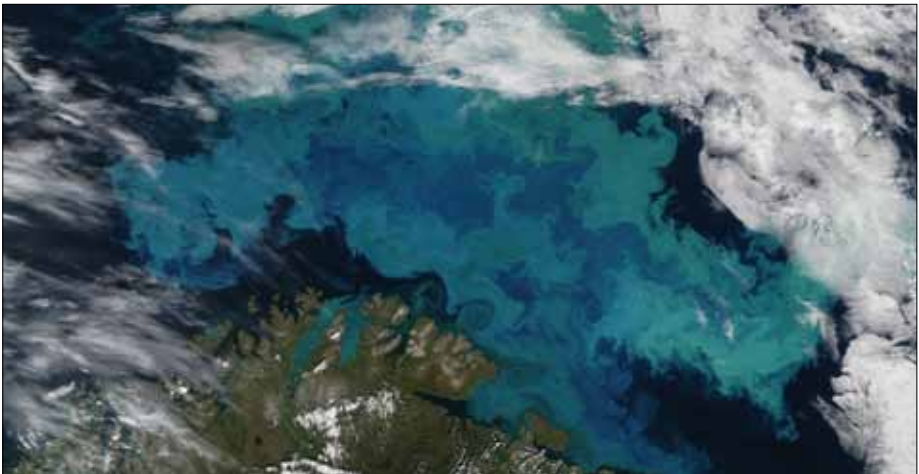
Water supply and availability can be affected by multiple Arctic hydrocarbon activities such as clearing of vegetation and water production processes. Surface water movement can be disrupted by vehicle traffic.

### Oil spills

Perhaps the most obvious and devastating way for an operator to contaminate water, oil spills can be disastrous for the Arctic. As well as contaminating seawater and onshore water, they pose an enormous risk to wildlife and vegetation.

In 1994, 140,000 barrels of oil were spilled in Russia's Komi Republic region and 20 years later, parts of the Kolka River are still affected. Grayfish population is down by 90% and in some places, the vegetation has not returned.

Offshore oil spills are hard to contain and can cover areas of at least 1000km<sup>2</sup>. Apart from the Komi Republic spill, there have been no major oil spills in the Arctic. However, important lessons should be learnt by operators in the wake of the 1989 *Exxon Valdez* spill in southern Alaska, where the conditions are comparable to the Arctic. Like the



Microscopic phytoplankton are present in vast numbers and form the basis of the aquatic food chain.





The *Exxon Valdez* oil spill and the resulting damage to the environment led to important changes in tanker design and operation in Arctic waters.

Arctic, the southern Alaska area where the *Exxon Valdez* spill happened has several species concentrated in small areas. Operators need to work to prevent spills and also to decide if, in the event of a spill, they will attempt to disperse the oil or let it wash to shore for an onshore clean-up operation. Both options have consequences for the environment, including water, so they need to be carefully considered, ideally with consultation at a local level with any residents who might be affected.



A Shell crew member taking part in a containment boom test during a training exercise near Valdez, Alaska.

After the *Exxon Valdez* spill, a tanker spill prevention system was put in place at Prince William Sound. This includes twin tug escorts for laden tankers, double hulls on all tankers, vessel tracking, ice-detecting radar, alcohol-screening of crew, regular tanker inspections and weather restrictions.

The 2007 oil spill onto the Alaskan North Slope tundra could have been prevented if routine inspections were carried out on the pipeline so the corrosion, which caused a rupture, could have been spotted and repaired. Shell, meanwhile, has developed Arctic-specific methods for oil recovery such as ice deflection, a method in which environmentally acceptable dispersants which are effective on ice are used.

Contingency plans also need to be put in place by operators to mitigate the damage in the event of an oil spill in the Arctic. Such plans need to include an alert process, a process to categorise the spill and a response action plan. They need to be tailored to take into account the Arctic weather conditions, facility type, and the capabilities and resources of the drilling zone.

In January 2012, a group of operators – BP, Chevron, ConocoPhillips, Eni, ExxonMobil, Shell, NCOC (North Caspian Oil Company) and Total – under the supervision of the International Association of Oil and Gas Producers, launched a major research programme, the Arctic Oil Spill Response Technology Joint Industry Programme (JIP). This aims to further industry knowledge on Arctic oil spill responses, with research focusing on the environmental impact of spills, trajectory tracking of released oil, mechanical recovery, on-site burning and dispersant chemicals. The Coastal Oil Spill Preparedness Improvement Programme (COSPIP) has also been a leader in developing oil spill contingency plans with the project's four categories of: strategy, equipment and software applications, logistics and chemistry.

Because current technologies to contain oil spills, such as skimmers and booms, are not effective when oil spreads under the ice cover, prevention remains the top priority for operators.

### Other water management processes for Arctic hydrocarbons projects

Initial evaluation is important. Before commencing a project, operators should thoroughly evaluate the site for multiple issues, such as the potential to affect fresh and marine waters, the water supply for local people, fisheries and wildlife. This is especially pertinent when water at a hydrocarbons site is also used by local people and fisheries. As such, it is important to consult with local communities on water management issues when water for domestic use, as well as other businesses or industries, may be affected.

### Meeting pipeline challenges

Arctic oil pipelines can't be buried in permafrost – the heat of the oil can cause the ice in the soil to melt and this, in turn, leads to pipelines sagging and leaking, another water contamination risk. In winter, water in the soil can freeze again, leading

to pipe movement, which is also potentially very damaging. Fast leak detection in Arctic oil pipelines is crucial because of the high risk of water contamination and other environmental damage. Furthermore, pipelines should be built so as not to disturb surface water.

North Energy has developed a pipeline solution aimed at protecting fisheries in the Arctic. The tunnel-to-oilfield concept has been used in areas such as Norway's Lofoten Islands. This solution, called the Eureka Concept, is made up of subsea tunnels leading to caverns where drilling rigs can be placed and wells drilled to multiple fields. Oil is then piped back onshore via separate tunnels.

The use of rail transportation has proven successful in the Russian Arctic as a safer means of transport, reducing the need for pipelines. For example, the northwest rail system, which runs through the Arkhangelsk province, Komi Republic and Yamalo-Nenetsky autonomous area, exceeds 8,000km. This system transports oil from the Timan-Pechora field by pipeline to the oil transshipment railway terminal at Privodino station.

An example of how to deal with the multiple challenges of seabed ice gouging, seabed perma-



Rail transportation in the Russian Arctic has been successfully employed to move oil and equipment with minimal environmental impact.





Oil pipelines laid over land in the Arctic must be raised off the surface, as seen here leading from Endicott Island, to prevent pipe movement, which can increase contamination risks.





Northstar Island – seen here surrounded in winter ice, was the first Arctic development to employ subsea pipelines.

frost thaw settlement, strudel scour and upheaval buckling can be seen with the Northstar project, the first offshore Arctic field development with a subsea pipeline. A US project, it features twin 25.4cm oil and gas pipelines that extend 9.7km offshore into the Beaufort Sea to a man-made island. Computer analysis was used in the pipe-laying process and Northstar pipelines are designed to avoid buckling at the maximum operating temperature of 38°C.

Earthquake activity was an additional challenge for the builders of the Trans-Alaska Pipeline System (TAPS). Engineers had to create a pipeline that could survive events, such as the 1964 southern Alaska earthquake which measured 9.2 on the Richter scale, the largest-ever earthquake to occur in the US. TAPS was built with a two-part system of “shoes” and “anchors” to hold it in place at fault lines while allowing enough movement so it does not come away from its supports if the ground moves. On the Denali fault line, an area known for heavy seismic activity, the pipeline is designed to move up to 6m side to side and up to 1.5m up and down.

Hydrotest fluids are another consideration when commissioning pipelines in the Arctic. These fluids should be of minimum toxicity and operators need to be aware that the volume of chemically treated water required to properly test lines can be several times the volume of the pipeline. As such, a disposal plan for hydrotest fluids is essential. Treatment of these fluids to remove toxic substances and careful selection of discharge sites are important to minimise the environmental impact.

### Drilling operations

Drilling operations will produce effluents from run-off, wash water, process water, excess drilling fluids, drill cuttings and fluids associated with well treatments.

Closed mud systems and tanks are preferred, with a water separation/recycling package included in the mud handling facilities. Selection of drilling fluids is also important and water-based, non-saline muds are generally better from an environmental perspective. However, when using water-based muds, it is important to control and avoid using additives containing oil or heavy metals,



which are in a form that could be taken up by organisms, or other bio-accumulating, persistent and acutely toxic substances.

If mud pits are used, these should be lined with an impermeable layer and have sufficient capacity to hold spent muds, cuttings and run-off water. The entry of run-off water into mud pits from the well site and nearby areas can be prevented by raising a bund. Accumulation of water in mud pits as a result of melting snow should be removed to reduce the hydraulic head in the pit.

### Produced water

Produced water is the principal waste arising from the production of oil and gas. It contains hydrocarbons and inorganic salts, and may contain minor quantities of metals and other constituents from formation and well treatment operations. Produced water can be treated to remove oil and solids and re-injected for secondary recovery operations or disposal purposes.

Injection is used to handle waste streams that need special attention. Produced water can be re-injected into formations for pressure maintenance or enhanced recovery. This is classified as a re-use or recycling alternative.

Produced water effluents should be treated to reduce oil content to a level that will not cause environmental damage. The final composition of produced water, and the dilution potential of the receiving body, determines whether discharge or re-injection is appropriate. Re-injection may be the only viable option in some cases, as long as permafrost and ground water protection is assured. Well treatment fluids need special attention – heavy brines and acids can be filtered and recycled, spent acids and workover fluids must be chemically neutralised prior to disposal off-site.

Safeguards are required to prevent the contamination of usable aquifers or breaches to the surface through proper design, construction, operation, maintenance and monitoring of injection facilities.

### Ice roads, ice pads and lakes

Ice roads and ice pads are used by operators as a cost-effective way to explore for oil and gas in the Arctic. However, these can impact on the water and underlying tundra, so the US government's National Energy Technology Laboratory (NETL) developed a water management planning tool which is being used on Alaska's North Slope by energy firms, indigenous peoples, environmental organisations, regulatory agencies, and the research community. Most oil and gas activities on Alaska's North Slope occur during winter, supported by ice and snow road networks. "Tundra travel" begins when 15cm of snow cover exists and temperatures at a soil depth of 30cm drop to  $-5^{\circ}\text{C}$ , and similar requirements also exist for withdrawal of fresh water and ice from nearby lakes.

The modelling tool is used to ensure that lakes, the main source of water for ice road construction, will have enough water under anticipated climate conditions. The impact of water withdrawal on remaining water quantity and quality can be assessed to ensure that sustainable water balances and dissolved oxygen levels are maintained for aquatic life. To do this, the tool integrates mapping software with Arctic hydrology and climatology, water resources management, and decision support through modelling.

NETL has also been instrumental in ensuring artificial barriers, known as snow fences, have been installed around lakes to assist with water retention.

### Chemical contamination, run-off and discharges in Arctic waters

Chemicals need to be handled and stored with care to ensure Arctic waters are not contaminated. The good news is that thanks to strong regulation and technological advances, most Arctic hydrocarbons operators are using less polluting fluids during drilling and production. Base fluids for drilling muds are now water-based instead of oil-based, for example.



The tanker *Mikhail Ulyanov* approaching Gazprom's Prirazlomnaya platform in the Pechora Sea. The often harsh Arctic weather conditions demand the greatest safety procedures be followed in operation and transfer of oil cargoes.

Fresh water and seawater are important resources for Arctic operators and treatment with chemicals can be required. Furthermore, water may need to be stored and disposed of carefully if it has been mixed with chemicals for hydrocarbon operations. There can be limitations on water disposal routes in the Arctic and these should be considered by operators to ensure contaminated water does not end up in the sea or in lakes.

When water needs to be discharged, protection of the environment is the main priority. Well test fluids should be incinerated, re-injected or contained and disposed of correctly off-site. Produced water treatment should take place at the same site as the oil dehydration/desalting operations. Wash water and process water can be treated biologically or chemically to prevent the introduction of bacterial or pathogenic organisms into the sensitive Arctic environment, and grey water can be filtered and discharged to the land surface. Grey water on Arctic ships should be treated in onboard sewage facilities before offshore discharge.

Simple actions can also be effective in preventing water contamination. For example, operators

should try to minimise the removal of vegetation near bodies of water to reduce surface run-off into the water. If vegetation needs to be burned, this should not happen near water either. Properly designed site drainage including separators or interceptors to remove oily waste, isolating reservoir and wellbore fluids down-hole, and inserting casing through permafrost and groundwater zones with cement designed to set before freezing are also effective, simple actions for protecting water in the Arctic.

Diligent reporting and data collection is important too. OSPAR is a mechanism by which 15 governments on the western coasts and catchments of Europe cooperate on marine protection, and within the OSPAR Arctic waters, there is a specific strategy for water management of the oil and gas industry. In this area, there is internationally coordinated control of discharges and operators are required to return data to their national authorities. These data are compiled and published by OSPAR.

*Georgia Lewis is Managing Editor for International Systems and Communications.*





# Environmentally responsible water management

By Tamar Gomez

Mitigating environmental risk is a major challenge for all oil and gas operators.

Approximately 400 km<sup>3</sup> of freshwater is withdrawn annually for the purposes of the energy industry, according to BP's *Water in the Energy Industry* publication from 2013. Though far lower in water use than agriculture (77% of global water consumption), the thirst for fresh water in the oil and gas upstream industry remains significant especially



Plans for shale gas exploration in South Africa's arid Karoo region faced strong opposition, leading to a temporary moratorium.

considering the diversity of local environments. Water availability being finite and unevenly allocated across the globe, the increasing need for water for extraction poses business and regulatory risks to companies. Efficient water management is crucial to reduce the environmental and social impact of exploration and production activities and to mitigate risks for operating companies.

## Assessing water availability and identifying related risks

Forecasting water demand over an industrial cycle through a thorough assessment of water availability and the identification of related risks is essential. This analysis is a prerequisite to ensure the sound management of water resources for a hydrocarbons project.

## Water availability

Water management efficiency or water stewardship is defined by the Alliance of Water Stewardship (AWS, 2014) as "the use of water that is socially equitable, environmentally sustainable and economically beneficial, achieved through a stakeholder-inclusive process".

The underlying assumption is that the use of water – as an interdependent resource – in exploration and production operations should be considered holistically and taking into account other users. Hence, the first step of water stewardship is the appraisal of water resources in the given environment of operations and the identification of risks associated. This step incorporates several phases:

### ● Defining the water requirements of a project

Water requirements of a project may vary significantly between projects. A project's water requirements should be assessed throughout the length of its industrial life since its profile is rarely uniform in time.

● **Taking into account the regulatory environment of operations** The regulatory framework of a hydrocarbons project is crucial in regard to



water resources and their uses. It requires a comprehensive consultation process taking into account all the different stakeholders.

#### ● Identifying the water sources in the area

Defining the available water sources is an important step in the initiation of a project as well as delineating areas of influence, including environmental and social, which are potentially altered by the operation. Seven indicators have been issued in the World Resources Institute's (WRI) Water Risk Atlas in 2013 as a canvas to determine water-related risks. They include: baseline water stress; seasonal variability; drought severity; ground-water stress; dominant water use; population density and reserve depth interval.

● **Determining the status of available water in the region** The final stage of water stewardship requires confronting the demand for water and determining whether the available resources can meet the project's water requirements during its entire length

The next step is the assessment of water-related risks of the project and concurrent water source selection. The risk appraisal process goes through these different phases several times during the project's life to ensure that conditions have not altered. The impact assessment of the water use encompasses different aspects: Social (impact on food species, impact on access to groundwater, productivity of grazing, health and sanitation), environmental (impact on freshwater species, erosion, flood retention) and economic (impact on navigation, agriculture and tourism).

#### Special challenges for shale gas

Shale gas extraction involves the use of a large amount of water resources for drilling and fracturing. In North America, hydraulic fracturing, one of the shale extraction techniques, in place on a single well is deemed to require from 7 million to 23 million litres of water compared to 0.2 million to 2.5 million litres for a classic well drilled, acc-

ording to US Environmental Protection Agency statistics. Hydraulic fracturing involves pumping water and several additives into a drilling hole under high pressure. The WRI found in 2014 that injected fluid flows back during the production phase in a range varying from 10 to 75% of the original injection in the form of waste water.

Furthermore, the WRI found that 38% of shale resources are deemed to be located in areas that are "under high to extremely high levels of water stress" – this includes China, South Africa, Pakistan and India. The WRI also estimates that 386 million people are living on land located over shale plays. Consequently, the water requirements of hydraulic fracturing are likely to conflict with the water needs of local populations. As a result, companies involved in the value chain of shale gas extraction are becoming managers of water resources on a par with their local and regional counterparts. The shale environment is a specific sector in which regulatory oversight as well as comprehensive risk assessment related to water availability is crucial. Water availability is thus regarded as a critical factor when appraising the shale potential by geography.

Related risks may be of a financial, reputational or regulatory nature.

● **Financial risks** The high cost of transportation of freshwater when available sources are unavailable on a drilling site is a major financial risk for operators. This is the case with Antero Resources which is financing a pipeline with an estimated cost of \$500 million running from the Ohio river to the states of West Virginia and Ohio, thus entailing an estimated \$900,000 cost of water per well.

● **Pricing of water** Just as oil and gas prices impact on operators, water prices can also be a challenge in environments of high demand. For instance, in 2011, a drought drove oil and gas companies to spend up to \$2,000 per acre-foot for treated water in Colorado in cases where it previously cost \$100.





- **Reputational risks** These risks may arise when industrial activities are considered to be conflicting with the operating environment. This may result in downtime and project delays, and even jeopardise the company's social licence to operate. In South Africa's Karoo region, Shell was confronted with strong social opposition which gave rise to a provisional government ban on hydraulic fracturing.

- **Regulatory uncertainty** Government concerns over the impact of shale extraction on water availability and potential environmental damage from shale development can, in turn, impact on the regulatory environment. In France, for example, the government has banned hydraulic fracturing and cancelled exploration licences.

Thus, especially in the shale environment, upholding good practices in terms of water management is essential to reduce uncertainties and business risks.

### Increasing water efficiency during operations

In the preliminary phase of a hydrocarbons project, a vital step recommended while conducting a water availability appraisal is to determine opportunities for water efficiency. However, not all are applicable to every project and should be considered on a case-by-case basis.

- **Water reduction** The amount of water consumed in one or several project phases can be drastically reduced through thorough control and monitoring of water consumption. This involves systematically tracking water flows on the production site. An efficient monitoring system is essential for allowing an optimal match of water supply and demand as well as the detection and elimination of leaks and non-essential water uses. Water reduction may also be achieved through the adoption of first-class technology in the production site's equipment.

- **Water replacement** Water replacement involves substituting, either partially or totally, the fresh

water used by lower quality water or a completely different resource. The most common options for replacement by water in the oil and gas industry are generally the use of brackish or saline water. That is water with a higher salinity than fresh water (from 0.5 to 50 parts per thousand). Brackish water is found in estuaries, mangroves, brackish seas and lakes.

Water may also be replaced, either fully or partially, by gases. The most common gas replacement option is production gases which are mostly a mix of methane and carbon dioxide. For fracturing operations, propane, methanol or sometimes oil combined with nitrogen are other potential water replacement options.

The feasibility of water replacement is generally determined on a case-by-case basis during water availability assessment phases. These operations also incur additional costs as the replacement water generally requires treatment to become usable. Furthermore, replacement options advance other environmental processes, such as waste management and supplementary energy consumption.

- **Water reuse** Water reuse is defined as water which has already been used once or several times in different industrial processes before returning to the natural water cycle. Water reuse usually entails minimal treatment such as filtration. Water may be reused within the same industrial process on oil and gas production sites. An example of this is the use of production water to maintain pressure on the reservoir through water flooding. Examples of water reused in alternative processes include the use of grey water for lavatories, cooling water for cleaning purposes or the collection of rainwater inside of the site.

- **Water recycling** Recycling is, in substance, the same concept as reuse but it requires a higher level of treatment and transformation. Technologies for recycling are available but they incur costs and are often subject to budgetary





Shell collaborated with the City of Dawson Creek to use reclaimed municipal waste water for its Groundbirch gas venture.

decisions. The returned water can be categorised into the following types:

- 1 Drilling fluids such as mud water can be recycled through the elimination of drilling cuttings and additives.
- 2 Effluent streams produced by treatment processes may be further recycled and reprocessed to be included in the same treatment phases. For example, during desalination processes, water can be collected and passed through several additional treatment phases to increase the ultimate amount of desalinated water.
- 3 Commissioning involves hydrotesting of pipelines. The water used for this process may be collected and recycled for other pipeline commissioning thus lowering the water needs of an oil and gas production project.
- 4 Produced water may be returned and recycled to be incorporated in production processes such as reservoir pressurisation. In the Delaware basin of New Mexico, ExxonMobil tested produced water recycling techniques on eight pilot wells and for hydraulic fracturing purposes. An IPIECA report found that this experiment showed that produced water could be successfully recycled into fracturing fluids thus saving 30.3 million litres of freshwater.

## Water treatment

Water efficiency opportunities almost always involve water treatment phases. Technologies associated with water treatment for replacement, reuse and recycling depend on the amount and the quality of influent water as well as the required quality of outflows. These technologies are constantly upgraded with continuous research and development. Depending on the level of complexity required by water efficiency measures, water treatment may be categorised as follows:

- **Low-level treatment** This is applied to returned waters and implies a basic level of filtration and maceration.

- **Filtration** This is the process which consists in removing particles present in the influent water by the successive passing of water through membranes. These membranes retain the particles and generate a “stream waste” that has to be disposed of. The lifetime and technological class of membranes depends on the filtration requirements and have to be taken into account in the efficiency process.

Total and Veolia Water have developed the application of filtration through ceramic membranes to recycle produced water into water used in reinjection to improve oil recovery rates. The recycled produced water is then reinjected.

- **Demineralisation and desalination** Treatment of water through demineralisation and desalination refers to successive processes aiming at eliminating cations, such as potassium, magnesium and sodium, and anions, such as chloride and sulphate, from the water. Demineralisation is applied to freshwater and desalination to non-freshwater.

Constraints associated with water availability in oil and gas operations have rendered desalination of water extremely useful and widespread. However, a major issue related to this treatment technique is the disposal of waste generated, such as salt and brine.





Demineralisation and desalination techniques include ion exchange, membrane technology with electrodialysis and distillation. These techniques have differentiated water treatment capacity as well as differing energy consumption levels.

● **Potabilisation** Recycling water into potable water requires complex filtration, disinfection and sometimes re-mineralisation when influent water was previously demineralised.

### Managing waste

Efficiency opportunities are likely to generate waste so waste management has to be factored in early to determine the cost-benefit impact of an efficiency measure. Filtration treatment, for instance, produces brine while desalination creates solid waste. Considering how this waste may be disposed of is crucial since it can encompass hazardous products.

Oil and gas companies have found solutions and determined that the waste by-products of a treatment process may actually become valuable resources for other industries. For instance, salt products derived from brine generated by water treatment are sold to chemical industries where they are incorporated in industrial processes as raw material to produce magnesium chemicals. Sludges are used for agricultural irrigation purposes. Hess and Target Logistics have, for example,

developed and implemented the reuse of waste water for hydraulic fracking in North Dakota.

### Case study: Eni maps water stressed areas

Conscious of the high stakes regarding water availability, Eni has put in place a multi-sectorial Health, Safety and Environment (HSE) team of operational and financial experts to screen the global oil and gas related operations of the company and create a tool to identify water stressed projects.

The first step was to identify projects in water-stressed locations. Next, a more detailed survey was conducted with an assessment of the water supply and consumption of these projects. Finally, an inventory of critical risks was compiled for the most complex projects and an action plan was set to mitigate those risks.

Eni was thus able to generate a worldwide mapping system of its operations and water-related risks. The identification of these risks and projects under water stress then gave rise to an enhanced awareness of the staff, a harmonisation of indicators and expectations and finally the implementation of risk-mitigation measures.

### Case study: Statoil's water risk assessment programme

Statoil has implemented IPIECA's Global Water Tool (GWT) and the Local Water Tool (LWT) in the Bakken and Three Fork Shale plays in North Dakota and eastern Montana respectively.

These tools were developed by IPIECA to execute water risk assessments in shale environments. The use of these tools was accompanied by systematic data monitoring of water sourcing, treatment and drilling with the aim being to eventually reduce Statoil's environmental footprint in these areas.

The outcome of this programme was an enhanced information set and higher awareness of the water risks. This helped the field teams and the reservoir teams in the offices. Furthermore, the



Statoil's implementation of IPIECA water tools provided many benefits.



tools provided valuable access to IPIECA experts and local data allowing for a more structured discussion with stakeholders and officials. The company noted that the GWT and LWT tools needed to be run at different stages of the operations since evolving settings could incur variability in water conditions. Finally, the importance of local staff training was noted especially with hands-on experience.

### Case study: ConocoPhillips reduces environmental impact

ConocoPhillips has set a company-wide rule regarding water management with mandatory water risk assessments of each of its development projects. In the Surmont 1 oil sands development project in Canada, the company has launched an assessment of all environmental, social and economic risks related to water issues.

Although, the project is not located in a highly stressed water environment, the regulatory and local official bodies were historically concerned with these issues so there was a risk of reputational harm to the company.

Within the due diligence process, all water inflows and outflows, available water sources and disposal wells were assessed. The water stress level was then rated, taking into account parameters such as local needs, supply reliability and regulation. Conducting this analysis allowed for the development of a joint effort by operators, local experts and local officials in order to determine the impact of activities on the environment. In addition, this risk analysis also created the opportunity to consider the project and its environment holistically, encompassing land and water biodiversity, technology and regulations.

### Conclusion

Assessing and mitigating environmental issues related to water management have become unavoidable for oil and gas operators. Water man-



ConocoPhillips undertook a thorough water risk assessment at Surmont 1 in Canada, a joint effort with local stakeholders.

agement is an issue for all stakeholders – operators, local populations, investors and state representatives. Consequently, sound water management policies are necessary in order to protect all stakeholders' interests and ensure smooth and efficient operations.

In this context, the first challenge associated with water resource management is the thorough and relevant identification of water availability in the projects' environment. Capitalising on the information gathered, the efficiency opportunities are numerous. The decision-making process to select water management measures is based on a multi-criteria analysis taking into account environmental, societal and financial factors. Sustainability of oil and gas activities regarding water resources should be considered as a standard for all operating companies to ensure the longevity of these operations. This goal may only be reached with the help of sound, transparent and consistent regulation locally and globally, and the adoption by operators of best practices and top-notch technologies.

*Tamar Gomez is a Research Analyst at CGG and a WPC Writing Fellow ([www.cgg.com](http://www.cgg.com)).*



# Glossary of terms

---

**Appraisal well** A well drilled to determine the extent of hydrocarbon reserves and the likely production rate.

**Arctic Circle** One of five of the major circles of latitude. It is the parallel that runs 66° 33' 44" north of the equator. Countries with territory that falls within the Arctic Circle include Canada, Greenland, Norway, Russia and the United States.

**Barrel** A unit of volume measurement for petroleum products – 7.3 barrels = 1 ton, 6.29 barrels = 1 cubic metre.

**Biocide** A poisonous substance, especially a pesticide.

**Boiler feed water** Water used for the generation of steam.

**Black water** Wastewater containing faecal matter or urine.

**Blow-down water** Water deliberately wasted from a boiler to avoid a concentration of impurities during the continuing evaporation of steam. This water is blown out of the boiler with force by steam pressure within the boiler.

**Brackish water** Water that has more salinity than fresh water but not as much salinity as sea water. Also known as briny water.

**Brown water** Waste water that does not contain faecal matter or urine but is still not fit for human consumption.

**Casing** Pipe cemented in a well to prevent it from caving in and to seal in formation fluids.

**Catalytic cracking** Petroleum refinery process whereby heavy oil is passed through metal chambers, called catalytic crackers, at high temperature and under pressure in the presence of catalysts such as alumina, silica or zeolites.

**Christmas tree** The assembly of valves and fittings which are installed on top of casing to control the production rate of oil.

**Coal seam gas (CSG)** Also called coal-bed methane (CBM), it is methane found in coal seams. It is always present in coal mines and can be produced when coal is being mined from virgin seams.

**Coal-to-liquids (CTL)** The result of converting coal to a liquid fuel, a process known as coal liquefaction. This can be done via direct or indirect liquefaction.

**Condensate** Hydrocarbons which are in the gaseous state under reservoir conditions. These become liquid when pressure or temperature is reduced.

**Conventional oil and gas** Refers to crude oil or gas which is extracted by conventional means and methods.

**Cooling tower** A heat rejection device that works by extracting waste heat into the atmosphere by the cooling of a water stream to a lower temperature.

**Corrosion** The gradual destruction of materials, usually metals, by chemical reaction with their environment.

**Cracking** The breaking down of large molecules as part of the refining process.

**Crude oil** A naturally occurring, unrefined petroleum product made up of hydrocarbon deposits. It can be refined to produce useful products, such as gasoline, diesel and different types of petrochemicals. The viscosity and colour of crude oil can vary, depending on its hydrocarbon composition.

**Cyclic steam stimulation (CSS)** Also known as the huff and puff method, it is a three-stage process of steam injection into a well, steam-soaking and production by either natural flow or artificial means.

**Demineralised water** See Boiler feed water.

**Dewpoint** The atmospheric temperature below which water droplets start to condense and dew can form.

**Desalter** A process unit that removes salt from crude oil.

**Downstream** The downstream sector refers to the refining, processing and purifying of hydrocarbons, as well as the marketing and distribution of products derived from oil and gas.

**Drainage** The natural or artificial removal of surface water or sub-surface water from a site.

**Drill** 1. To bore a hole. 2. Equipment with cutting edges that is used to bore holes.

**Drilling** The use of a rig and crew for drilling operations, and the associated processes such as production testing, data collection and preparation for production.

**Drilling fluid** See mud

**Drilling mud** See mud.

**Drilling rig** A unit for drilling that is not permanently fixed to the seabed, such as a jack-up unit, a drillship or a semi-submersible.

**Ecosystem** Areas with similar climatic conditions on Earth, such as communities of plants, animals and other organisms.

**Effluent** An outflow from a sewer or sewage system or a discharge of liquid waste from a factory, power plant or hydrocarbons facility.

**Electrolysis** The decomposition of a chemical compound brought about by passing an electrical current through the compound or through the solution that contains the compound.

**Enhanced oil recovery (EOR)** A generic term for techniques aimed at increasing the quantity of crude oil that can be extracted from a source. It is also known as improved oil recovery or tertiary recovery.

**Exclusive Economic Zone (EEZ)** A seazone that has been prescribed by the United Nations Convention on the Law of the Sea in which states have special rights over the exploration and use of marine resources.

**Extra heavy oil** The portion of heavy oil having an API gravity of less than 10°.

**Exploration drilling** Drilling that is performed to determine the presence of hydrocarbons.

**Exploratory wells** A deep hole that has been drilled by an energy company or government in the hope of finding a new source of hydrocarbon. Also known as wildcat wells.

**Feedstock** The raw material that is needed for some industrial processes.

**Fischer-Tropsch process** A collection of chemical reactions that converts a mixture of carbon monoxide and hydrogen into liquid hydrocarbons. It was developed in 1925 in Germany by Franz Fischer and Hans Tropsch.

**Formation pressure** The pressure of fluids within the pores of a reservoir.

**FPSO vessel** Floating, production, storage and offloading vessel. A floating facility for offshore hydrocarbon extraction that is usually based on a converted oil tanker hull. An FPSO vessel is fitted with hydrocarbon processing equipment for the separation and treatment of crude oil, water and gases that arrive on board from sub-sea wells.

**Fracking** See hydraulic fracturing.

**Fracture acidising** A well-stimulation operation in which acid, usually hydrochloric acid, is injected into a carbonate formation at a pressure above the formation-fracturing pressure. See also, matrix acidising.

**Gasoline** A volatile mixture of flammable liquid hydrocarbons derived mainly from crude petroleum and principally used as a fuel. Also known as petrol.

**Gas hydrates** Crystalline, water-based solids that physically resemble ice, in which small molecules, usually gases, are trapped inside “cages” of hydrogen-bonded water molecules. Also called gas clathrates or clathrate hydrates.

**Geophysical surveys** Surveys that are used to collect geophysical data. Different sensing instruments may be used and data can be collected from above or below the Earth’s surface or from aerial, orbital or marine platforms.

**Greenhouse gases (GHG)** Gases, either naturally occurring or man-made, which allow sunlight to enter the Earth’s atmosphere freely. These gases absorb infrared radiation and trap heat in the atmosphere.

**Grey water** Any domestic wastewater excluding sewage.

**Groundwater** The water located beneath the surface of the Earth in soil pore spaces and fractures of rock formations.

**Heavy oil** Any of the relatively dense hydrocarbons (denser than water) derived from petroleum, coal tar and similar materials.

**Hydraulic fracturing** Also known as fracking, it is the forced opening of fissures in subterranean rocks by introducing liquid at high pressure for the extraction of oil or gas.

**Hydrocarbon** A naturally occurring organic compound comprising hydrogen and carbon. The most common hydrocarbons are natural gas, oil and coal.

**Hydrotesting** Also known as hydrostatic testing, this is a way in which pipelines can be tested for strength and leaks by filling it with a liquid, usually water, and pressurisation is applied.

**In-situ combustion** The injection of an oxidising gas to generate heat by burning a portion of resident oil.

**Kick** A well “kicks” when the formation pressure exceeds the pressure exerted by the mud column.

**Liquefied natural gas (LNG)** Natural gas that has been converted to liquid for ease of storage, transportation and distribution.

**Matrix acidising** The injection of acid into a geological formation at a pressure below that which will create a fracture. The acid flow is confined to the natural permeability and porosity of the rock with no new fractures created.

**Midstream** This term may include aspects of upstream and downstream sectors. Broadly, the midstream sector involves hydrocarbon transportation, storage and wholesale marketing of hydrocarbon products.

**Mud** A mixture comprised of a base substance and additives used to lubricate the drill bit and counteract the naturally occurring pressure of the formation. Also known as drilling mud.

**Natural gas** A fossil fuel. Natural gas is a mixture of naturally occurring hydrocarbon gases and it is primarily used as fuel and for making organic compounds. Deposits are found beneath the Earth's surface. Methane is the primary component of natural gas but it also contains varying quantities of ethane, propane, butane and nitrogen.

**Oil sands** Sand and rock material containing bitumen. The bitumen is extracted and processed using surface mining or in-situ processes.

**Permeability** The property of a formation which quantifies the flow of fluid through pores and into a wellbore.

**Petrochemicals** Any substance obtained from petroleum or natural gas.

**Petrol** See Gasoline.

**Petroleum** A thick, flammable mixture of gaseous liquid and solid hydrocarbons occurring naturally beneath the Earth's surface.

**pH** The pH scale measures the acidity of a substance.

**Pipeline** A means of transporting oil and gas through pipes over large distances.

**Potable water** Water that is safe for human consumption.

**Process water** A broad term for a wide range of water used in the hydrocarbons exploration, extraction and production process.

**Produced water** Water that is produced as a by-product along with oil and gas.

**Proven reserves** Reserves which, on available evidence, are virtually certain to be technically and economically viable for production – i.e. having a greater-than-90% chance of being produced.

**Raw water** Natural water found in the environment, such as groundwater, rainwater and water from lakes and rivers.

**Recoverable reserves** The proportion of hydrocarbons that can be extracted using available techniques.

**Refinery** An industrial plant where a crude substance, such as crude oil, natural gas or coal, is purified so it can then be turned into more useful products.

**Reservoir** A subsurface pool of hydrocarbons contained in fractured or porous rock formations.

**Return water** Also known as return flow, the reinjection of salt water that is produced along with the oil in a water-injection operation for an oil reservoir.

**Rig** A structure with equipment for drilling a well or a platform for this purpose.

**Riser (drilling)** A pipe between a seabed blow-out preventer (BOP) and a floating drilling rig.

**Riser (production)** The section of pipework that joins a seabed wellhead to the Christmas tree.

**Sedimentary basin** An area in which sediments have accumulated over a period of time at a significantly greater rate and thickness than surrounding areas.

**Sedimentary rock** Rock formed by the deposition and solidification of sediment, usually transported by water, ice (in the form of glaciers) or wind. These rocks are frequently deposited in layers.

**Seismic exploration** A set of geophysical methods used in the exploration of potential oil and gas fields in the Arctic, based on a study of artificially induced waves of elastic vibrations in the Earth's crust.

**Sewage** Water-carried waste that is intended for removal from a community, vessel or site. Also known as wastewater.

**Shale oil** An unconventional oil extracted from shale rock by processes such as pyrolysis, underground mining and surface mining. These techniques convert the organic matter within the rock (also known as kerogen) into synthetic oil. This oil can be used as a fuel or upgraded to meet refinery stock specifications by

adding hydrogen and removing impurities. The products can be used for the same purposes as those which come from crude oil.

**Shale gas** Natural gas found trapped in shale rock formations.

**Shelf** The extended perimeter of each continent and associated coastal plain.

**Solvent extraction** Methods for extracting shale oil by treating the shale with a solvent system of water and an alcohol at an elevated temperature.

**Sour water** Any refinery process water that contains hydrogen sulphide.

**Steam Assisted Gravity Drainage (SAGD)**

A technique to extract bitumen from oil sands by injecting steam into the reservoir before it flows by gravity to a second well and is pumped to the surface for processing.

**Steam cracking** The high-temperature cracking of petroleum hydrocarbons in the presence of steam as part of the petroleum-refining process.

**Steamflooding** Also known as a steam drive, this is a process where some wells are used as steam injection wells and others are used for oil production.

**Surface mining** A broad term for mining in which soil and rock overlying the mineral deposit are removed. Surface mining techniques include strip mining, open-pit mining and mountaintop-removal mining.

**Surface water** Water which is on the surface of the Earth, such as a lake, ocean, river, stream or wetland.

**Synthetic crude** A complex mixture of hydrocarbons that are somewhat similar to petroleum. These are obtained from oil sands, shale oil, synthesis gas or coal. Known as syncrude.

**Thermal recovery** Methods of extracting oil using the effect of heat.

**Topography** The field of geoscience and planetary science comprising the study of surface shape and features of the Earth.

**Total dissolved solids (TDS)** A measure of the combined content of all organic and inorganic substances contained in a liquid in a molecular, micro-granular, ionised or suspended form.

**Total suspended solids (TSS)** Solid materials, both organic and inorganic, that are suspended in water.

**Unconventional oil** Petroleum that is produced or extracted using techniques other than the conventional oil well method.

**Unconventional resource** An umbrella term for oil and natural gas produced by means that do not fit the criteria for conventional production. The term is currently used to reference oil and gas resources whose porosity, permeability, fluid trapping mechanism or other characteristics differ from conventional sandstone and carbonate reservoirs. Coal-bed methane, gas hydrates, shale gas, fractured reservoirs and tight gas sands are all examples of unconventional resources.

**United Nations Convention on the Law of the Sea (UNCLOS)** A comprehensive regime of law and order for the world's oceans and seas. UNCLOS governs all uses of the oceans and their resources. It was signed in 1982 and involves the participation of more than 150 countries.

**Upstream** The upstream sector of the oil and gas industry includes searching for potential oil and gas fields, drilling of exploratory wells and subsequently drilling and operating wells that bring hydrocarbons to the surface.

**Viscoelastic diverting acid (VDA)** A self-diverting, polymer-free acidising fluid used for high fluid efficiency during acid fracturing processes.

**Viscosity** The property of a fluid that resists the force tending to cause the fluid to flow, or the measure of the extent to which a fluid possesses this property.

**Washwater** When crude oil has to be desalted or dehydrated, the processes involved use high quality water which is commonly referred to as washwater or wash.

**Wastewater** Water that has been used in flushing, washing, oil and gas extraction processes or manufacturing.

**Watercourse** A broad term for a channel that a flowing body of water follows, such as canals, rivers and streams.

**Waterflooding** The injection of hot water into oil beds to aid in oil recovery.

**Well completion** The process of making a well ready for production or injection.

**Well pad** The area that has been cleared for a drilling rig to work on a plot of land used for oil or gas extraction.

# Acknowledgements

---

## **For WPC:**

*Director General:* Dr Pierce Riemer

*Director of Communications:* Ulrike von Lonski

*Senior Project Manager:* Sarah Ashmore

## **For ISC:**

*Editor-in-Chief:* Mark Blacklock

*Managing Editor:* Georgia Lewis

*Copy & Picture Editor:* Adrian Giddings

*Publisher:* Robert Miskin

*Finance Director:* Yvonne O'Donnell

*Finance Assistants:* Anita d'Souza

*Senior Consultants:* Jeffrey Fearnside, Michael Gaskell, Karin Hawksley, Jonathan Unsworth

*Art and Design Director:* Michael Morey

*Printed by:* Buxton Press Ltd

WPC and ISC would like to express their thanks to the following companies, people and organisations for providing pictures. The credits are listed by article. Where the pictures for an article came from a variety of sources, the appropriate page numbers are given in brackets after each source.

*Cover:* Siemens AG (Al Taweelah combined cycle power plant, left), Royal Dutch Shell (Qatargas 4, centre), morgueFile (right).

*Message from Director General, WPC overview:* WPC.

*Introduction to water management for oil and gas operations:* Helge Hansen/Statoil ASA (14), IPIECA (15 and 17).

*Efficient use of water for oil and gas operators:* Queensland Gas Company (19), BG Group (20), Royal Dutch Shell (23), Siemens AG (25), Saudi Aramco (27).

*Advanced technologies for water management:* Queensland Gas Company (31), Siemens AG (33), Veolia MPP Systems (34).

*Water management for unconventional oil and gas:* Accenture (41), IPIECA (47).

*Water management for LNG, FLNG and GTL projects:* Australia Pacific LNG (48), Union Fenosa Gas (49), Origin Energy (50), Tullow Oil plc (52), Wison (53), Royal Dutch Shell (55).

*Produced water storage, treatment and disposal:* Nexen.

*Water management for Arctic oil and gas projects:* Glenn Williams/US National Institute of Standards and Technology (62), Jeff Schmaltz/NASA Earth Observatory (63), NOAA Office of Response and Restoration (64 upper), Royal Dutch Shell (64 lower), OAO Gazprom (65 and 69), Marc Morrison/BP (66), BP (67).

*Environmentally responsible water management:* Frames-Of-Mind [CC-BY-2.0] (70), Royal Dutch Shell (73), Statoil ASA (74), ConocoPhillips Company (75).



# CUSTOMISED CONTRACT PUBLISHING SOLUTIONS



International Systems and Communications Limited (ISC) was set up in 1991 to offer a high-quality, customised publishing service for event-linked, commemorative and annual publications. Today's prestigious client base is testimony to a business philosophy based on quality and a flexible approach.

## ■ CLIENTS

Organisations including the World Petroleum Council, International Gas Union, United Nations Conference on Trade and Development, Universal Postal Union and the Secretariat General of the Gulf Cooperation Council have contracted ISC to produce publications.

## ■ QUALITY

Experienced editing, production and sales team; editorial contributions from respected journalists and international figures; and high-quality production standards.

## ■ FLEXIBILITY

We tailor our services to meet your requirements ranging from an advertising sales and printing contract to a full turnkey operation including multiple language editions.

## ■ DELIVERY

On-time performance; international distribution.

## ■ SERVICE TO ADVERTISERS

Targeted access to an international audience of influential decision-makers; full design

and production service available for advertisements.

For all your contract event-linked, commemorative and annual publishing needs contact Robert Miskin, Publisher:

## INTERNATIONAL SYSTEMS AND COMMUNICATIONS LTD

140 Tachbrook Street

London SW1V 2NE

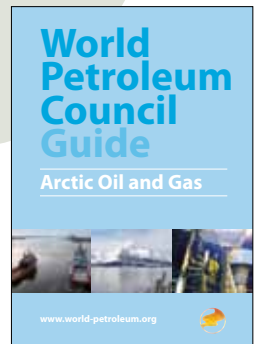
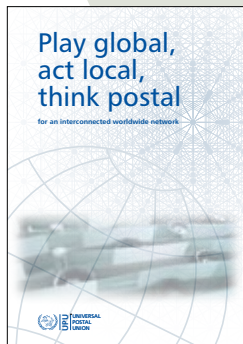
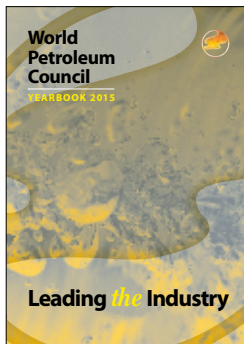
England

Telephone: + 44 20 7901 3830

Facsimile: + 44 20 7901 3838

E-mail: [general@isyscom.com](mailto:general@isyscom.com)

Website: [www.isyscom.com](http://www.isyscom.com)





**TURKISH PETROLEUM**

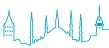
60 YEARS OF EXPERIENCE



www  
**tp**  
gov.tr



RESPONSIBLE FOR THE FUTURE



**BRIDGES** to our ENERGY *Future*



**istanbul**  
22<sup>nd</sup> WORLD  
PETROLEUM  
CONGRESS

09 - 13 July **2017**

www  
**22WPC**  
com

