Concawe

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Report

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Definition Guidelines of Water Reuse, Recycling and Reclamation for European Refinery Sector

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Definition Guidelines of Water Reuse, Recycling and Reclamation for European Refinery Sector

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ABSTRACT

The current Best Available Techniques (BAT) Reference document (BREF) for the mineral oil refining sector (REF BREF) contains requirements such as reducing water consumption by water recycling and internal water reuse. However, the terms water reuse, water recycle, and water reclamation are not defined in the Industrial Emissions Directive (IED) and associated reference documents.

This report reviews the main literature and provides an overview of current definitions of water reuse, recycle and reclamation used by industry, reporting organisations and international institutions. The literature review has shown that there are no consistent definitions of the terms.

The report provides recommended definitions of the terms water reuse, water recycle and water reclamation, based on technical evidenced encountered during the literature review and industry sources. It also provides guidelines on which refinery processes can be considered water reused, recycled and reclaimed, to facilitate future technical discussions and to allow Concawe members, and others, to report water reused, water recycled, and water reclaimed in a more consistent way.

KEYWORDS

Best Available Techniques, Industrial Emissions Directive, water reuse, water recycle, water reclamation, wastewater treatment, freshwater, sour water, sour water strippers, stormwater, petroleum refineries, water stewardship, process water, boiler feedwater, cooling tower make up water, media filtration, ultrafiltration, nanofiltration, reverse osmosis.

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SUMMARY

There are currently no consistent definitions for the terms water reuse and water recycle in an industrial context, with several terms being used in the water literature. The terms “reused”, “recycled”’ and “reclaimed” have, in some cases, been used synonymously, whereas in other cases each has been specifically defined. Water reused/recycled are typically used for water that has been used more than once in a single process or used in other processes, with or without treatment and that can reduce the amount of freshwater withdrawal required. “Reclaimed water” is primarily used for the further treatment of treated domestic and industrial wastewater for further beneficial reuse.

There are no specific definitions of water reuse and recycle in EU IED documents and associated reference documents, referring to water reused at large when discussing the reuse of water within the confines of a refinery or chemical facility. The terms “recycle”, and “recycling” are used in relation to water in certain instances, such as when referring to “recycled final effluent”, in relation to the effluent from the refinery wastewater treatment plant, although it is mostly used with reference to waste management issues and the recycling of products and by-products.

Concawe contracted NewFields to do a literature review that addresses how the terms are used, in what circumstances and how they can be defined in a refinery context. The literature review looked at how water is used in refinery processes and where and how water is reused. Sources of water include surface waters (rivers, lakes), groundwater, purchased raw or potable water (typically water supplied by a municipality) and brackish water (sea water or brackish water from an estuary, primarily for once through cooling). In much lesser volumes, recycled water and harvested rainwater has been reported by European refineries. Source water typically undergoes some primary treatment to remove suspended solids, but further treatment is typically required for use within the refinery depending on its ultimate use. Excluding once through cooling, the main uses of freshwater in European refineries are recirculating cooling, demineralized (‘demin’) water, general wash water, firewater, chemical process, crude desalting and domestic water. The review identified opportunities to reuse water within the confines of a refinery and included primarily the reuse of stripped sour water, collected rainwater, the reuse of the treated final refinery effluent and a few other reuses.

The reuse of stripped sour water is a common practice and is typically reused in the oil desalting process. Non-contaminated rainwater can be reused with minimal or no treatment as fire water or utility water and with minor treatment as cooling tower make up water or boiler feed water. However, the presence of combined sewers in most refineries*[1] means that this practice is not very widespread. The final treated refinery effluent can be reused within the confines of the refinery for similar uses as described for non-contaminated rainwater but typically necessitating more advanced treating technologies including media and membrane filtration, reverse osmosis, or ion exchange technologies. These techniques are expensive, and therefore the reuse of treated effluent is not common. Other possible reuses include the reuse of backwash from clarifiers, rejects from reverse osmosis, reuse of condensates and reuse of water from tank bottoms. While the use of reclaimed water may provide opportunities to reduce freshwater use, this depends on the

[1] **2016 Survey of Effluent Quality and Water Use at European Refineries,** Concawe report 10/20, CONCAWE, Brussels (2020), 2020, https://www.concawe.eu/wp-content/uploads/Rpt_20-10.pdf

availability of reclaimed water at the location (municipal suppliers and facilities) and the cost to implement such facilities and infrastructures.

The report presents options for the definitions of the terms water reuse, water recycle, and water reclamation based on a number of criteria such as degree of treatment, purpose and location. Based on the technical evidenced encountered during the literature review and industry sources the report recommends the use of a combined water reuse/recycle definition. To gain alignment within the industry and improve water reuse, recycle and reclaim reporting, the report provides lists of refineries activities that can be used by companies to report their water reused and recycled in a consistent way.

1. INTRODUCTION

1.1. PURPOSE OF THE REPORT

This report is submitted by NewFields in response to CONCAWE's Request for Proposal (RFP) to develop definition guidelines of water reuse, recycling and reclamation for the European Refinery Sector. The current Best Available Techniques (BAT) Reference document (BREF 2014) for the mineral oil refining sector contains requirements such as reducing water consumption by water recycling, internal water reuse[1] and separation of water streams of different qualities. However, the terms water reuse, water recycle and water reclamation are not defined in the Industrial Emissions Directive (IED) and associated reference documents. Given the EU Commission commitments to a circular economy, and its commitment to promote further uptake of water reuse at EU level, it is important that such terms are given consistent definitions, appropriate for a refinery context.

This report discusses definitions for water reused, water recycled and water reclaimed in Europe and other regions, provides examples of how water is reused in a refinery context, and suggests guidelines on how to identify these terms in refining operations. The content of the report is based on a literature search of selected sources, and interviews with selected Concawe member companies.

1.2. BACKGROUND

Water management is an essential component of industrial operations. While the global amount of water used by the oil and gas industry is considerably lower than in the agriculture, food and drink, power and a number of other sectors, the use of water is essential for O&G operations (Ref. 19).

Petroleum refineries are large and complex industrial sites that involve many different processing units and auxiliary facilities such as utility units and storage tanks. Each refinery has its own unique arrangement and combination of refining processes and water management, largely determined by the refinery location, desired products, and economic considerations.

Many processes and activities in a petroleum refinery use water, however, not each process needs raw water or treated water, and water can be cascaded or reused from one process to the next (Ref. 17). In this way, a large portion of the water used in a refinery is continually reused. Water losses to the atmosphere occur along the process via steam loses and cooling evaporation, and make up water is necessary to compensate for these.

Water used in the refinery processes and auxiliary services is eventually discharged to the environment as wastewater. Refineries can generate wastewater that has been in contact with hydrocarbons and that require treatment before they leave the refinery. Water consumption is the difference between freshwater withdrawn and freshwater returned into the same source or a different source within the same catchment / watershed (Ref.20). Loses to the atmosphere as described earlier, leakages, water in final products and discharges to sea are examples of water volumes consumed.

[1] While proposed technical definitions of water reuse and recycle are provided in Section 7, Definitions Guidelines, the term reuse is frequently used across the report as a verb, meaning water that is used again in another use, and in those circumstances, has no other technical meaning attached.

Concawe members report water reuse for the Concawe water survey. In 2016, 36 refineries reported a total of 107 Mln m^3 for the year as water reused or recycled involving 80 individual reuse streams (Ref. 4). They include a large variety of reuses and is not always defined what is the actual reuse destination. It is expected the guidance presented in this report will improve the way member companies report water reuse and recycle in future surveys.

Population and economic growth, urbanization, climate change and other factors are adding pressure on sustainable water supplies. These pressures could eventually affect the availability of fresh water for petroleum refining activities. Declining water reserves can impact the amount and quality required potentially affecting production efficiencies.

Petroleum refineries can retain the benefits of an adequate water supply by optimising water use and considering the principles of water stewardship and integrated water resource management to reduce their impact on freshwater reserves. The use of the water management hierarchy can help operations reducing the risk and impact of freshwater use (Ref. 33). This can be summarised as the 5 Rs: reduce, reuse, recycle, restore and recover. As stated in the Background section, this document focuses on the water reuse and water recycle steps and looks also at the concept of water reclamation in the context of a refinery operation.

1.3. STRUCTURE OF THE REPORT

The report is structured as follows:

- *Section 2* presents definitions of water reuse, recycle and reclamation as stated by industry associations, individual O&G companies, reporting organisations and intergovernmental organisations.
- *Section 3* includes a brief description of refinery processes and how water is used in the various processes.
- *Section 4* describes how water is reused/recycled in refinery processes and operations, technologies involved, and the general additional treatment requirements for reusing water that has been treated by the facility's wastewater treatment plant (WWTP).
- *Section 5* discusses water reclamation processes including general description and treatment technologies.
- *Section 6* discusses barriers to water reclamation implementation, and examples of water reclamation in Europe and other regions.
- *Section 7* presents a summary of water reuse, how Concawe members report water reuse in refineries and other ways to reduce freshwater use.
- *Section 8* presents criteria to define water reuse and recycled and definitions options.
- *Section 9* provides the conclusions of the literature review.
- *Section 10* includes the glossary.
- *Section 11* presents the list of the references consulted.

The Annex 1 attached to this report includes proposed definitions and guidelines for identifying and reporting water reuse, recycling, and reclamation.

2. DEFINITIONS

2.1. GENERAL

Several terms are used in the water literature associated with the reuse of water in an urban and industrial context. The term "water reuse" is most frequently found in the relevant literature, commonly accompanied by terms such as "recycled water," "reclaimed water," "purified water," "alternative water supplies," "improved water reliability," and "water resource recovery" (Water Reuse Association). The terms "reused", "recycled"' and "reclaimed" have, in some cases, been used synonymously, whereas in other cases each has been specifically defined. The terms reused and recycled appear to be used more often in an industrial setting, and they are discussed first. The term reclaimed water is primarily used for the treatment of domestic and industrial wastewater for further beneficial reuse.

2.2. WATER REUSED AND RECYCLED

In an oil and gas industrial context, IPIECA defines **water reused / recycled** as "water that has been used more than once in a single process or used in other processes, with treatment as appropriate, to reduce freshwater withdrawal" (Ref.20). Note that the terms reused and recycled are not differentiated in this instance given that the intention is the reporting of reductions in the volume of freshwater withdrawn that result from reusing or recycling water. However, in other guidance (Ref.19), IPIECA differentiates reuse from recycling by the amount of treatment required: without or minimal treatment for reuse, while a higher level of treatment is required in the case of recycle, to make the water quality suitable for another use. It suggests that a low level of treatment may include physical, chemical or mechanical conditioning of the water (basic filtration, maceration and settling processes such as coagulation).

The World Business Council for Sustainable Development Guide to Circular Water Management (Ref.33) also assigns a higher degree of treatment to the definition of recycled water, while minimum or no treatment is required to define water as reused. It provides a simple definition of low, intermediate, and high- grade water quality based on Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and conductivity indicators. Similarly, the BP publication "Water in the Energy Industry" (Ref.2), defines recycled water as "that which undergoes significant treatment such that water quality is sufficient for other uses"; while water reuse is "wastewater that is used again (within the facility boundary) before is discharged to final treatment". This definition also includes rainwater harvesting within a facility's boundary, even if this water was not used before.

The location where water is to be reused also matters with the term reuse sometimes applied to the treatment of process waters that are reused within the boundaries of the site, while recycling is sometimes used for water that is reused outside the boundaries of a site, usually treated, and typically for uses different from those within the industrial facility.

There are no specific definitions of water reuse and recycle in EU IED documents and associated reference documents, referring to water reused at large when discussing the reuse of water within the confines of a refinery or chemical facility. The Reference Document for the Refining of Mineral Oil and Gas (REF BREF, Ref. 8) tends to use the term reuse when discussing the reuse of water from one process to another while the term recycled is applied primarily for the recovery of products or by-products such as the recycling of collected dust from cyclones or the recycling of H_2S, catalyst material, etc, in line to the waste management context from where it originates. However, the term “recycle” or “recycling” is used in relation to water in certain instances, such as when referring to “recycled final effluent”, in relation to the effluent from the refinery wastewater treatment plant, or the “recycling of clarified water”, in relation to cutting water in the delayed coking process. Similar to the REF BREF, the BAT conclusions document for the refining of mineral oil and gas (Ref. 3) uses primarily the term “reuse” when discussing water, while the term “recycling” is applied mostly to waste management issues.

The Reference Document for Common Waste Water and Waste Gas Treatment (CWW BREF, Ref. 11) appears to use the terms reused and recycled indistinctively when referring to water, with the term water recycling commonly used to refer to both water and materials.

Table 1 includes a list of the most common definitions for water reused and water recycled found in the literature search. Water reclaimed definitions are provided in the next section as they are primarily related to the treatment of urban wastewater.

Table 1: Definitions of Water Reused and Recycled Found in the Literature

Source	Water Reused	Water Recycled
IPIECA (Guidance on voluntary sustainability reporting)	Water reused / recycled: water that has been used more than once in a single process or used in other processes, with treatment as appropriate, to reduce freshwater withdrawal.	
IPIECA (Reuse of produced water from onshore O&G industry)	Treated water/wastewater that is used more than once before it passes back into the water cycle (Water Reuse, 2020).	Used water/wastewater employed through another process cycle after treatment (IPIECA, 2014b)
WBCSD (Business Guide to Circular Water Management (from IWA))	Reuse water, with minimal or no treatment, within and outside the fence for the same or different processes.	Recycle resources and wastewater (treated by membrane or reverse osmosis to a very high quality) within and outside the fence.
United Nations (Wastewater, The Untapped Resource)	Use of untreated, partially treated or treated wastewater.	Treated (‘fit-for-purpose’) wastewater that can be used under controlled conditions for beneficial purposes within the same establishment or industry.
USEPA	All water reuse applications that do not involve potable reuse (non-potable reuse).	Municipal wastewater that has been treated to meet specific water quality criteria with the intent of being used for a range of purposes. The term recycled water is synonymous with reclaimed water.
Water in the Energy Industry (BP)	Used water and wastewater that is used again before discharged for final treatment and/or discharge to the environment. Reuse includes wastewater used for irrigation within a facility boundary. It also includes harvesting of rainwater within a facility boundary.	Water that undergoes significant treatment (to reduce salinity and/or other contaminants), such that the water quality is sufficient for other uses that require fresh or near-fresh water.
ICMM	Worked[1] water that is used in a task[2] without treatment beforehand	Worked water that is treated before it is used in a task.
ISO, 2015	Water reuse/water recycling is the use of reclaimed water for beneficial use under controlled conditions for beneficial purposes, such as agricultural or landscape irrigation etc.; synonymous to water reclamation.	

[1] Worked water is water that has been through a task [2] Task is any activity that uses water

Given the high level of dependency the mining industry has on water, corporate disclosure has become very important. The ICMM has developed disclosure guidelines following the Water Accounting Framework for the Mining Industry developed by the Minerals Council of Australia (Ref.16). The focus of the Framework is to provide measurement, monitoring and reporting protocols, to support public and investor confidence in the amount of water used by the industry. Reuse and recycling are reported in the context of operational efficiencies, where water reused is defined as “worked water that is used in a task without treatment beforehand”, while recycled water is defined as “worked water that is treated before it is used in a task”. A task is any activity that uses water, while worked water is water that has been through a task.

The framework also uses the concept of water quality categories with three Categories identified:

- Category 1: water of high quality that requires minimum treatment to raise its quality to drinking water standards (i.e., by disinfection or a settling pond for example).
- Category 2: medium quality water which would require a moderate level of treatment to meet appropriate drinking water standard.
- Category 3: low quality water with high Total Dissolved Solids (TDS) and metals that requires significant treatment to achieve drinking quality standards.

These categories are important to understand the quality of the water returns to the environment. However, they are not directly linked to the definitions of reused and recycled, although it is inferred that a poor-quality water (i.e., Category 3) intended for a use where high-quality water is required (i.e., potable water), will require significant treatment, and therefore would be considered as water recycled.

Reporting frameworks are also important when it comes to providing definitions of environmental indicators that companies use to report their environmental performance in a consistent way. The Global Reporting Initiative (GRI) (Ref. 15) defined water reuse and recycle as “the act of processing used water/wastewater through another cycle before discharge to final treatment and/or discharge to the environment”. It specifies three general types of water recycling/reuse practices including:

- Wastewater recycled back in the same process or higher use of recycled water in the process cycle.
- Wastewater recycled/reused in a different process, but within the same facility.
- Wastewater reused at another of the reporting organisation’s facilities.

The GRI standard for water was revised in 2020 when it appears the definitions of water reuse and recycle were removed. It is unclear why this was the case. **Table 2** lists selected reporting organisations commonly used by industry to report the use of water resources in their operations. Not all provide definitions for water reuse and recycle.

Table 2. Reporting Organisations Definitions of Reuse and Recycle

Reporting Organisations	Reuse/Recycle Definitions
GRI 303, 2020	None
DJSI Corporate Sustainability Assessment	None
CEO Water Mandate Corporate Disclosure Guideline	The act of processing used water and wastewater through another cycle before discharge to final treatment and discharge to the environment
CDP Water Security Questionnaire	Water and wastewater (treated or untreated) that has been used more than once before being discharged from the organisation's boundary, so that water demand is reduced. This may be in the same process (recycled), or used in a different process within the same facility or another of the organisation's facilities (reused)
Platform on Sustainable Finance	None

International organisations also define water reused and recycled within their statistical divisions to aid data collection at national level. For example, the International Recommendations for Water Statistics (IRWS) (Ref.27) was prepared by the United Nations Statistics Division (UNSD) in 2010 as part of its regular work program to assist countries in the development of water statistics. They define water recycling as "the volume of water that is used more than once by an economic unit within the territory of reference per year. This water does not leave the site of the establishment or household between uses". In this way, the indicator is able to reflect technological savings of water in the production of goods and services. Thus, they reserve the term recycled for the reuse of water within establishments while the reuse of reclaimed wastewater by establishments and households is not included, and suggest it should become a separate water indicator

In fact, the UNSD defines reused water as "used water directly received from another user with or without treatment for further use. It also includes wastewater received for further use from treatment plants and excludes recycling of water within industrial sites". UNSD together with Eurostat and FAO/Aquastat, all compile data on "water reuse" only, referring primarily to the quantity of treated wastewater which is reused in a given year. These definitions seem to separate reused and recycled by location (i.e., external or internal to a facility or establishment) and not by the degree of treatment required to be able to reuse a water stream.

2.3. RECLAIMED WATER

Definitions in this section relate mainly to the reuse of wastewater which is treated after collection in urban areas, what the Urban Waste Water Treatment Directive (Ref.12) refers to as **"treated wastewater reuse"**. The terminology associated with treating municipal wastewater and its reuse varies around the world. The USEPA defines reclaimed water as "municipal wastewater that has been treated to meet specific water quality criteria with the intent of being used for a range of purposes".

The USEPA uses the term *reclaimed* as synonymous with *recycled water* while the Government of Western Australia defines **water recycling** as the "multiple use of water, usually sourced from wastewater (also known as sewage) or stormwater, after it has been treated to a standard appropriate for its intended use".

The European Commission defines **reclaimed water** as "urban wastewater that has been treated in compliance with the requirements set out in the Urban Wastewater Treatment Directive, and which results from further treatment in a reclamation facility". In this context, a reclamation facility means an urban wastewater treatment plant or other facility that further treats urban wastewater that complies with the requirements set out in the Directive.

Wastewater itself is defined in several different ways and as such, there is no single universally accepted definition. For example, the USEPA defines wastewater as "water that has been used and contains dissolved or suspended waste materials". The term wastewater has also been equated with sewage, implying that the definition is limited to used water (from domestic, industrial or institutional sources), carried off by sewers, thus excluding the uncollected runoff from urban settlements and agricultural systems. However, as urban and agricultural runoff can be heavily polluted (and potentially become mixed with other wastewater streams), they are also important elements of the wastewater management cycle (Ref.26). Raschid-Sally and Jayakody's (2008) definition of wastewater, adapted by the United Nations Environment Programme (UNEP) states that:

"Wastewater is regarded as a combination of one or more of: domestic effluent consisting of blackwater (excreta, urine and faecal sludge) and greywater (used water from washing and bathing); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban runoff; and agricultural, horticultural and aquaculture runoff".

The Water Reuse Association (Ref.31) calls water reuse or water recycling "the process of intentionally capturing wastewater, stormwater, saltwater or graywater and cleaning it as needed for a designated beneficial freshwater purpose such as drinking, industrial processes, surface or ground water replenishment, and watershed restoration". While the UN defines reclaimed water as "treated ('fit-for-purpose') wastewater that can be used under controlled conditions for beneficial purposes, such as irrigation".

Treated wastewater is normally disposed of in natural water bodies from where it can be withdrawn for reuse at some point that is spatially or temporally separated from the treated wastewater discharge point. In these cases, the treated wastewater is mixed, transformed, or both by the receiving water before use. This is commonly known as indirect reuse. In the case where the treated wastewater is transported without dilution directly to its application is known as direct reuse. According to the Joint Mediterranean Group (Ref.14) the application of direct treated wastewater reuse can include various uses such as:

- Irrigation water (agriculture, landscape, sport and recreation).
- Water for manufacturing and construction industry (cooling and process water).
- Dual water supply systems for urban non-potable use (toilet flushing and garden use).
- Firefighting, street washing, dust suppression and snowmaking.

- Water for restoration and recreation of existing or creating new aquatic ecosystems.
- Recreational water bodies (including land redevelopment).
- Aquifer recharge through injection wells for saline intrusion control.
- Fishponds.

Unplanned or "**de facto**" **indirect** potable reuse is a term typically used to describe the discharge of treated wastewater into a river which is then mixed with surface run off before being abstracted for potable treatment downstream. In EU countries, as in most of the highly populated countries, indirect potable reuse through groundwater recharge and surface water augmentation is a common situation and is common in cities such as London, Berlin, and Barcelona.

Planned indirect potable water reuse implies an intentional project where is publicly acknowledged that recycled water is being used for drinking water and may involve a more formal public consultation process. It typically involves blending recycled water with other environmental systems such as a river, reservoir or groundwater basin, before the water is reused for drinking water.

3. WATER USE IN REFINERIES

This section provides a brief description of refining processes and how water is used. Further information can be obtained in the documents listed in the References section; in particular, "IPIECA's Petroleum Refining Water/Wastewater Use and Management, 2010" (Ref. 18) and the "REF BREF 2014" (Ref. 8) provide a description of water uses and water reuse in the various refinery processes and auxiliary services.

3.1. GENERAL REFINERY PROCESSES

Crude oil entering a refinery is subjected to several processes including desalting, distillation, hydrotreatment, cracking and coking and reforming. Auxiliary facilities required in the refining process includes steam generation, cooling systems, wastewater collection and treatment, sour water stripping, steam reforming for hydrogen generation, firefighting water storage and general utilities services (e.g., washing).

The desalting process removes salt impurities contained in the crude oil. The heavier the crude oil the higher the temperature required and typically, the larger the amount of water required for washing the crude to remove the salts. The crude oil distillation unit heats the crude oil to separate the oil into fractions for further processing in other units. Some refineries have also vacuum distillation to recover additional heavy molecules from the residue that do not boil at atmospheric pressure. Process steam is used in the distillation process to vaporize and separate the components of the crude oil mixture.

Hydrotreatment includes processes such as hydrodesulphurization to remove sulfur and other impurities, and hydrotreatment to convert unsaturated hydrocarbons to saturated hydrocarbons (paraffins). Process steam is used for separation and may also be used for steam reforming to produce hydrogen.

Heavier molecules leaving the distillation unit and the residue that remains are further broken down to smaller molecules. Catalytic cracking upgrades the heavier, higher-boiling fractions from the crude oil distillation by converting them into lighter and lower boiling, more valuable products. Hydrocracking introduces hydrogen in the cracking process making molecules that are more suitable for diesel oil. Process steam is used to aid separation in these processes.

Coking converts very heavy residual oils into end-product petroleum coke as well as naphtha and petrol oil by-products by heating the distillation residue. Finally, reforming includes a number of processes to maximise the production of gasoline by reacting hydrocarbons to produce molecules with the appropriate properties, or to increase the octane number of molecules in the gasoline range.

The primary final products of the refinery processes include gasoline, kerosene, diesel, fuel oil, and base oils for lubricants.

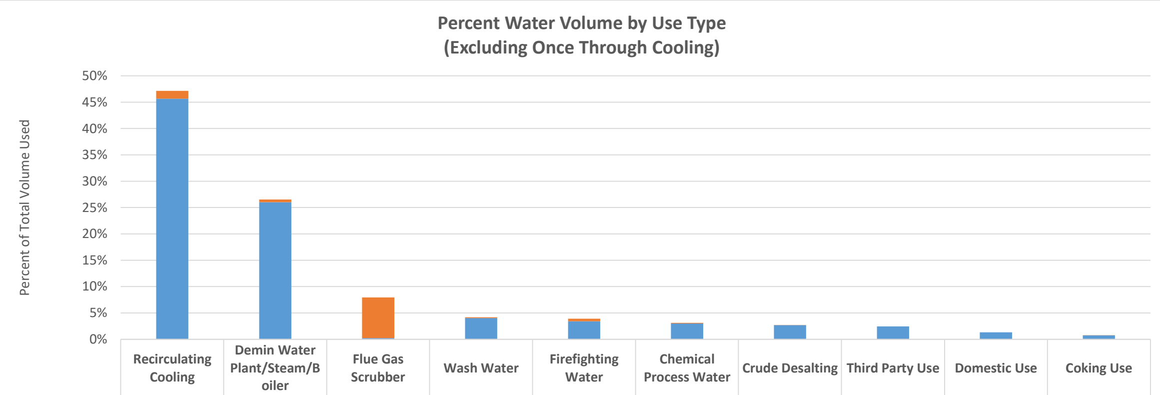
3.2. WATER USE IN REFINERY PROCESSES

Many of the processes and services mentioned in the previous section require water. Water can be supplied to a refinery from various sources and refineries are typically located close to one or more sources of water to satisfy the amounts of water needed for their operation. Typically a refinery's water usage is higher as its complexity increases due to the greater need for steam and cooling.

Sources of water include surface waters (rivers, lakes), groundwater, purchased raw or potable water (typically water supplied by a municipality) and brackish water (sea water or brackish water from an estuary, primarily for once through cooling). In much lesser volumes, recycled water and harvested rainwater has been reported by European refineries (Ref. 4). Source water typically undergoes some primary treatment to remove suspended solids, but further treatment is typically required for use within the refinery depending on its ultimate use.

Source water brought into the refinery is used in several processes and services including cooling, water for steam generation (demineralized or 'demin' water) used mainly in the refining processes, firewater and utilities including washing and domestic use. Once-through cooling, when used by the refinery, is the largest user of water, although this tend to be sea water. **Figure 1** shows 2016 data of water use in European refineries (Ref. 4). The figure shows that, excluding once-through cooling, most of the water brought into the refineries were for recirculating cooling, followed by demin water for steam generation, which is used in most parts of the refinery processes (distillation, hydrotreatment, cracking, desalting, reforming, etc.). Most of this water is typically sourced from fresh water sources.

Figure 1: Water Used in European Refineries (Concawe 2020 Water Report)

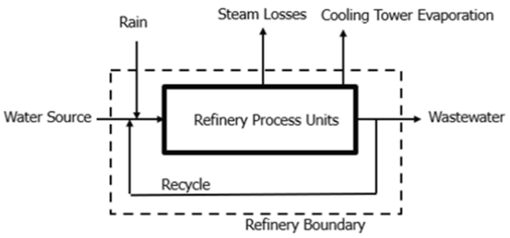


	Recirculating Cooling	Demin Water Plant/Steam/Boiler	Flue Gas Scrubber	Wash Water	Firefighting Water	Chemical Process Water	Crude Desalting	Third Party Use	Domestic Use	Coking Use
Salt/Brackish	1.46%	0.51%	7.70%	0.14%	0.48%	0.12%	0.01%	0.00%	0.00%	0.00%
Fresh	45.68%	26.03%	0.23%	4.03%	3.43%	3.02%	2.66%	2.44%	1.32%	0.74%

Most of the water leaving a refinery is via wastewater discharges. Other water leaving the refinery includes steam and evaporative losses. Most of the water losses occur via recirculating cooling, considering the process has substantial evaporative loss and minimal blowdown volumes. European refineries have reported about 76% of water losses occur via evaporation at recirculating cooling systems, followed by steam boiler use (10%) and demineralized water production (7%).

Figure 2 provides a summary of water uses, possible sources of water and how water is consumed within refineries.

Figure 2: Overview of Refineries Water Sources, Uses and Consumption



Adapted from Petroleum refining water/wastewater use and management, IPIECA, 2010

Water Sources

- Surface Water
- Groundwater
- Purchased Water
- Harvested Water
- Recycled Water
- Sea water

Water Uses

- Process Water
  - Desalter makeup
  - Coker quench
  - Coker cutting
  - Flare seal drum
  - Hydrotreaters
- Boiler feedwater
- Cooling water
- Potable water
- Firewater
- Utility water

Consumption

- Evaporative losses
- Leakages
- Water in product
- Discharges into sea, estuaries.

4. WATER REUSE IN REFINERIES

4.1. PROCESS WATER REUSE

Wherever water or steam come into contact with hydrocarbons, sour water is generated. Nearly all refineries have steam injection to enhance distillation or separation, and this leads to the production of sour water. This water is contaminated with hydrocarbons and other chemicals such as hydrogen sulphide (H_2S) and ammonia (NH_3)[2] that require stripping prior to reuse, or further treatment at the facility's Wastewater Treatment Plant (WWTP). Sour water is produced in various units such as the atmospheric (tower overhead drum) and vacuum distillation units, catalytic cracker, delayed coker, visbreaker and hydrotreaters.

Typical treatment for sour water is to use a sour water stripper (SWS) that removes H_2S and NH_3. Sour water is passed through a flash tank to separate oil and vapours. The sour water is then passed through a feed bottom exchanger to heat up the water before it is sent to the stripper. Steam is used in the reboiler to heat up the bottoms while some strippers use direct steam injection which generates more wastewater compared to the use of reboilers. The separated H_2S and NH_3 vapours are typically sent to a sulfur plant and the stripped water is reused in other process. Any excess water that cannot be reused is sent to the refinery wastewater treatment plant (Ref. 8 and 18).

There are single-stage and two-stages strippers. Two-stages strippers can achieve better recovery of H_2S and NH_3 resulting in lower sulphide and ammonia loads to be treated in the WWTP. Two-stage stripping is not very common in refineries, but two examples are provided in the REF BREF 2014 (Ref. 8): the Holborn refinery in Germany, where a two- stage SWS was integrated as an alternative to an effluent denitrification stage in the WWTP, and TOTAL's Mitteldeutschland refinery. Concawe members that were interviewed as part of this project stated most strippers in their refineries are single-staged. It was also indicated that two-stage strippers required more water for their operation although the additional volume require is not substantial.

Stripped sour water from the various refinery units is the main process water source in refineries and can be reused together with the crude distillation unit overhead wash water as desalter wash water. The desalting process plays an important role in the wastewater management of a refinery as the water used in other processes can be reused in the desalter. For instance, if stripped sour water is used as desalter wash water, the ammonia, sulphides, and phenols that it contains can be reabsorbed by the crude to some extent. Normally, stripped sour water can be used as desalter wash water, provided its contaminant levels are adequate (typically NH_3 less than 150 ppm and H_2S less than 20 ppm) (Ref. 8). Other potential sources of water for the desalter include vacuum tower overhead and crude tower overhead although their use may be more challenging, as pH control may be required due to their ammonia content.

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[2] A typical composition of sour water: 900 mg/l of hydrogen sulfide, 2 000 mg/l ammonia, 200 mg/l phenols and 15 mg/l hydrogen cyanide (REF BREF 2015, Ref.8).

Dedicated sour strippers are sometimes needed at refineries with catalytic crackers and delayed cokers as the sour water from these processes contain phenols and cyanides and are typically segregated from other sour waters. Stripped sour water is also reused as quench coker water and coke cutting water.

Reused of process water into wet scrubbers was also mentioned during interviews with Concawe members but it is unclear how common it is. Other reuses mentioned included the reuse of backwash from clarifiers, recirculated blowdowns and rejects from reverse osmosis. All those interviewed agreed that the recirculation of water in closed and semi-closed systems should not be classified as water reused or recycled.

The possible reuse of tank bottom waters is mentioned in the technical literature, however, Concawe members confirmed this is not normally done. The potential volume of tank bottom waters is likely very small compared with other potential reuses.

4.2. STORMWATER REUSE[3]

Rainwater can be segregated according to where it falls. Rainwater in process/storage areas is typically treated before discharge while rain falling in non-process areas (administrative, parking areas) can be harvested and reused within the refinery. While uses such as firewater and utility water may require minimum or no treatment, the use of rainwater for cooling or boiler feed water requires some treatment such as the removal of suspended solids and additional treatment to remove hardness.

Companies interviewed for this report have indicated that rainwater harvesting is not common, given that many refineries have combined sewer systems and therefore cannot segregate between uncontaminated and contaminated rainwater. Segregation of contaminated and non-contaminated streams can be very costly, especially in older refineries. During the interviews, one company stated that one of their refineries mixes non-contaminated rainwater with a low TDS treated water stream in a pond. This water is then reused for several uses including wash water, desalter, firewater and cooling tower water make up (with some additional treatment).

Rainwater harvesting is unlikely to meet a refinery's raw water requirements, even in the wet season and in rain abundant areas, but it can supplement the main sources of raw water. Harvested water is more challenging in southern Europe, especially in the summer, while it may be more applicable in northern European regions. Seasonal storage (capturing water in the wet season and using it in the dry season) requires large storage facilities, that many refineries cannot obtain without significant modifications.

4.3. REUSE OF UPGRADED REFINERY WASTEWATER

The reuse of the treated effluent from the refinery water treatment plant is another potential source of water within the refinery. In countries where water is a scarce resource, it may be sometimes economically attractive to further improve the quality of the effluent to reuse within the refinery (such as firewater, cooling tower make up water (CTW), wash water, etc.). This requires the use of additional

[3] While collected rainwater has not been used before it is used in a refinery, some sources consider rainwater harvesting and its use as water reuse. However, it is generally reported as water withdrawal or water intake.

treatment techniques such as different types of filtration, reverse osmosis or ion exchange, usually in combination, EDR (electrodialysis reversal) to achieve high grade water for uses such as CTW or boiler feed water (BFW).

Media filters/sand filtration is the most basic additional treatment for refinery WWTP effluent. It can remove particles greater than about 5 µm, so it can remove suspended solids but not dissolved inorganic compounds (salts) or metals. This type of treatment generates a water quality suitable for use as utility water or firefighting water but not always usually for CWT or BFW, as it depends on the final quality of the WWTP effluent (Ref. 8, 18, 32).

Microfiltration (MF) and ultrafiltration (UF) use hydrophobic membranes to remove particulate material and colloids to sizes up to 0.1 µm (MF) and 0.01 µm (UF). These membranes cannot remove dissolved salts and metals but produce a clarified effluent that can be used as utility water of firefighting water. Hydrophobic membranes are susceptible to fouling in the presence of oil and hydrocarbons and for this reason granulated activated carbon filters are typically used to remove dissolved organic compounds prior to filtration. Ceramic membranes are now widely available and are more suitable for effluents containing oil (Ref. 8, 18, 32).

Higher quality water can be achieved by the use of nanofiltration (NF), reverse osmosis (RO) and ion exchange (IX) that are capable of removing dissolved salts and metals. The overall treatment set up for nanofiltration and reverse osmosis are similar in that they both need media filtration, followed by granulated activated carbon to remove dissolved organic compounds, microfiltration or ultrafiltration to removed suspended solids and finally reverse osmosis or nanofiltration for salt and metals removal. A typical treatment configuration is shown in **Figure 3** (Ref. 8, 18, 32).

Figure 3: Refinery WWTP Effluent further Treatment using Filtration and Membrane Technology. Adapted from IPIECA, 2010

Reverse osmosis treatment systems are composed of polyamide membranes with pore sizes of less than 0.001 µm and they have a high salt rejection of 99%. They are more susceptible to fouling by the presence of hydrocarbons and therefore oil and grease concentrations limits are typically less than 1 mg/l, although concentrations in the ug/l range is known to have caused fouling problems.

Nanofiltration uses membranes of similar size as those in reverse osmosis and is used to remove selected organic compounds and for general softening. It has a lower salt rejection rate than reverse osmosis and therefore the operating pressure of nanofiltration is lower than reverse osmosis. Nanofiltrations achieves treated water of a quality suitable for most uses including BFW and CTW.

Ion Exchange is another option for the removal of dissolved inorganic compounds. It uses packed beds of anions and cation exchange resins through which water is passed. The process exchanges ions such as calcium and magnesium with ions such as hydronium (H+). Depending on the strength of the resin exchange beds, refinery effluent can be treated to boiler feed water quality. In this set up, sand filtration and granulated activated carbon filter are still required followed by the strong acid cation and strong base anion exchange resins. Ion exchange can also achieve water qualities suitable for CTW and BFW make up water.

The concentrations of dissolved salts determine whether reverse osmosis or ion exchange is more suitable. At concentrations of dissolved solids above 400 mg/l, reverse osmosis is typically more cost effective while ion exchange tends to be more cost effective at lower dissolved salt concentrations (Ref. 18). The techniques described above can be expensive. For example, the addition of sand filtration (SF) and granulated activated carbon (GAC) treatment to a refinery effluent can double the operating costs of a wastewater treatment plant, while the use of ultra-filtration or reverse osmosis can increase operating costs even further (REF BREF 2015). These technologies are not widely applied in refineries due to their costs and energy requirements, but refineries in areas experiencing water scarcity and water restrictions may consider these options.

Zero Liquid Discharge (ZLD) is a treatment process design to remove all the liquid waste from the system by reducing wastewater and producing water that is suitable for reuse. Application of ZLD in refineries is very rare given its high cost and energy requirements. A new concept, Minimum Liquid Discharge (MDL) has the potential to minimize operating costs and maximize water recovery while reducing the amount of energy required to operate. Minimum Liquid Discharge (MLD) uses a combination of treatment processes such as filtration and ion exchange processes that were described earlier.

The reuse of treated refinery effluent is not common. In 2016, approximately 4 Mln m^3 were reported as reused water from the wastewater treatment plant by Concawe members, a relatively small amount. Reported reuses included production of demin water and chemical process water. No information was reported as to what, if any, additional treatment to the wastewater treatment plant was used.

Responses during the interviews seem to confirm this is not a common practice for all companies and for every refinery. Of the four companies interviewed, one indicated they do not reuse treated effluent although in one refinery a feasibility study was implemented after a request by the local regulator. The other two respondents indicated only one of their refineries was reusing treated effluent in Europe, again suggesting this is not a common practice. The fourth respondent indicated that they have installed tertiary treatment in their refineries allowing them the reuse of the effluent water. It is important to note that high reuse/recycled rates imply higher pollutant values in the discharge due to technology rejections.

Reported reuses of the treated effluent included firewater, cooling tower make up water, desalting water and wash water. In one refinery, additional treatment included a membrane bioreactor (MBR) for the reuse of treated effluent as cooling tower make up water, and filtering for reuse as firewater. The other case, already discussed above, uses the effluent from a low TDS water stream, after passing via a surface water pond and mixed with rainwater, which is then reused in several other refinery activities.

4.4. BAT REQUIREMENTS

The European Union Directive 2010/75/EU defines “Best Available Techniques (BAT) conclusions” as the key element of BAT reference documents. They “lay down the conclusions on best available techniques, their description, information to assess their applicability, the emission levels associated with the best available techniques, associated monitoring, associated consumption levels and, where appropriate, relevant site remediation measures” (Ref. 3). And they are the reference for setting permit conditions for installations.

The BAT conclusions for the refining of oil and gas cover a series of refining activities and sub-activities that generate emissions to air and to water in the processes discussed in Section 3, as well as general water management practices.

BAT conclusions 11 and 33 are the only BAT conclusions that refer to the reuse /recycling of water streams to reduce water consumption. BAT Conclusion 11 (BAT 11) requires refineries to reduce water consumption[4] and the volume of contaminated water by:

- applying water stream integration (i.e., by reducing process water produced at unit level prior to discharge and by internal reuse of water streams such as from cooling and condensates and especially for use in crude desalting);
- using water drainage systems for segregation of contaminated water streams so that each stream is treated appropriately;
- by segregating non contaminated streams; and
- by preventing leakages and spills.

BAT 33 requires the reduction of water consumption and emission to water from the desalting unit in particular:

- by recycling water and optimizing the desalting process;
- by using a multistage desalter to increase efficiency; and
- by installing additional separation steps.

Other BATs provide requirements for the reduction of emissions of insoluble and soluble pollutants to the environment by water treatment before discharge (three stage wastewater treatment as BAT) and the need to treat sour water from the distillation process in stripping units.

While a few of these measures are easily applicable to existing operations (i.e., adding a settling drum to the desalter), the majority of the conclusions are applicable to new units or to existing units after complete rebuilding of the unit or installation.

The BAT conclusions for the Chemical Sector (CWW BREF, Ref 11) for water emissions are similar in nature to the REF BREF BAT conclusions. CWW BAT 7, requires: the reduction of the volume and/or pollutant load of wastewater streams; to increase the reuse of wastewaters within the production processes; and to recover and reuse raw materials. BATs 8 and 9 refer respectively to the segregation of contaminated and uncontaminated water streams to reduce emissions to water and the provision of appropriate buffer capacity for wastewater.

Finally, BATs 10, 11 and 12 are about the use of adequate treatment techniques to reduce emissions to water (such as process integrated techniques, recovery of pollutants at source, wastewater pre-treatment and final treatment); the pre-treatment of pollutants that cannot be treated at the facility's WWTP; and the use of the appropriate combination of wastewater treatment techniques.

The BAT conclusions deal with processes within the refinery /chemical facilities and do not elaborate on the use of external sources of recycled/reclaimed water to reduce the intake and consumption of freshwater.

[4] There is no definition of consumption in the BAT conclusions, and it is not clear that it refers to consumption as defined by IPIECA and endorsed by Concawe in their Water Survey Reports.

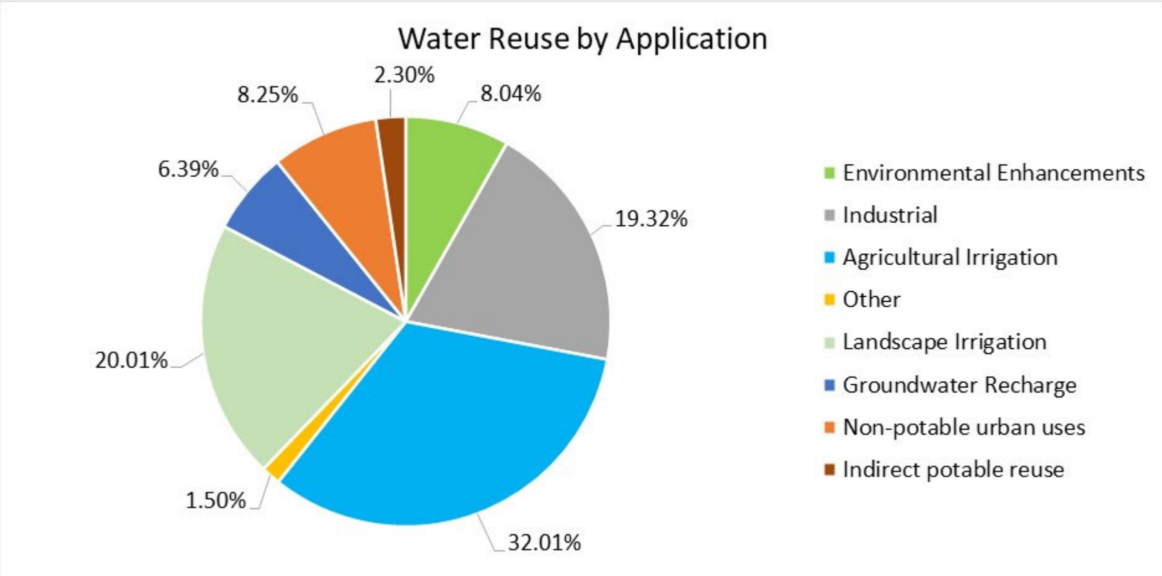
5. WATER RECLAMATION

5.1. GENERAL

The previous Sections dealt with reuse/recycling opportunities within the confines of the refinery installation. This section looks at the treatment and reuse of wastewaters from industrial and domestic/municipal sources, as an external source of water for use within the refinery.

Water is reused worldwide for several uses such as agriculture, aquaculture, industry, drinking water, non-potable household uses, landscape irrigation, recreation, and groundwater recharge. **Figure 4** shows the percentages of global water reused and their uses as per data from 2010.

Figure 4: Global water reuse after advanced (tertiary) treatment. Adapted from USEPA's Guidelines for Water Reuse (Ref. 29)



Approximately 20% of the global water reused was used in industry in 2010. While traditionally industries such as pulp, paper and textiles were the main users of reclaimed water in the past, other industries are now commonly using reclaimed water such as power generation, food processing and electronics. However, the reclaiming of urban wastewater is growing quickly in many countries (Ref.33) as it reduces the requirements for freshwater intake. The United States recycles approximately 7 to 8 % of their municipal effluent, while Singapore reuses about 30% of their water (i.e., the Singapore NEWater facility treats wastewater to provide potable reuse). Treated wastewater is increasingly being seen as a resource rather than a 'waste.' In this context, water reclamation and water reuse are important to achieve efficient resource use, ensure protection of environmental and human health, and improve water management (Ref.29). In addition, stricter effluent discharge limits imposed in many countries have resulted in improvements in municipal treatment technologies.

Although Europe has been experiencing increasing water scarcity, it represented only a small percentage of the global water reuse market in 2006 with some 2.6 million m^3/day total installed water reuse capacity compared to 30 million m^3/day globally. A survey carried out in 2017 by Water Reuse Europe (Ref. 34), identified 787 schemes practicing water reuse, distributed across 16 countries. Most of the schemes were located in southern Europe, primarily in Spain, Italy and Greece, with about 30% of the schemes located in northern Europe (primarily in France, Germany and the Netherlands).

The above schemes cover both non potable and indirect potable uses across the whole spectrum of possible reuse purposes from agricultural irrigation to landscape irrigation including golf courses, and from industrial uses to the augmentation of water supply resources. Overall, agricultural reuse remains the most common water reuse application in Europe (39% of the schemes) followed by industrial reuse (15%) and reuse for recreational purposes (11%). Most of the schemes classified as industrial (68%) are in northern Europe (Ref. 34).

The report "Municipal Water Reuse Markets 2010", published by Global Water Intelligence in collaboration with the Singapore Public Utilities Board (SPUB) (Ref.35), indicated that urban development represents the largest potential for water recycling applications with growth in the global water reuse sector expected to migrate from agricultural irrigation towards higher-value applications, mostly in municipal applications, such as drinking water supply, industry, and landscape irrigation reuse. It also states that water reuse will grow more quickly than desalination in percentage terms.

The use of treated wastewater from external sources by Concawe members refineries (and other European refineries) is not a common practice, with only 0.3% of total water intake (excluding once-through cooling) in 2016 reported as "purchased recycled water" (Figure 2 in Concawe Water Report 2020). An example of reclaimed water used in refineries/petrochemicals installations is the Tarragona Water Reuse Project, in Catalonia, Spain (Ref. 23). Reclaimed water is reused in a petrochemical complex that free up existing raw water to take advantage of a resource that otherwise would be disposed of in the Mediterranean Sea. The Tarragona Advanced Water Reclamation Plant (AWRP) was completed in 2011 to reclaim municipal secondary effluent from the Tarragona and Vilaseca-Salou wastewater treatment plants, which is used for cooling and process at the nearby Tarragona petrochemical park. In June 2014, production of demineralized water for boiler feed was started at a nearby satellite facility within the petrochemical park, using an ion-exchange process.

In 2014, the AWRP's capacity was 19,000 m^3/d, and further expansions were planned to take production to 55,000 m^3/d. This locally available additional water supply replaces surface water supplies currently transferred from the Ebro River and, as a result, an equivalent volume of surface water will be available for urban water supply.

5.2. TREATMENT TECHNOLOGIES ASSOCIATED WITH WATER RECLAMATION

When discussing treatment technologies for water reuse, the key objective is to achieve a quality of reclaimed water that is appropriate for the intended use and is protective of human health and the environment (Ref.29). Sources of reusable water may contain a range of microbial, chemical, physical and radiological agents that could pose a risk to human health (one of the main concerns in municipal water reuse) and to the environment. For the implementation of water reuse practices, these risks must be managed, and the public must be kept informed in a transparent and clear way.

The technologies available for upgrading municipal wastewater are similar to the ones discussed in Section 4.3 (refinery treatment) where the WWTP effluent was treated with media filtration, membranes or ion exchange, to achieve the required quality for reuse within the refinery. However, for the reuse of municipal wastewater some additional post-treatment is generally required, in particular the use of disinfection technologies for protecting public health.

For example, at the AWRP in Tarragona discussed earlier, secondary effluent undergoes a basic reclamation process consisting of a clarification step, followed by disc filtration, multimedia filtration and sand filtration. This is followed by an advanced reclamation process including a two-pass Reverse Osmosis treatment and disinfection, using ultra-violet light and chlorine, before it enters the reclaimed water distribution system (see **Figure 5**).

Figure 5: Treatment Line-Up Tarragona Advanced Water Reclamation Plant (Adapted from Ref 24)

Most wastewater in Europe, United States and other regions is treated to secondary levels, which at a minimum, involves the removal of degradable organic matter and suspended solids. Filtration and disinfection provide additional removal of pathogens and nutrients, and advanced oxidation processes can target trace chemical constituents. Filtration removes particulates, suspended solids, and some dissolved constituents, depending on the filter type. In addition, by removing particles remaining after secondary treatment, filtration can result in an efficient disinfection process. While chemical or biophysical disinfection processes inactivate or destroy many classes of microorganisms, pathogens removed by filtration are removed by physical adsorption or entrapment.

Most types of filtration methods are able to remove some of the largest pathogens, such as protozoan cysts. Smaller pathogens, including bacteria or viruses, can be removed in filtration either through size exclusion by filters with very small pore sizes, or by filtering out larger particles to which the smaller pathogens are adsorbed (Ref. 29).

Disinfection is designed to inactivate microorganisms, including viruses, bacteria, protozoan oocysts and cysts, and helminthes. The most common reclaimed water disinfection methods in use includes chlorination and UV disinfection. Ozone is also widely used. Other disinfection methods such as pasteurization and ferrate are being investigated for their use in the treating of wastewaters.

Advance oxidation processes are a class of water treatment technologies, including UV/H_2O_2, ozone/H_2O_2, ozone/UV, UV/TiO_2 (titanium dioxide), and a variety of Fenton reactions (Fe/H_2O_2, Fe/ozone, Fe/H_2O_2/UV). They can be added to the end of a treatment train for a range of purposes, from reducing contaminants of emerging concern and general toxicity of industrial effluent and wastewater to finishing water to a high quality for high-tech industries. They are particularly valuable for reclaimed water treatment for potable applications since they can remove Pharmaceuticals and Personal Care Products (PPCPs) and Endocrine Disrupting Chemicals (EDCs) that are not significantly removed during conventional wastewater treatment processes.

There have been hundreds of reuse projects implemented around the world for various end uses and these projects, cumulatively, have demonstrated that the use of properly treated reclaimed water is protective of human health and the environment. Particularly on this issue, the Water Reuse Research Foundation (Ref. 38) has stated: "there have not been any confirmed cases of infectious disease that have been documented in the U.S. as having been caused by contact, ingestion, or inhalation of pathogenic microorganisms at any landscape irrigation site subject to reclaimed water criteria".

6. BARRIERS TO WATER REUSE AND WATER RECLAMATION

Despite the water reuse applications already developed in many countries, several barriers still prevent the widespread implementation of water reuse throughout Europe and on a global scale. The Water Reuse in Europe Guidelines (Ref. 35) identified several barriers that will have to be overcome if wastewater reuse is to increase on a larger scale than at present.

Inconsistent or inadequate water reuse regulations/guidelines are a common barrier to water reuse in Europe and in other regions. While a few EU member states have their own guidelines (Spain for example), most don't, and therefore the EU recently issued (2020) regulations for the reuse of reclaimed water in agriculture (Ref. 10) is a welcome development. The regulations provide minimum requirements applicable to reclaimed water intended for agricultural irrigation in terms of pathogens and other quality indicators such as TDS (total dissolved solids) and BOD (biological oxygen demand) and prescribes minimum monitoring requirements. Guidance on the application of the EU 2020 water reuse regulations is currently under development. It will consider administrative responsibilities/ obligations, water quality responsibilities, the granting of permits, compliance and penalties and awareness raising issues. The guidance will also discuss risk management and risk assessment of the different types of irrigation systems when using reclaimed water in agriculture.

Inconsistent and unreliable methods for identifying and optimising appropriate wastewater treatment technologies and difficulties in implementing effective monitoring techniques and technologies for the whole system are also a problem, specially to reliably assess the environmental and public health risk and benefit of water reuse across a range of geographical scales.

Low levels of public and government enthusiasm, limited institutional capacity, and lack of financial incentives are also common barriers to the implementation of water reuse schemes. In fact, technically feasible water reuse projects often do not get implemented due to institutional, economic, and organisational barriers, or poor public perception and education. Contractual issues and the designation of liabilities is another common barrier. One Concawe member indicated a water reclamation project, intended to provide reclaimed water to their refinery, faced many contractual issues associated with safety and quality responsibilities. The price of the reclaimed water was also an issue. These factors meant the project did not go ahead.

The WBCSD undertook a survey of member companies as part of the development of their Business Guide to Circular Water Management publication (Ref. 32). The survey, that represents an industry view of the issue, identified several barriers to water reuse including:

- Achieving an acceptable return on investment (ROI). Low prices for water and high infrastructure costs, or a combination of these factors, make it difficult to achieve a ROI in projects related to circular water management.
- A lack of awareness is often a barrier to the implementation of water reuse/recycle projects, which can be made more difficult to overcome by lack of data.
- Reducing wastewater discharges may impact on maximum effluent concentration for certain substances permitted for a facility.

- A lack of dialogue and collective action. Depending on the facility location and related water issue, collective action by local stakeholders might be required. Stakeholder engagement can help raise awareness of the need to reduce water use and reuse and recycle water options.

The Guide goes on to describe some key factors for successfully overcoming the identified barriers from an industry point of view. Changing perceptions about the value of wastewater and water in general can be a key success factor. The price of water is generally low in most regions. Therefore, many water reuse projects failed to gain approval because they cannot achieve an acceptable ROI. The use of a shadow cost of water has been used by some companies to provide a more realistic value to water making certain projects viable. For example, Nestle started using a base cost of water adjusted by the degree of water scarcity based on the use of three water stress indices. By multiplying the combined water stress index with the base cost of water, the value of water was increased in water stressed areas. The method worked well, favouring water reuse projects in water scarce area (Ref. 32).

Another factor of success identified was changing perceptions about water reuse and engaging stakeholders at an earlier phase of the project. In recent years, dialogue with the public and general public awareness has increased, such as in the United States. Research has shown that public involvement for water reuse projects can result in a community having a more favourable collective attitude toward a project as its level of familiarity with water reuse increases. Gaining a good understanding of regional water balances and engaging stakeholders with similar goals are important to gain public acceptance. Proactive education and involvement programs have also been proven successful.

A good example is Singapore, a small island city-state that has no natural aquifers or groundwater and relies on rainfall from catchments and raw water imported from neighbouring Malaysia. NEWater, a high grade reclaimed water of drinking water standards, is key to achieving water sustainability in Singapore because of the multiplier effect through infinite recycling within the water system. An important part of the NEWater success story is its high public acceptance. This was achieved through a long and extensive public education program done in various phases. Before NEWater's launch, extensive briefings were held for critical groups, which comprised of community leaders, business communities and government agencies.

Another success factor identified relates to the company culture and leadership. The support of top management is a primary factor in success. Effective communication with internal and external stakeholders, and convincing them of the need for recycling water, are also essential for the success of projects to reduce, reuse and recycle water.

7. WATER REUSE OVERVIEW

7.1. SUMMARY OF WATER REUSE

Excluding once through cooling, the main uses of freshwater in European refineries are recirculating cooling, demin water, general wash water, firewater, chemical process, crude desalting and domestic water (Ref. 4). As discussed in Section 4, opportunities to reuse water within the confines of a refinery are primarily the reuse of stripped sour water, non-contaminated stormwater and treated effluent as identified in the literature review and confirmed during the interviews with Concawe members. **Table 3** shows a summary of the sources, treatment options and where the water is mostly reused.

Table 3: List of main[1] refinery water reuse/recycle activities and associated level of treatment

Source	Treatment	Destination
Process Water	Sour Water Strippers	Desalter
		Coke Quench
		Coke Cutting
Non-Contaminated Stormwater[2]	No treatment	Fire Water
		Utility Water
	Particles removal, softening	CTW
	Particles removal, hardness, demineralization	Boiler Feed Water
Refinery Wastewater Reclaimed Water[3]	Media Filtration, UF, MF	Utility water Firewater
	UF or MF + RO	CTW, BFW
	UF or MF + NF	CTW, BFW
	Ion Exchange	CTW, BFW

[1]Other reuse and recycle activities exist and are briefly discussed in the report, such as the reuse of reverse osmosis rejects, recirculated blowdowns, and process water into scrubbers. However, their potential reuse volumes are less significant.
[2]While collected stormwater can be reused in refinery processes and utilities, it is generally considered water withdrawal of water intake for reporting purposes.
[3] Treated urban wastewater requires similar treatment technology to produce reclaimed water of sufficient quality for most uses.

Non-contaminated stormwater (i.e., rainfall collected from non- process or storage areas), is generally reported as water withdrawn or water intake since no previous used of this water occurred; however, rainwater harvesting can reduce the amount of freshwater intake from other sources and at least one definition (Ref. 2) considers rainwater harvesting and its subsequent use within a facility as water reused. Harvested rainwater can be used as fire water or utility water with no or minimum treatment, while its use as cooling tower may require some treatment such as solids removal and softening. It's used as boiler feedwater makeup will require yet further treatment. Rainwater harvesting in European refineries is uncommon due to the prevalence of combined sewers.

The reuse of the refinery final treated effluent after little or more treatment is widely referenced in the technical literature and has been reported by Concawe members (Ref.4). With additional treatment such as media filtration, microfiltration and ultrafiltration discussed in Section 4, treated effluent can be used as a source of utility or fire water. Adding further treatment to filtration methods such as reverse osmosis or nanofiltration, or the use of ion exchange can make treated effluent suitable for use as cooling tower water makeup and boiler feedwater makeup.

As reported in Concawe's Water Report 2020, approximately 398 mln m^3 of treated effluent were discharged in 2016 by the European refineries included in the survey. Of these, approximately 50% were effluents that were treated through a 3-stage wastewater treatment plant. As indicated previously, the addition of tertiary treatment including sand filtration (SF), granulated activated carbon (GAC) and ultra-filtration (UF) or reverse osmosis (RO) can more than double treatment operating costs, although the author could not find costs estimates in the literature reviewed. It is expected that refineries without 3 stage treatment will result in higher costs to achieve a treated effluent quality suitable for higher quality uses such as cooling water tower and boiler feed water makeup.

87 Mln m^3 yr^{-1} of refinery effluent were discharged (in 2016) to salty/brackish receiving environments and therefore considered as consumed since this water is not available to other users. Further treatment and reusing of these discharges could reduce water consumption.

Municipal wastewater reuse, as an alternative water source, can provide significant, social and environmental benefits, something that is well recognised and embedded within European and national policy. Water reuse is the top-listed priority area in the Strategic Implementation Plan of the European Innovation Partnership on Water (EIPW, 2012), and maximisation of water reuse is a specific objective of the European Blueprint for Water. In northern Europe, municipal water reuse is practiced primarily for environmental and industrial applications, whereas in southern Europe, environmental and agricultural applications dominate.

Although difficult to implement, the use of reclaimed municipal water has the potential to supply reclaimed water to refineries operations in quantities sufficient for their needs depending on their cost and funding availability. The supply of reclaimed water to various customers can reduce costs for the individual industries making this option more attractive. The reuse of municipal effluent has been demonstrated at various locations around the world for urban consumption, irrigation and industrial uses. However, examples of reclaimed water used in a refinery context are few. We have already discussed the used of reclaimed water for the Tarragona Petrochemical complex in Section 5.1, where high- quality water is used in cooling towers and as boiler feed makeup. In other regions, examples include the BP Kwinana refinery in Western Australia, the Durban reclamation project in South Africa and the Singapore NEWater reclamation, already discussed in Section 5.3.

Finally, no examples of refinery treated effluent reused outside the refinery were found. However, there are many examples of produced water reused within the O&G industry Upstream Sector where it is much more common and, on the increase, in particular in the USA and Australia. Reuse of produced water in drilling and completion activities and in hydraulic fracturing are now common, especially in the US, where some unconventional oil and gas fields achieve more than 90% reuse of the produced water (Ref.17). Reuse for external uses includes irrigation, surface water augmentation, livestock watering, cooling and steam production among others.

7.2. REPORTED WATER REUSE

In 2016, a total of 36 refineries reported water reuse for the Concawe water survey report including 80 individual reuse streams. They include a large variety of reuses and is not always clear what is the actual reuse destination. In 2016 a total of 107 Mln m^3 were reported as reused/recycled, a large amount considering a total freshwater intake of 352 Mln m^3 for that year. The largest volume of reported water reuse was the demineralization of water for steam production although it is unclear why it would be classified as water reused/recycled. Some 4 Mln m^3 were reported as the reuse of treated water effluent for demin water and other uses as already mentioned, while the recycle of condensates for steam generation was reported at 2.18 Mln m^3. The volume of reused stripped sour water in the desalter seems low (0.4 Mln m^3), considering this is a common practice in most refineries.

Some of the reported reuse and recycling categories are unclear at present. Recommendations for streamlining the reported categories are included in the definition criteria sections in Annex 1.

Finally, while some of the reported values have been measured using flowmeters (for example for cooling and treated effluent) most of the reported volumes are based on estimates.

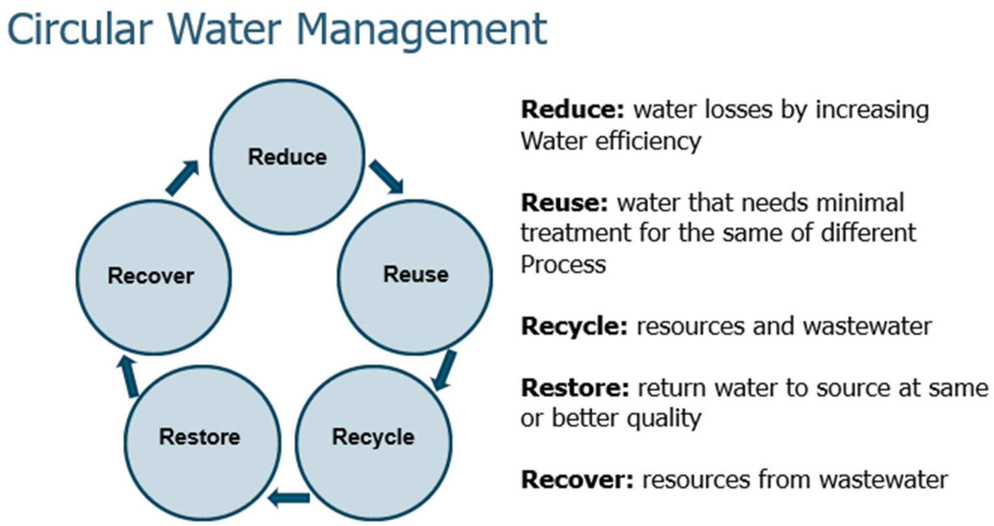
7.3. OTHER WAYS TO REDUCE FRESHWATER USE

As described in previous sections, refineries reuse and recycle water in several processes and in different ways according to specific refineries' configurations that result in a reduction in freshwater use. Reusing and recycling water are not the only ways to achieve notable freshwater use reductions or to respond to gradual changes to freshwater availability. Water efficiency improvements can be achieved through organizational commitment to a systematic approach for continued improvement in water use. The introduction of water efficiency programs enables organizations to assess and account for their water use, and to identify, plan and implement measures to achieve water savings (Ref. 21).

In addition to reuse/recycle, reduce and replace (i.e., the so called 3 Rs) are also ways in which refineries can reduce the amount of freshwater they use in their operations. Reduce is about reducing water losses, boosting water efficiency through the use of water-efficient fittings and equipment and, for example, putting in place a proper monitoring system for usage and leak detection (Ref.21). Replace includes the substitution of potable water with reclaimed water, sea water and rainwater wherever feasible, as already discussed in previous sections. A refinery in Europe stated that rainwater is used to replace the use of potable water reducing the amount of freshwater intake and reducing water management costs.

The 5Rs approach to circular water management, developed by the International Water Association (IWA) goes further and includes also the concepts of “restoration”, i.e., restoring the used water into the source from where it came from, and “recovery”, meaning the recovery of resources (materials) from the wastewater before is returned to the environment (**Figure 6**).

Figure 6: Circular Water Management (adapted from WBCSD Business Guide to Circular Water Management)



Process water integration approaches can be used to identify water reduction and reuse opportunities. It involves taking an inventory of water demand and effluent production for each refinery unit operation and to assess the water losses. This inventory provides the water balance across the refinery. This allows the identification of all possibilities to reduce the amount of water required, and to reuse as much as possible by matching effluents by means of a water optimisation scheme. Such methodology can reduce the amount of process water for final treatment prior to discharge saving operational costs. It can also save high-quality potable and demineralised water, which can be expensive in some locations (Ref. 8).

With increasing local demands on both the availability of water resources and the ability of the environment to assimilate wastewater discharges, the need to optimise the efficiency of water use in refinery operations is essential. To achieve this, a comprehensive and detailed balance of water use at the site level is a powerful tool to identify water efficiency opportunities (IPIECA water management Framework)

An example of water reduction measures is the BP Kwinana Refinery in Western Australia (now closed). With water supply constraints and cost pressures as potential risks, BP implemented a program of water reduction that included the completion of a detailed cost analysis, development of a detailed water balance, setting and promoting targets for water use, and detailed examination of each refining process. These measures achieved a reduction of water demand of 48% which were followed by the use of reclaimed water from treated municipal wastewater for use in industrial processes, reducing further potable water demands.

8. DEFINITION GUIDELINES FOR WATER REUSED, RECYCLED AND RECLAIMED

8.1. DEFINITIONS CRITERIA

As discussed in the definitions section (Section 2), many organisations use the reuse and recycle terms indistinctively without providing any definition of the terms, such as in the EU IED regulations, while others provide the same definition to both terms which can then be used interchangeably (most reporting organisations for example). Distinct definitions for each term were found in several literature references typically based on criteria such as the level of treatment required, the location where the water is reused (i.e., inside or outside the facility), or whether the water is reused in the same process or in another process (see **Table 4**).

Table 4: Water reuse and recycle definitions criteria

Criteria	Comment	Organisations
No definitions	Generic terms to described water that is used again without any specific definition.	– -EU IED documents
Reused/recycled used interchangeably	There is one definition that applies to both reused and recycled	– IPIECA Sustainability Reporting – GRI
Degree of treatment	Higher treatment typically applied to recycled while little or no treatment applied to reused.	– IPIECA – WBCSD Guide to circular water management – BP Water in the energy industry – Minerals Council of Australia/ICMM
Location	For example, recycled water when the water is reused within the same facility. Reused when water us reused in another facility.	– IRWS/UNSD – FAO/Aquastat – Eurostat
Purpose	Reuse /recycled of water in the same process or in a different process (recycled typically applied to reuse in the same process)	– CDP Water Security Questionnaire

Assigning no definition to either term makes the identification of water reusing activities more challenging and a potential obstacle to gaining a common understanding among interested stakeholders when discussing water efficiency issues or reporting freshwater reduction volumes. A combined definition for both reuse/recycle has been used extensively for reporting purposes and, when sufficiently generic, can be applied to many different industrial settings; an advantage when comparing water reuse/recycling initiatives and freshwater reduction volumes between industry sectors. In a refinery context though, it requires: 1) the identification of all those activities where reuse and recycle do reduce the amount of freshwater needed, 2) the need to adequately quantify/estimate water reuse/recycle at an industry level, and 3) that it can be applicable to most refinery operational units.

Several industry organisations have defined the terms based on little or no treatment (i.e., water reuse) and a degree of treatment to allow its use in another process requiring higher quality water (i.e., water recycle). However, no list of reuse or recycle activities have been developed and is left to the user to define when an activity is to be classified as reused or recycled. The mining industry provides some examples; however, no formal use of the terms exists for the refining industry. At least one Concawe member has stated that they use the term "reuse" for treated effluent water used in another refinery process (cooling tower make up water for example), while others stated they use the terms interchangeably and therefore they have one definition encompassing both terms. At least one Concawe member has stated that they have identified and listed several processes where water is reused or recycled for reporting purposes.

The Concawe survey includes reclaimed water as a water intake. In Europe, the term reclamation is commonly used to mean the treatment of wastewater beyond commonly applied primary and secondary treatment, in a municipal treatment plant, for further reuse in a variety of different uses. These are commonly referred to by the EU as reclamation projects. In the US, the term recycling is frequently used to mean the same as reclamation. Most definitions relate to the treatment of urban wastewater including domestic (grey and black water) and industrial wastewaters collected via a sewer system. The terms are also applicable to any reuse, whether for agricultural irrigation, industrial use or environmental restoration or augmentation.

8.2. DEFINITIONS OPTIONS FOR THE REFINING INDUSTRY

As discussed in the previous section, having definitions for reuse/recycle either combined or separately, seems to be preferable (as stated by some Concawe members) and more useful to meet several objectives, including:

- Identifying refinery processes where reuse and recycle occur;
- Measuring/estimating reuse and recycling activities in a refining context;
- Having a common reporting language between individual Concawe members and the industry;
- Clear understanding by external stakeholders of how the refining sector reports water reuse and recycle; and
- Stronger basis for technical engagement with the European Commission.

Based on the above objectives, two main options are discussed in this section based on the findings of the literature review and interviews with selected Concawe members. These include:

- Water reused and recycled used interchangeably with same definition for both; and
- One definition for water reused, and a different definition for water recycled.

The first option has the advantage of encompassing all water reuses within a refinery without consideration for its location or the degree of treatment required. It ignores the water quality required for another use and how many times the water is reused. This can lead to stronger consensus on what reuse/recycle activities reduce freshwater use, facilitating the reporting of this environmental parameter.

The second option implies different definitions for water reused and water recycled. The definitions encountered during the literature review, and discussed in Section 2, appear to be based primarily on the degree of treatment (or lack of) a water stream undergoes before a subsequent reuse. Water reused typically implies little or no treatment while water recycled implies a higher degree of treatment. This does not always agree with definitions provided by the companies interviewed. One company indicated they use the “water recycled” term to indicate a reuse in the same unit, while “water reused” is applied to reuse in another process and usually without treatment. Another company gave the example of stripped sour water in the desalter as water recycled while water reused is water treated, such as that from the refinery wastewater treatment plant and then reuse in other processes. Other companies interviewed indicated they have a common definition for both terms. Different definitions of water reused and recycled may be an obstacle to full acceptance of definitions different to the companies’ own and may contradict local legislation.

While “no treatment” is simple to identify, little treatment is less so. Some sources reviewed provide some suggestions. ICMM suggests disinfection or the use of a settling pond as examples of little treatment (i.e., water reused). At the other end of the scale, the use of a combination of treatment options as those described in Section 4.3 regarding the tertiary treatment of refinery effluent would qualify as water recycled. Assigning “water reuse” to treatment technologies that mainly remove suspended solids, and “water recycle” to treatments that remove dissolved salts and other dissolved contaminants (organics, metals, etc) seems a useful approximation. However, identifying whether a treatment technology is reusing or recycling water when not using traditional water treatment technologies is more difficult, such as when discussing sour water striping.

It is therefore challenging to find criteria to which associate definitions to the degree of treatment that can be applicable in all situations. However, this can be mitigated by providing agreed examples or lists of reuse/recycle activities that can be used by companies to report their water reused and recycled in a consistent way. Such list of reuse/recycle activities in a refinery context are provided in Annex 1.

Tables 5 and **6** show reuse and recycle activities based on the degree of treatment. **Table 5** shows activities defined as reused or recycled based on the degree of treatment, i.e., removal of suspended solids or dissolved solids irrespective of where they are located in the refinery or to what processes they are associated.

Table 5: Proposed main[1] water reuse and recycle activities (based on degree of treatment)

Source	Treatment	Destination
Process Water	Sour Water Strippers[2]	Desalter
		Coke Quench
		Coke Cutting
Non-Contaminated Stormwater[3]	No treatment	Fire Water
		Utility Water
	Particles removal, softening	CTW
	Particles removal, hardness, demineralization	Boiler Feed Water
Refinery Wastewater Treated Water	Media Filtration, GAC, UF, MF	Utility water Firewater
	GAC, UF or MF + RO	CTW, BFW
	GAC, UF or MF + NF	CTW, BFW
	GAC, Ion Exchange	CTW, BFW

Reported as Water Withdrawal (Non-Contaminated Stormwater)

Reused? (Process Water; Non-Contaminated Stormwater with no treatment and particles removal, softening)

Recycled? (Non-Contaminated Stormwater with particles removal, softening and with particles removal, hardness, demineralization; Refinery Wastewater Treated Water)

[1] Other reuse and recycle activities include the reuse of reverse osmosis rejects, recirculated blowdown, and reuse of process water in scrubbers. However, their potential reuse volumes are less significant.
[2] Sour Water Strippers can also be considered a technology for recycling since they remove dissolved chemicals (NH_3 and H_2S).
[3] Non-contaminated stormwater to CTW could be both reused or recycled depending on the level of treatment required.

Table 6 shows a distinction between reuse and recycle based on the decision to reuse water that is destined to final discharge, such as the reuse of the treated refinery effluent. In this case, water recycled is water that is used again within the facility after tertiary treatment at the facility's WWTP, while water reused is water that is used again, with or without treatment, before is passed through the facility's WWTP.

Table 6: Proposed main[1] water reuse and recycle activities (based on degree of treatment and location).

Source	Treatment	Destination
Process Water	Sour Water Strippers[2]	Desalter
		Coke Quench
		Coke Cutting
Non-Contaminated Stormwater	No treatment	Fire Water
		Utility Water
	Particles removal, softening	CTW
	Particles removal, hardness, demineralization	Boiler Feed Water
Refinery Wastewater Treated Water	Media Filtration, GAC, UF, MF	Utility water Firewater
	GAC, UF or MF + RO	CTW, BFW
	GAC, UF or MF + NF	CTW, BFW
	GAC, Ion Exchange	CTW, BFW

Reported as Water Withdrawal (Non-Contaminated Stormwater)

Reuse? (Process Water; Non-Contaminated Stormwater)

Recycled? (Refinery Wastewater Treated Water)

[1] Other reuse and recycle activities exist and are discussed in the report. However, their potential reuse volumes are much less significant.
[2] Sour Water Strippers can also be considered a technology for recycling since they remove dissolved chemicals (NH_3 and H_2S)

The above examples were used to develop definitions, and these are included in Annex 1 together with a definition for both terms. In addition to the definitions, examples of water reused and recycled within the refinery are provided for each case to facilitate more consistent reporting in future Concawe water surveys. A proposed definition of water reclamation is also provided in Annex 1.

8.3. RECOMMENDED DEFINITIONS FOR THE REFINING INDUSTRY

Based on the above discussion, this report recommends a combined definition for both water reuse and water recycle. This is based on the advantages described earlier such as including all water reuses within a refinery without consideration of location, degree of treatment or number processes and times the water is reused. It is also aligned with O&G Industry definition which can result in greater consensus by Concawe members, while facilitating internal and external reporting.

The definition proposed is that from IPIECA Sustainability Guidelines: "Water that has been used more than once in a single process or used in other processes, with treatment as appropriate, to reduce freshwater withdrawal (IPIECA Sustainability Reporting Guidelines)". Other possible definitions are listed in Annex 1.

Further consensus and alignment in reporting can be achieved by developing an agreed list of reuse/recycle activities most companies agreed involved the reuse of water and help reduce freshwater intake. A list of such activities is included in Annex 1 for the combined reuse/recycle option and also for the other options described earlier.

As for reclaimed water, the EU already has a definition which is embedded in EU legislation and this is the definition endorsed in this report:

"**Reclaimed water** is urban wastewater that has been treated in compliance with the requirements set out in the Urban Wastewater Treatment Directive (91/271/EEC) and which results from further treatment in a reclamation facility. Urban wastewater means domestic wastewater or the mixture of domestic wastewater with industrial wastewater and/or run-off rainwater".

9. CONCLUSIONS

This report provides an overview of refineries water use and water reuses, and of definitions of water reused, recycled, and reclaimed in a refinery context. It is based on a literature review of publicly available technical reports, academic papers, water organisations opinions; interviews with a small number of Concawe members; and Concawe members reported data.

No consistent definitions of the terms were found. Many organisations use the reuse and recycle terms indistinctively without providing any definition of the terms, while others provide the same definition to both terms which can then be used interchangeably (most reporting organisations for example). Distinct definitions for each term were found in several literature references typically based on criteria such as the level of treatment required, the location where the water is reused and whether the water is reused in the same process or in another process. More importantly, no definitions are included in EU IED documents (and none were found in the refining REF BREF).

The review of water reuses in the European refining industry concluded that the reuse of harvested rainwater and treated refinery effluent is not widespread, with only few refineries involved in the practice. Given the general old age of European refineries, segregation of contaminated and uncontaminated streams is not common given most refineries have combined sewers, providing an obstacle to the reuse of rainwater. The general low cost of freshwater in most member states is an obstacle to reusing the refinery treated effluent given the high costs involved with the provision of tertiary treatment. The reuse of stripped sour water is a common practice which is mostly reused in the desalter. While the use of reclaimed water may provide opportunities to reduce freshwater use, this depends on the availability of reclaimed water at the location (municipal suppliers and facilities) and the cost to implement such facilities and infrastructures.

Water reuse, water recycle, and water reclamation are not the only ways to reduce freshwater use. The implementation of water reduction measures through detailed cost analysis, development of detailed water balances, setting and promoting targets for water use and detailed examination of the efficiency of each refining process including reduction of leaks and other loses can provide significant reduction in freshwater use.

This report recommends the use of a combined definition for both water reuse and water recycle which is considered to increase alignment among companies' identification and reporting of such practices. Annex 1 provides other options for definitions of the terms water reuse, water recycle and water reclamation, based on technical evidenced encountered during the literature review and industry sources. Annex 1 also provides guidelines on which processes can be considered water reused, recycled, reclaimed, to facilitate technical discussions with the TWG in relation to the upcoming revision of the REF BREF for the refining of mineral oil and gas.

10. GLOSSARY

AQUASTAT	The Food and Agriculture Organisation global information system on water resources and agricultural water management.
Augmentation	The process of adding recycled water into an existing raw water supply (such as a reservoir, lake, river, wetland, and/or groundwater basin) (Association of California Water Agencies).
Best Available Techniques	'Best available techniques' means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole: (a) 'techniques' includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned; (b) 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator; (c) 'best' means most effective in achieving a high general level of protection of the environment as a whole; (Directive 2010/75/EU, Article 3(10))
Biochemical Oxygen Demand (BOD)	The amount of oxygen organisms require to decompose organic matter (under standard aerobic conditions). Used as a measure of the amount of biodegradable organic matter (pollutants) in wastewater, and hence as an indicator of water quality and the performance of wastewater treatment systems. Generally measured in mg/L. (Water and wastewater reuse, UNEP).
Blackwater	Wastewater generated from the toilet, collected separately from the remaining wastewater flow; contains urine, faeces, flushwater and/or toilet paper.
Brackish water	Water where the salinity is appreciable but not at a constant high level. The salinity may be subject to considerable variation due to the influx of fresh or sea waters (OECD, 2007).
Chemical oxygen demand (COD)	A measure of the oxygen-consuming capacity (due to both biotic and abiotic processes) of inorganic and organic matter present in water or waste.
Condenser	Cooler used for condensation of a gas flow or steam (BREF Cooling systems).

Cyst	In bacteria and protozoa, a resting stage in which the whole cell is surrounded by a protective layer (UNEP).
Discharge	Is the release of effluent, which meets regulatory standards, and designated by a regulatory permit to be safely discharged into the environment without causing harm (Association of California Water Agencies).
Total Dissolved Solids (TDS)	A measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular or ionised form (Wikipedia).
Effluent	Treated or untreated wastewater that is discharged (Alliance for Water Stewardship (AWS).
Enteric pathogens	Pathogens that typically enter the body through the mouth. They are acquired through contaminated food and water, by contact with animals or their environments, and by contact with the faeces of an infected person.
EUROSTAT	A Directorate General of the European Commission responsible for providing statistical information to the Institutions o the European Union.
FAO	Food and Agriculture Organisation of the United Nations.
Freshwater	Naturally occurring water on the Earth's surface (in ice, lakes, rivers, and streams) and underground as groundwater in aquifers containing low concentrations of dissolved solids (ISO 16075-1 2015).
Freshwater Withdrawn	The volume of fresh water removed from sources (including surface water, groundwater, harvested rainwater, and municipal water supplies) and taken into the boundaries of a facility for use (IPIECA).
Greywater	Wastewater generated from a washing machine, bathtub, shower or bathroom sink, collected separately from a domestic wastewater flow; does not include wastewater from toilets and can, but does not necessarily include wastewater from kitchen sinks (United Nations).
Helminthes	Parasitic worms that live and feed off living hosts, receiving nourishment and protection while disrupting their hosts' nutrient absorption, causing weakness and disease (Science Direct)
Hydrotreatment	A process within oil refining where impurities are removed by reaction with hydrogen. (BP)
Hydrocracking	A process that turns low quality, heavy oils into more useful products such as petrol and diesel. (BP)
Hydraulic fracturing	Well completion operation involving the injection of fluids and proppant into the target formation to induce and maintain fractures in the rock through which oil or natural gas can flow to the wellbore (IPIECA).

Integrated Water Resources Management (IWRM)	Is a process which promotes the coordinated development and management of water, land, and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment (Global Water Partnership).
Ion exchange	Ion exchange is the reversible interchange of ions between a solid (ion exchange resin) and a liquid. Ion exchange resins are made from insoluble polymers and are typically bead-shaped. Ion exchange can be used to soften water by capturing multivalent cations, such as calcium and magnesium, for specific ion removal such as boron, or for full demineralization where all dissolved inorganic solids are removed from the water (WBCSD).
Make up water	Is defined as all water mass per time unit, which is added to the system to compensate the loss of water due to evaporation and blow down (BREF Cooling Systems).
Membrane filtration	Membrane-based processes used in (waste) water treatment to obtain a high-quality final effluent for various end-users. Microfiltration (MF) and/or ultrafiltration (UF) are typically used as pre-treatment for nanofiltration and reverse osmosis (WBCSD).
Nanofiltration (NF)	NF is a pressure-driven membrane process which, with respect to separation level, lies between ultrafiltration and reverse osmosis (RO). NF membranes have a larger pore size and higher salt permeability than RO membranes (WBCSD).
Non-potable water	Water that is not of drinking water quality (ISO 16075-1 2015).
Once-through cooling	Cooling system where the cooling capacity of the water is used only once without contacting the fluid or vapour being cooled. These systems use water withdrawn from a surface water source such as a lake, river or estuary and typically return the water to the same (IPIECA).
Oocysts	A cyst containing a zygote formed by a parasitic protozoan such as the malaria parasite (medical dictionary).
Ozonation	Also called Ozone Disinfection, a common method of disinfecting wastewater that uses ozone (O_3), an unstable gas that can destroy bacteria and viruses (UNEP).
Paraffins	Alkanes consisting of hydrogen and carbon atoms arranged in a tree structure in which all carbon-carbon bonds are single. It has a general chemical formula C_nH_{2n+2}.
Pathogens	Organisms (mostly microbes) that cause disease. Examples in wastewater include Salmonella, Vibrio Cholera, and Entamoeba histolytica (UNEP).
Primary treatment	Removal of a portion of the suspended solids and organic matter from raw wastewater (United Nations).

Produced water	Water that is brought to the surface during the production of hydrocarbons, including formation water, flowback water and condensation water (IPIECA, API, IOGP, 2020).
Potable water	Water that is safe for human consumption without requiring treatment beyond its current state (BP).
Rainwater Harvesting	Is the collection and storage of rainwater, as opposed to allowing the rainwater to run off (Wikipedia).
Raw Water	Is surface or groundwater that has not gone through an approved water treatment process. (Association of California Water Agencies).
Recirculating cooling	Cooling system where the heat that is picked up by the recirculating cooling water is rejected in a cooling tower by evaporation. The heat in the cooling water is removed by heating the air as well as evaporation of the cooling water (IPIECA).
Reverse Osmosis	Is a method of removing dissolved salts and other constituents from water. Pressure is used to force the water through a semi-permeable membrane that transmits the water but stops most dissolved materials from passing through the membrane. This treatment method is commonly used in desalination, a process that takes salt out of seawater (Association of California Water Agencies).
Runoff	Part of precipitation that flows towards a river on the ground surface (i.e., surface runoff) or within the soil (i.e., subsurface flow) (UNESCO International Glossary of Hydrology, 2012).
Sand filtration	Sand filtration is a process that removes suspended particles from water (WBCSD).
Secondary treatment	Removal of biodegradable organic matter (in solution or suspension), suspended solids, and nutrients (nitrogen, phosphorus, or both) (United Nations).
Surface water	Water that occurs naturally on the Earth’s surface in ice sheets, ice caps, glaciers, icebergs, bogs, ponds, lakes, rivers, and streams. (CDP Water Security Reporting Guidance, 2018).
Suspended Solids (SS)	Small particles of solid material (pollutants) suspended or dispersed in wastewater. Total Suspended Solids is one important measure of water quality/pollution level and hence treatment system performance (UNEP).
Tertiary treatment	Removal of residual suspended solids (after secondary treatment), further nutrient removal and disinfection (United Nations).
Unconventional Extraction	The extraction of hydrocarbon resources with low mobility and/or which are present in low permeability production geological formations. Includes oil sands, shale/tight oil and gas, and coal bed methane (IPIECA, 2014a).

Wastewater treatment plant (WWTP)	Facility designed to treat raw wastewater by a combination of physical unit operations and chemical and biological processes for the purpose of reducing the organic and inorganic contaminants in the wastewater (ISO 16075-1 2015)
Water reuse facility	Any technical plant or network applied for the treatment or distribution of reclaimed water (e.g., wastewater treatment plant, advanced water treatment, storage, distribution network, irrigation devices) (DWA).
Water scarcity	Refers to the volumetric lack of freshwater resources. It is a function of the volume of human water consumption relative to the volume of water resources in a given area. (CEO Water Mandate).
Water stewardship	Use of water that is socially equitable, environmentally sustainable, and economically beneficial, achieved through a stakeholder-inclusive process that involves facility- and catchment-based actions (AWS).

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ANNEX 1: DEFINITIONS OPTIONS AND GUIDELINES

This Annex includes definitions for water reused and recycled based on the findings of the report. Three definitions options are provided for water reused and water recycled (one for combined terms, and two for water reused and recycled based on two different criteria. A definition of reclaimed water is also proposed.

Option 1: Combined Water reused/recycled

Proposed Definition

Water that has been used more than once in a single process or used in other processes, with treatment as appropriate, to reduce freshwater withdrawal (IPIECA Sustainability Reporting Guidelines).

Reason: O&G Industry definition. Includes reuse in the same process and in other processes and with or without treatment. Includes purpose to reduce freshwater use.

Other Possible Combined Definitions

- Water and wastewater (treated or untreated) that has been used more than once before being discharged from the organization's boundary, so that water demand is reduced (CDP Water Security Questionnaire).

- The act of processing used water and wastewater through another cycle before discharge to final treatment and discharge to the environment (CEO Water Mandate).

- Water that has had one or more previous uses within the refinery and has or has not been treated internally before being used again within the same refinery and therefore reduces the consumption of freshwater withdrawn (Concawe's member internal definition).

Refinery Processes/Activities classified as reused/recycled

- Use of stripped sour water for use as desalter wash water.
- Use of stripped sour water for use as coker quench water.
- Use of stripped sour water for use as coker cutting water.
- Condensate water used for heating other processes before it is disposed of as wastewater.
- Use of wastewater or treated wastewater effluent for use as firewater.
- Use of wastewater or treated wastewater effluent for use as utility water.
- Use of treated wastewater effluent for use as boiler feed make up water.
- Use of treated wastewater effluent for use as cooling tower makeup water.
- Reuse of rejects from reverse osmosis treatment.
- Reuse of recirculated blowdowns (from boilers, cogeneration, cooling towers).
- Condensate recovery for reuse as cooling tower make up water.

Note 1: Closed and semi-closed circuits such as the water circulation in recirculating cooling towers should not be reported as water reused/recycled.

Note 2: For reporting purposes water reused/recycled should be measured or estimated as the difference between the total quantity of fresh water required in all processes and the quantity of fresh water withdrawn.

Note 3: IPIECA guidance defines the use of collected stormwater and of reclaimed or recycled water from external sources as water withdrawal or water intake, although reclaimed water from external sources is sometimes reported separately from freshwater intake as it is considered a more sustainable practice than the direct use of freshwater sources.

Option 2: Separate water reused/recycled definitions. Based on degree of treatment

Proposed definitions

Water Reuse: water that has been used more than once in a single process or used in other processes, with minimal or no treatment, to reduce freshwater withdrawal (modified from IPIECA).

Water Recycle: Water that undergoes significant treatment (to reduce salinity and/or other contaminants), such that the water quality is sufficient for other uses that require high quality water (modified from BP Water in the Energy Sector, 2013).

Reason: Separates the terms by the degree of treatment as frequently encountered in the literature sources. It is not linked to whether it is reused within the same or in a different process, nor to its location (inside or outside the facility).

Other Possible Definitions

Water reused

Treated water/wastewater that is used more than once before it passes back into the water cycle (Water Reuse, 2020, used by IPIECA, 2020).

The reuse of water, with minimal or no treatment, within and outside the fence for the same or different processes (WBCSD Guide to Circular Water Management).

Used water and wastewater that is used again before discharged for final treatment and/or discharge to the environment. Reuse includes wastewater used for irrigation within a facility boundary. It also includes harvesting of rainwater within a facility boundary (BP Water in the Energy Industry, 2013).

Water recycled

Used water/wastewater employed through another process cycle after treatment (IPIECA, 2014b)

Recycle resources and wastewater (treated by membrane or reverse osmosis to a very high quality) within and outside the fence (WBCSD Business Guide to Circular Water Management).

Water that undergoes significant treatment (to reduce salinity and/or other contaminants), such that the water quality is sufficient for other uses that require fresh or near-fresh water (BP Water in the Energy Sector, 2013).

Refinery processes/activities classified as reused and recycled

Water reused

- Use of stripped sour water for use as desalter wash water.
- Use of stripped sour water for use as coker quench water.
- Use of stripped sour water for use as coker cutting water.
- Condensate water used for heating other processes before it is disposed of as wastewater.

- Use of treated wastewater effluent for use as firewater (with little treatment).
- Use of treated wastewater effluent for use as utility water (with little treatment).
- Condensate recovery for reuse as cooling tower make up water.

Water recycled

- Reuse of stormwater as boiler feed make up water requiring softening/removal of dissolved solids.
- Reuse of treated wastewater effluent for use as boiler feed make up water.
- Reuse of treated wastewater effluent for use as cooling tower makeup water.
- Reuse of rejects from reverse osmosis treatment.
- Recirculated blowdowns (from boilers, cogeneration, cooling towers).

Note 1: Minimal treatment in water reuse typically involves the removal of particles or solids in suspension. Water recycling implies a higher degree of treatment involving the removal of dissolved solids and dissolved organic contaminants.

Note2: Closed and semi-closed circuits such as the water circulation in recirculating cooling towers should not be reported as water reused or recycled.

Note 3: For reporting purposes water reused and recycled should be measured or estimated as the difference between the total quantity of fresh water required in all processes and the quantity of fresh water withdrawn.

Note 4: IPIECA guidance defines the use of collected stormwater and of reclaimed or recycled water from external sources as water withdrawal or water intake, although reclaimed water from external sources is sometimes reported separately from freshwater intake as it is considered a more sustainable practice than the direct use of freshwater sources.

Option 3: Separate water reused/recycled definitions. Based on whether the water has been reused before or after treatment at the facility's WWTP)

<u>Proposed Definitions</u>

Water reused: water and wastewater that has been used more than once in a single process or used in other processes, with or without treatment, before discharged for final treatment and/or to the environment (modified from IPIECA 2020 and BP Water in the Energy Sector).

Water recycled: Water that undergoes significant treatment, typically at the facility's WWTP, to reduce salinity and/or other contaminants, such that the water quality is sufficient for other uses that require high quality water, within and outside the fence. The term applies also to any treated industrial effluent from another industrial facility used by the refinery to supplement or replaced freshwater intake (modified from BP Water in the Energy Sector, 2013 and WBCSD Business Guide to Circular Water Management).

Reason: it provides emphasis on intention to apply further treatment to the final effluent for reuse inside or outside the refinery.

<u>Other possible definitions</u> (As per Option 2)

Refinery processes/activities classified as reused and recycled

Water reused

- Use of stripped sour water for use as desalter wash water.
- Use of stripped sour water for use as coker quench water.
- Use of stripped sour water for use as coker cutting water.
- Condensate water used for heating other processes before it is disposed of as wastewater.
- Reuse of stormwater as firewater.
- Reuse of stormwater as utility water.
- Reuse of stormwater as cooling tower make up water.
- Reuse of stormwater as boiler feed make up water.
- Condensate recovery for reuse as cooling tower make up water.
- Reuse of rejects from reverse osmosis treatment.
- Recirculated blowdowns (from boilers, cogeneration, Cooling Towers).

Water recycled

- Use of treated wastewater effluent for use as boiler feed make up water.
- Use of treated wastewater effluent for use as cooling tower makeup water.
- Use of treated wastewater effluent for use as firewater.
- Use of treated wastewater effluent for use as utility/wash water.

Note 1: Closed and semi-closed circuits such as the water circulation in recirculating cooling towers should not be reported as water reused or recycled.

Note 2: For reporting purposes water reused and recycled should be measured/estimated as the difference between the total quantity of fresh water required in all processes and the quantity of fresh water withdrawn.

Note 3: IPIECA guidance defines the use of collected stormwater and of reclaimed or recycled water from external sources as water withdrawal or water intake, although reclaimed water from external sources is sometimes reported separately from freshwater intake as it is considered a more sustainable practice than the direct use of freshwater sources.

Reclaimed Water Definition

As discussed in Section 2.2, water reclamation is the reuse of wastewater which is treated after collection in urban areas, typically via a network or sewers. It can include both domestic and industrial wastewaters, which after primary and secondary treatment in municipal treatment plants, their quality is further improved by additional treatment including disinfection. The treated wastewater (i.e., reclaimed water) can then be reused in agriculture (irrigation), industrial facilities, environmental applications, and other activities.

Proposed definition

Reclaimed water is urban wastewater that has been treated in compliance with the requirements set out in the Urban Wastewater Treatment Directive (91/271/EEC) and which results from further treatment in a reclamation facility. Urban wastewater means domestic wastewater or the mixture of domestic wastewater with industrial wastewater and/or run-off rainwater.

Reason: appropriate in a European context, however, it requires definition of urban wastewater.

Other Possible Definitions

Municipal wastewater that has been treated to meet specific water quality criteria with the intent of being used for a range of purposes (EPA).

Treated wastewater that, where appropriate, has undergone an additional or complementary treatment process that allows its quality to be adapted to the use for which it is intended to (Spanish Regulation RD 1620/2007).

As reclaimed water is the reuse of treated wastewater there is a need to define wastewater. The most comprehensive definition of wastewater found is perhaps Raschid-Sally and Jayakody's (2008) definition, adapted by the United Nations Environment Programme (UNEP) and included in Section 2.2 of this report:

"Wastewater *is regarded as a combination of one or more of*: *domestic effluent consisting of blackwater (excreta, urine and faecal sludge) and greywater (used water from washing and bathing); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban runoff; and agricultural, horticultural and aquaculture runoff*".

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