D4.1

Market Analysis of Key Water Reuse Technologies

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Abstract	The principle objective of this report is to benchmark the most relevant countries and markets promoting water reuse technologies and to detail the key considerations and main tools available. Its content provide assistance to water operators wanting to implement a new reuse scheme but are unsure of which of the current leading technologies can give them the best value for money. It can also act as a guide to technology suppliers requiring a better understanding of the current water reuse market in terms of the opportunities, trends and constraints for their technologies in the water reuse sector in European as well as in the global markets.

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1 Executive Summary

The principle objective of this report is to benchmark the most relevant countries and markets promoting water reuse technologies and to detail the key considerations and main tools available. Its content provide assistance to water operators wanting to implement a new reuse scheme but are unsure of which of the current leading technologies can give them the best value for money. It can also act as a guide to technology suppliers requiring a better understanding of the current water reuse market in terms of the opportunities, trends and constraints for their technologies in the water reuse sector in European as well as in the global markets.

The structure is divided into four main sections: Firstly it underlines the methodology that was used to implement the study; secondly there is a review of technologies and costs of the implementation and operation of current water reuse technologies implemented by European operators; third, it then moves on to review the selected innovative water reuse technologies through an analysis of questionnaires and interviews of two focus groups (experts and technology suppliers). Finally an analysis of these technologies to benchmark the most relevant countries and markets promoting water reuse technologies is presented.

Identifying the most relevant technologies for the research project began by reviewing the technologies that were identified by the DEMOWARE project. The DEMOWARE consortium had already undertaken the task of reviewing the most relevant innovative water reuse technologies that will overcome some of the main technological barriers currently facing the water reuse sector, therefore this was the most logical starting point.

After a thorough methodological process engaging the board of DEMOWARE in the process, the final technologies studied in this report are the following:

- Microfiltration - Reverse Osmosis / Ultrafiltration – Reverse Osmosis (MF/UF RO)
- Anaerobic MBR for waste management and water reclamation (AnMBR)
- Forward Osmosis MBR (FO – MBR)
- Modular Wastewater Treatment
- Soil Aquifer Treatment (SAT)
- Advanced oxidation for pre-treatment in SAT (AOP – SAT)
- Struvite Crystallization

Each technology is presented through the same analysis structure which focuses on (i) the technological aspects of the technology and (ii) its main market characteristics before providing (iii) an overview of its main perspectives for further development. For each of these three sections, the following key components have been analysed thoroughly:

(i) Technology Profile

a) Description of the technology
b) **Treatment capacity (m3/day)** – This parameter indicates the filtration capacity of the selected technology and how many cubic meters of used water it can filter over a 24 hours period. Despite the result depends on the treatment plant size and capacity, it sill gives a good indication of the potential of the technology compared to other ones.
c) **Technological Maturity** – The technological maturity indicates whether the water reuse technology analysed has been validated and can be used widely at industrial, urban or agricultural levels, or, on the contrary, whether it remains at the pilot phase implying further development and pilot testing before being able to be introduced to the market.

d) **Advantages and limitations** - where the specific technological advantages and limitations characterising the water reuse technology are presented

(ii) Market overview

a) **Suppliers** – This section presents the main suppliers that manufacture and offer the technology to the market and their geographical origin.
b) **Market analysis** - Overview of the water reuse market for the given technology in terms of demand for industrial, urban or agricultural applications and perspectives of the technology at a market level in Europe and globally.
c) Investments and operational costs

- CAPEX – A key factor for deciding which technology to use is the initial investment and capital expenditures (CAPEX) it requires. Important variations can be observed at this level regarding the level of technology it implies, the infrastructures needed, etc. A segmentation has been applied between the technologies that need high (superior to 100M€), medium (from 10M€ to 99M€) or low investments (inferior to 9 M€).
- OPEX: Similarly, the operational costs (OPEX) are key for taking a technological decision as they vary dramatically among different technologies and can balance the initial investment. While some technologies might be relatively inexpensive in terms of investment, they might imply high operational costs. Major operational costs in the water reuse sector are linked to energy consumption, maintenance (use of chemicals for cleaning the processes) and replacement needs (directly linked to the lifespan of the technology). Operational costs have been classified for the purpose of the study between "high" (superior to 2.1 € per cubic meter treated), "medium" (from 0.6€ to 2 € per cubic meter treated), and "low" (inferior to 0.5 € per cubic meter treated).

d) **Final reuse applications** – Water reuse technologies, especially in their probing phase or early years, are usually used for specific applications, either agricultural, urban or industrial that often can be extended to other applications when they are more technologically mature.

(iii) Future perspectives

a) **Needs for further technological development**- this section presents an overview of the principal areas for technological improvement in the coming years.
b) **Opportunities and challenges**: summarizing the market perspectives for the technology.

Based on the information processed through the research study, a specific benchmark analysis has been performed considering different comparative variables. Such variables can be appreciated below:

On types of technologies	On technology management	On market and country analysis
Reuse application by type Reuse production capacity Technological qualitative analysis Level of maturity	Investment and cost operation analysis Supplier analysis	Market trends Legislation analysis

As a final conclusion of the research process, the research team has identified major advantages and disadvantages of each technology, and highlighted the major opportunities and challenges associated with each one of them. In terms of specific advantages and disadvantages for each one of the technologies analysed, the research identified the following major key points:

Technology	Advantages	Disadvantages
1.UF/MF + RO	• MF/UF filtration allows for the chemical cleaning requirements and power consumption for RO membranes to be reduced significantly and increases the permeate production per unit membrane area	• Fouling and Energy cost of RO
2. AnMBR	• Nearly absolute biomass retention • Low nutritional requirements • Allows for operation at high sludge retention time (SRTs) • low energy requirements • Ability of producing net energy (biogas) • Produces mineralized nutrients (ammonia, orthoP) for agricultural use	• Cake formation: membrane fouling more severe than under aerobic conditions • WWT in lower temperate climates (<20ºC) is still a challenge
3. FO MBR	• Much higher rejection than MF/UF RO scheme at a lower hydraulic pressure • Lower fouling propensity than pressure-driven systems meaning less frequent backwashing.	• Low water flux resulting in large FO membrane areas/cost • Accumulation of salts into the bioreactor resulting in salt leakage • High energy demand linked to the need for re-concentration
4. Modular WWT	• Portable and easy to install • Designed for use in projects with time, space, and budget constraints • Can be placed strategically to generate reclaimed water at the point of reuse • Can be installed incrementally to meet growing demand	• Getting rid of the sludge can be a challenge in some cases • They require a high operator knowledge
5. SAT	• Natural pretreatment system • Allows securing and enhancing water supplies while mitigating floods and flood damage. • Low cost and a fitting option for wastewater reclamation. • Can contribute to an improvement of the aquifer water while preserving water levels in wetlands • mitigates contaminant intrusion and freshens saline aquifers or prevents aquifer salinization • Enhances environmental flows in water supply catchments • Augments water supplies and improving coastal water quality by reducing urban discharges.	• Groundwater recharge should not be viewed as a treatment method. Introducing pollutants into groundwater aquifers may have long-term negative impacts and SAT could change the soil and groundwater hydrological properties. • Requires a large area for the infiltration basin which adds to the cost of the project and may increase the risk of flooding in areas where groundwater levels are already high.

Technology	Advantages	Disadvantages
6. AOP + SAT	• Hydroxyl radical (HO•) can break down most organic components into carbon dioxide, water and mineral acids • A number of AOPs exist that can function at normal temperatures and pressures and can be operated with equipments of small dimensions • HO•in the AOP are non-selective towards different classes of reduced compounds. • No secondary waste stream is generated, reducing costs • Capacity to remove micro pollutants favouring the biodegradability of effluents and avoiding aquifer clogging. • Ability to increase the biodegradability of micro pollutants in the SAT system. • Land reduction: with AOP before SAT, it results in less land needed to treat the water to reuse standards.	• Capacity to generate by-products of concern such as brominated by-products, various oxygenated by-products, carboxylic acids and halogenated acetic acid. • Performance of the process affected by high concentrations of bicarbonate (HCO3–) and carbonate (CO32–) ions, which react with the hydroxyl radical. • HO•, in spite of their great oxidizing power cannot be used effectively for disinfection due to their short half life which disables high radical concentration. • Relatively high treatment costs and special safety requirements because of the use of very reactive chemicals and high-energy sources (UV lamps, electron beams, and radioactive sources)
7. Struvite	• Increase overall WWTP performance due to reduction of pipeline incrustations, return load, sludge volume and the consequent disposal costs. • Struvite can be recovered to use as agricultural SRFS (slow release fertilizer). • Can also be used as chemical reagent, fireproof agent, cement adhesive, etc. • Increases the recovery rate of nutrients through the water reuse scheme.	• The key limitation is enhanced biological phosphorus removal with anaerobic digestion (AD) to provide enough phosphorus in the sludge water. • Needs stable climate (better warm than cold).

Furthermore, in terms of challenges and opportunities, the research identified the following major key points:

Technologies	Challenges	Opportunities
UF/MF + RO	• Lack of standardization among the different suppliers; • Legislation and public acceptance of re-used water; • Commoditization would certainly lead to a significant reduction on R&D expense due to lack of attractiveness for continuous innovation.	• Demand for replacement; • General interest for membrane technologies which have a number of applications; • Increasing investments and investigation; • Large field for development and innovation:

Technologies	Challenges	Opportunities
AnMBR	• As of today, not appropriate for municipal WWT to reach reuse quality due to too high costs and high shear stress in the biology. • Legislation and public acceptance of re-used water; • Will not develop significantly until cake formation is solved • High cost of membranes still impedes a faster commercialisation (both MBRs and AnMBRs). • Membrane costs appear to be up to 10 times higher than the energy consumption costs per m3 of treated water. • Treatment of domestic waste water at low temperatures (<15ºC).	• Use in the peri-urban to rural context to recover water, nutrient and biogas for combined heat and power generation. • Suitable for high loads (ability to treat water of poorer quality) and provides a possibility for the agricultural use of the treated effluent for non-potable purposes in many regions suffering from water shortage • Integral municipal waste water treatment with pathogen free but nutrient rich effluent for re-use in irrigation and enable energy recovery.
FO MBR	• No market so far as more expensive than MBR-RO schemes • Legislation and public acceptance of re-used water; • High energy requirements of the re concentration • Limited performance of the FO membrane.	Potential opportunities linked to characteristics: • Compact wastewater treatment concept • Effective in treating difficult wastewaters • Produces high quality effluents which can be re-used directly.
Modular WWT	• Larger international corporations (Chinese, Korean, US) might encroach on the European Market outcompeting European SMEs. • Legislation and public acceptance of re-used water; •	• Change in legislation (i.e. polluter pays principle, hydraulic footprint etc.) might force a lot more industries to install modular wastewater treatment plants to treat effectively their wastewater and reuse the treated water. • Growing trend in compound recovery, where compounds of economic value can be recovered from certain industries from treating their wastewater. • Wide range of applications ranging from emergency wastewater treatment and off grid applications.
SAT	• • Need to develop evaluations that integrate SAT into a wide range of direct and associated costs and benefits versus current narrow sectoral evaluations of alternative supplies. • Legislation and public acceptance of re-used water; • Lack of operator and regulator training • Cost or unavailability of required lands in urban area • Concern about introducing pollutants into groundwater aquifers that may have long-term negative impacts and further investigation reducing those risks appear necessary today.	• In a context where many cities and agricultural areas rely on the combined use of surface water and groundwater, SAT appear as a promising option for integrated water resource management. • It allows reclaimed water such as treated blackwater, greywater or stormwater not to be just discharged into other surface waters, but also reused as water for irrigation in agriculture or to intentionally recharge groundwater aquifers via MAR. • SAT implies a better knowledge on the use of natural systems in its entirety

Technologies	Challenges	Opportunities
AOP + SAT	• Further research should also be promoted to analyse the real toxicology of cocktails (effect of all by-products as a whole, not one by one studies). • Legislation and public acceptance of re-used water;	• Many development opportunities for AOP SAT schemes in a context of increased contamination of water effluent. • AOP SAT scheme appears as a highly effective treatment for the removal of organic contaminants from water and could apply to small and medium facilities if the technological aspects can be simplified in the future. • Highly populated areas with difficulties for (tap) water supply.
Struvite	• Competition with primary fertilizers could jeopardize its market development. • Legislation and public acceptance of re-used water; • Indecisive policies and non-reliable regulation could also hamper investment significantly. The downstream use of recovered nutrients still need to be harmonised, a regulation would be needed at this level.	• Phosphorus is considered as a critical raw material by the EU since 2014 as its availability has been identified as a globally relevant bottleneck for fertiliser and food supply. Europe has an import dependency above 90% with regards to mineral phosphorus. • Strong potential for new WWTP treatment schemes with integrated nutrients recovery steps As to municipal wastewater, they represent a relevant phosphorus reserve and have the potential to cover about 20% of the demand.

2 Introduction

The global water reuse market outlook in 2010 when the *"Municipal Water Reuse Markets 2010*" (Global Water Intelligence) was published, showed significant growth, nearly doubling that of the desalination market. However, since then there have been a number of factors that have reduced the potential of this Global Market. In Spain the economic crisis has significantly affected public water authorities who are now more reluctant to implement water reuse schemes without the guarantee of economic compensation. In Australia after some good wet years, water reuse projects were taken off the political agenda. In America the water reuse momentum was lost due to the financial crisis and the el Niño effect.

However, the Global Water Intelligence research team is currently working on a new report focused on the food and beverage industry. This is because they believe that in this sector, water efficiency has become a major priority. Many of the major FMCG (fast-moving consumer goods) brands have set themselves targets for water consumption, and the only way they can meet them is through greater reuse. Therefore they believe that the need for water efficiency in industry will drive the water reuse market, which in turn will have a knock-on effect on the municipal water reuse market. Another aspect that they believe will drive the water reuse market is the development of technologies that permit lower CAPEX and OPEX which at the same time improves the quality of the treated water, which in turn opens up new potential water reuse clients. BBC Research has estimated that the global markets for wastewater-recycling and reuse technologies during the period from 2009 to 2012 increased from nearly $6.7 billion to $9.5 billion, equivalent to a compound annual growth rate (CAGR) of 12.6%. Global markets are expected to increase from $9.5 billion in 2012 to $23.4 billion in 2017, reflecting a five-year CAGR of 19.7%

The technologies used for water reuse purposes are embedded in wastewater treatment schemes. In general terms urban wastewater treatment follows the following treatment cycle:

- Preliminary Treatment
- Primary Advanced Treatment
- Secondary Treatment
- Secondary Treatment with nutrient removal
- Tertiary Treatment
- Advanced Treatment

Technologies to treat water to the quality required for reuse are generally focused on secondary treatment through to advanced treatment schemes. Secondary treatment is the biological removal of biodegradable organic matter and suspended solids. It can also include nutrient removal (nitrogen and/or phosphorus). Broadly speaking, secondary treatment can be divided into two main categories of processes: membrane and non-membrane.

Non Membrane

- Suspended growth (Activated sludge) Attached growth (TF, RBC, MBBR)
- Hybrid processes (TF/SC)
- Lagoons (waste stabilization pond)

Membrane

- Membrane Bioreactor

On the other hand, the implementation of advanced water treatment technologies is highly dependent on the final application of the treated water. As opposed to secondary treatment, advanced treatment involves the removal of total dissolved solids and/or trace constituents as required for the specific water reuse application. Membrane technologies are therefore used in advanced treatment for the removal of the dissolved solids, which can either be pressure driven (NF and RO) or electrically driven (ED).

Focusing on the secondary and advanced urban wastewater treatment cycles, the DEMOWARE project has identified a number of barriers to the more widespread development of water reuse with regards to water recycling in urban, agricultural and industrial sectors. One of the main barriers identified is the inconsistent and unreliable methods of identification and optimization of appropriate wastewater treatment technologies for reuse applications which are able to balance the competing demands of sustainable processes. Therefore one of the main objectives of the DEMOWARE project is to demonstrate the technical feasibility of innovative technologies for wastewater reclamation and reuse. Although there are many readily available current technologies highly effective for water recycling, depending on the water quality requirement, the DEMOWARE project has identified the need to explore new technologies and approaches that meet not only technical but also economical, environmental and social criteria.

Four main issues, currently regarded as the technical barriers for widespread implementation of water reuse are investigated in the project, namely:

i. capital and operational costs of advanced membrane technologies,
ii. technical feasibility of soil aquifer treatment not only as water low cost reclamation technology but also as a storage system,
iii. low-cost and reliable disinfection strategies, and
iv. revalorization of wastewater and concentrate brines as a source of valuable compounds.

Therefore the DEMOWARE project chose the following treatment and monitoring technologies on which it will innovate and demonstrate. These technologies were chosen as they demonstrate the most potential for advancement in the four above mentioned technical barriers. These technologies are listed in the tables below (see Table 1 and Table 2).

Table 1 DEMOWARE Wastewater Treatment Technologies for Water Reuse

Demonstration of double membrane processes to achieve water quality tailored to specific industrial uses/issues (MF/UF RO)
Flow reversal RO
Smart design and pretreatment options in SAT to avoid changes in soil/aquifer system
Partial disinfection technologies for water reuse
Anaerobic MBR for waste management and water reclamation in rural zones
Struvite Crystallization

Table 2 DEMOWARE Wastewater Monitoring Technologies for Water Reuse

New tools to monitor membrane integrity
Online flow cytometry and molecular biological tools to assess disinfection effectiveness
Effect-based bioassays for chemical contaminants detection
Chemical fingerprinting for chemical contamination
Innovative CO2-based technology for clogging reduction in networks
Electrochemical sensor for biofilm monitoring in distribution networks

3 Methodological research approach to the report

3.1 Objective

The principle objective of this report is to benchmark the most relevant countries and markets promoting water reuse technologies and to detail the key considerations and main tools available. Its content provide assistance to water operators wanting to implement a new reuse scheme but are unsure of which of the current leading technologies can give them the best value for money. It can also act as a guide to technology suppliers requiring a better understanding of the current water reuse market in terms of the opportunities, trends and constraints for their technologies in the water reuse sector in European as well as in the global markets.

The structure is divided into four main sections: Firstly it underlines the methodology that was used to implement the study; secondly there is a review of technologies and costs of the implementation and operation of current water reuse technologies implemented by European operators; third, it then moves on to review the selected innovative water reuse technologies through an analysis of questionnaires and interviews of two focus groups (experts and technology suppliers). Finally an analysis of these technologies to benchmark the most relevant countries and markets promoting water reuse technologies is presented.

3.2 Defining the selection process of Water Reuse Technologies

The technologies chosen to be studied in this report followed a systematic process of selection. There are a number of technologies that are currently used around the world for treating water to reuse quality. The Global Water Intelligence report *"Municipal Water Reuse Markets 2010*" undertook an exhaustive research of the global water reuse market, involving 20 researchers. They stated that collecting data on an outcome like reuse is difficult. The equipment suppliers are not homogenous, and they do not know whether their equipment has been sold to a reuse project or a simple wastewater treatment project. Reuse is a very fragmented and dispersed industry, and one which it is very difficult to draw a straight line around.

Therefore it was really important for this report to be far more focussed to achieve a benchmark of the most relevant countries and markets for water reuse, within the framework of a task of a much larger multi-focus water reuse project. The main focus of benchmarking countries and markets was undertaken under the structure of water reuse technologies.

Identifying the most relevant technologies began by reviewing the technologies that were identified by the DEMOWARE project. The DEMOWARE consortium had already undertaken the task of reviewing the most relevant innovative water reuse technologies that will overcome some of the main technological barriers currently facing the water reuse sector, therefore this was the most logical starting point. All the treatment and monitoring technologies that are to be innovated on during the DEMOWARE project were chosen to be studied for this report.

The initial study process was presented to the DEMOWARE management board meeting in London (June 2014), through this discussion, it was decided to further include Forward Osmosis MBR and modular wastewater treatment technologies, as they were both identified as technologies that could have potential market impacts in the water reuse sector.

Microfiltration - Reverse Osmosis (MF – RO) and Ultrafiltration - Reverse Osmosis (UF – RO) were originally proposed to be studied separately, however after initial results of the study, it was evident that the market for these two treatment schemes is not sufficiently significant to warrant a separation of these two schemes, therefore the two schemes were studied together as MF/UF – RO. After initiating the study it was also soon realised that the market and country analysis for water reuse monitoring technologies was much more widespread than just the water reuse sector and therefore, discussing this aspect with DEMOWARE management board, it was decided that a benchmark analysis of monitoring technologies would not be specific enough for water reuse and therefore a benchmark analysis would not be valuable for the water reuse sector. It was therefore concluded that water reuse technologies and not monitoring technologies would be incorporated in the benchmarking analysis.

Therefore, based on this methodological process, the final technologies studied in this report are listed in Table 3.

Table 3 Final Technologies Selected for the Benchmark Analysis

Microfiltration - Reverse Osmosis / Ultrafiltration – Reverse Osmosis (MF/UF RO)
Anaerobic MBR for waste management and water reclamation (AnMBR)
Forward Osmosis MBR (FO – MBR)
Modular Wastewater Treatment
Soil Aquifer Treatment (SAT)
Advanced oxidation for pre-treatment in SAT (AOP – SAT)
Struvite Crystallization

3.3 Research phases of the methodology

In order to fulfil the objective of completing the benchmark, the research team has proposed a five phase methodological approach (see Figure 1).

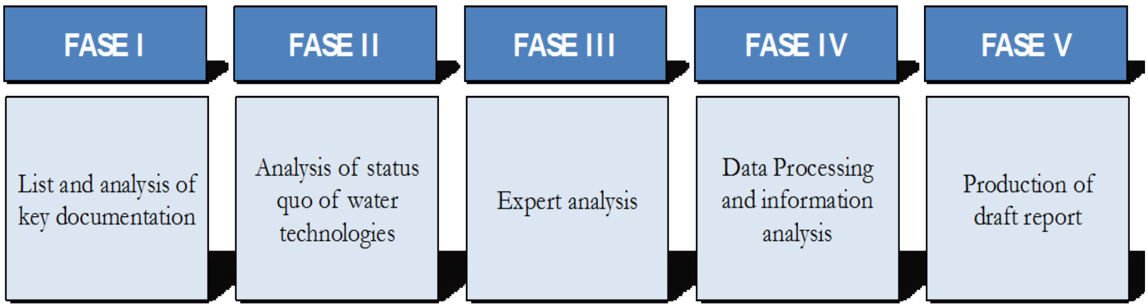

Figure 1 Five Phase Methodological Approach

3.3.1 Phase one: List and analysis of key documentation

The **first phase** of the study was to do an extensive and exhaustive literature review, from the latest scientific articles, thesis, magazines and scientific databases on all aspects related to the selected water reuse technologies. Main literature reviewed includes:

- General literature (4)
- UF/MF – RO membrane scheme (8)

- Anaerobic Membrane Bioreactor Technology (7)
- Forward Osmosis MBRs (3)
- Modular Wastewater Treatment Plants (1)
- Soil Aquifer Treatment (SAT) for indirect potable reuse (4)
- Advanced oxidation for pretreatment in SAT (2)
- Struvite (3)
- Measuring and monitoring (9)

A total 41 references were consulted for this study (see Annex II for a whole list of references used within this first phase).

3.3.2 Phase two: Analysis of Status Quo of current water reuse technologies in operation

The second phase of the study was initiated with a review of water reuse technologies currently in use in Europe. This was achieved through consulting wastewater treatment operators using a questionnaire template (see Annex III) on their current operational practices and technologies. This starting point allowed to gain an understanding of the current technologies in use, why those technologies were chosen, what would force the operators to change their chosen technology, what are their current OPEX and CAPEX costs etc.

This initial study allowed to gain a representative baseline of the technologies currently in use for water reuse applications through the analysis of the target market for water reuse technologies: the technology operators. This status quo allows us to gain an understanding of how the DEMOWARE technology innovation can improve on the current issues facing water operators. This second phase of the study gained a representative sample across Europe where 9 treatment company operators currently running water reuse schemes replied to the questionnaires. These treatment operators are listed below by their site and company name (see Figure 2).

Table 4 Main sites considered

No	Site	company
	El Port de La Salva	Veolia
	Old Ford Water Recycling Plant	Thames Water
	Torreele	Intercommunale Waterleidingsmaatschappij van Veurne-Ambacht (IWVA)
	Camp de Tarragona Water Reclamation Plant	Tarragona Municipality Operated by Veolia
	Capitanata	Fiordelisi
	Sabadell	CASSA (Suez)
	Steinhof WWTP	Stadtentwässerung Braunschweig
	Yecla	Acciona Agua
	Shafdan	Mekorot

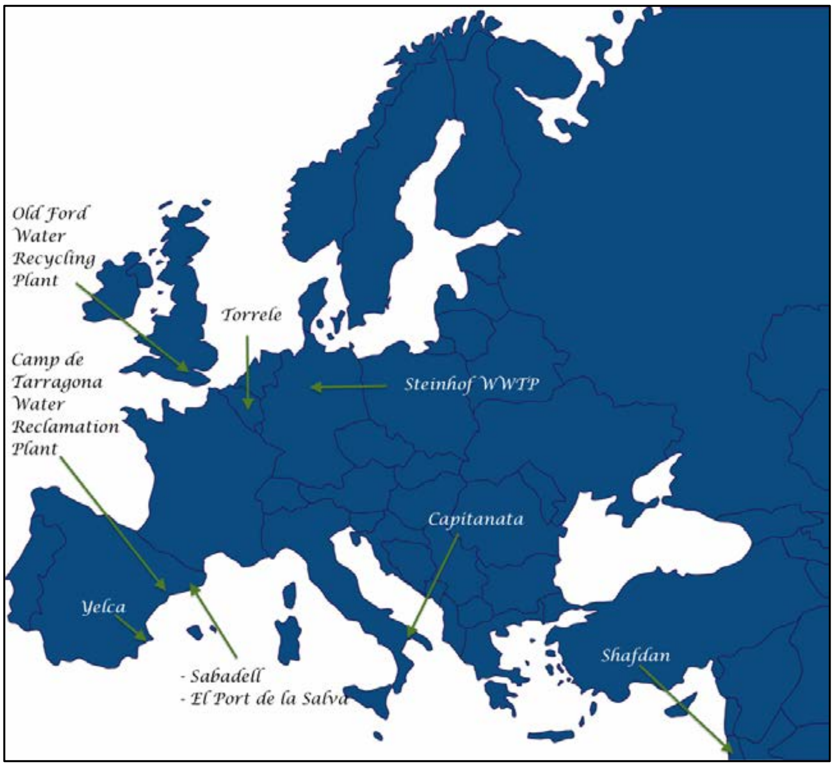

Figure 2 Showing the sites and countries of the treatment

Furthermore, the European countries represented by this study are presented below, France has been included in this list as two of largest water treatment companies (Veolia and Suez) are operating and maintaining plants outside of France as noted in the list above.

The list is as follows:

- Spain
- United Kingdom
- Belgium
- Italy
- Germany
- Israel
- France

3.3.3 Third Phase: Expert analysis

The third phase of the study was first to identify, for each of the water reuse technologies, a series of global research and technical leaders (experts) for the specific technology. Once they were identified, they were each sent a specifically designed questionnaire regarding the market and country trends, market size, opportunities and the challenges to bring this technology to market (see Annex III).

Furthermore, this third phase included in-depth interviews of global reuse technology suppliers. In this case, company leaders in supplying these water reuse technologies were identified, with the objective to understand from the companies, the market trends, OPEX, CAPEX, market size, geographical tendencies, the opportunities and challenges of the technologies from a commercial market orientated point of view (see Annex IV). The analysis and interviews performed have been the following:

3.3.3.1 Experts

A total of thirteen experts were identified to cover all the chosen water reuse technologies. Tailored questionnaires were devised and separated for each technology, which were then sent to an expert with the best experience in a particular technology area. Some experts received more than one technology questionnaire either due to the similarity of the technology (for eg. SAT, AOP+SAT) or the broad experience of the expert with experience covering more than one technology type.

The analysis from the experts covered all the technologies chosen and as global technology leaders were targeted, the majority of replies were of high quality. However, two replies required further verification and clarification, therefore two phone interviews were held to augment the replies gathered from the experts.

3.3.3.2 Companies managing the selected technologies:

A total of 24 European or Global market leaders and suppliers of water reuse technologies were identified to cover all the selected technologies. As in the case of the experts, some companies are suppliers of more than one technology type (for eg. MF, UF and MBRs) and therefore a number of companies were sent more than one technology questionnaire. With regards to FO MBR, no questionnaire was sent out as currently there are no suppliers for FO MBR as this technology is still at academic level.

A number of the larger membrane companies such as: GE Water, Toray, PenAir Xflow, BiWater, Siemens and Norit declined to participate as they were concerned with revealing potentially sensitive market information.

The six companies that did reply covered the selected water reuse technologies of this report. The companies were:

- DOW Chemical
- Veolia
- BioProcess H2O
- Verdygo
- NeRuSus
- Mekorot (As a user of SAT technology)

Following the first round of questionnaire evaluations, it was revealed that some of the information was not completely clear or that the companies did not answer fully the information required, therefore three phone interviews with three of the suppliers and one face to face interview with one supplier were held to augment the initial information.

3.3.3.3 Overall Questionnaire Analysis

A total of 60 questionnaires were sent out with a split of twenty-five going to experts and thirty-five going to companies. A total of 25 questionnaires were returned, 12 returned by the experts and 13 returned by the companies.

Questionnaires that were not returned either were a result of none reply, not willing to participate or unable to participate due to the fear of revealing sensitive company information

The graphs below detail the overall results of the questionnaires set out and received (figures 3 and 4).

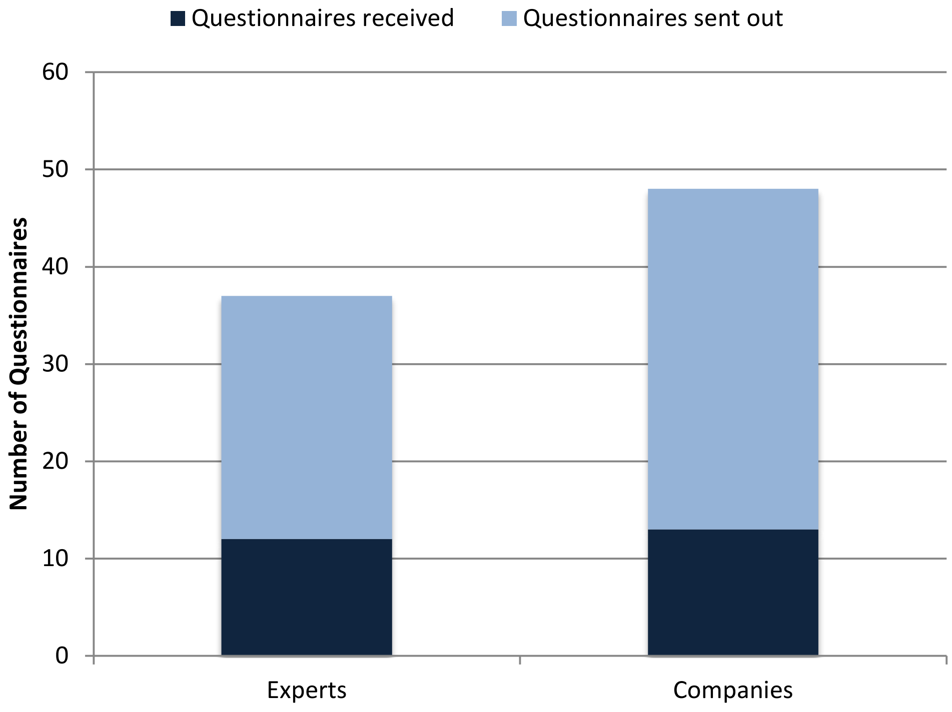

Figure 3 Graph detailing the split between questionnaires set out and received for Experts and Companies

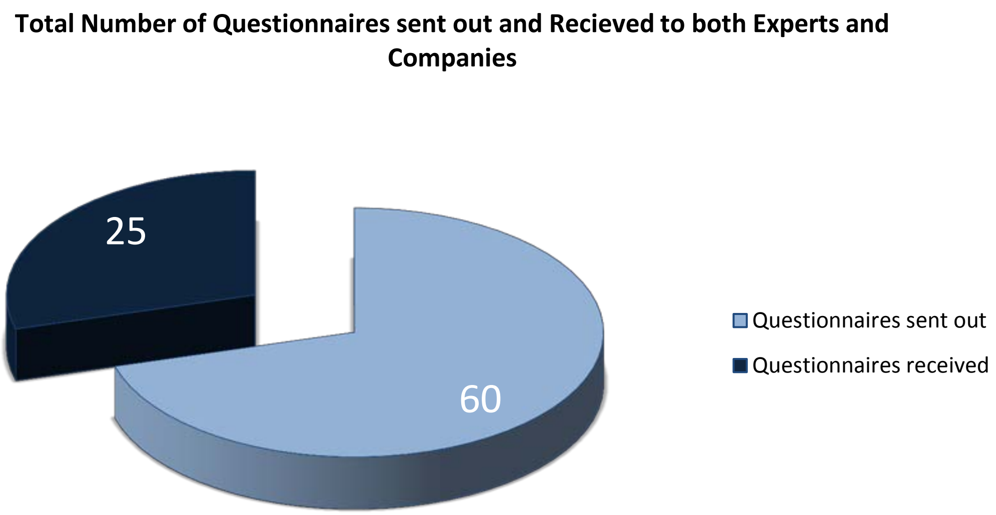

Figure 4 Pie Chart showing the split between the total number of questionnaires sent out and received.

3.3.4 Phase Four: data processing and analysis of information gathered

The data and information gathered were processed following a threefold analysis structure focusing to define for each technology:

(i) Main technology profile

(ii) The market overview

(iii) An overview of future perspectives

For each of these three sections, the following key components have been analysed thoroughly:

(i) Technology Profile

- Description of the technology
- Treatment capacity (m3/day)
- Technological Maturity
- Advantages and limitations

(ii) Market overview

- Suppliers
- Market analysis
- Investments and operational costs
- Final reuse applications

(iii) Future perspectives

- Needs for further technological development
- Opportunities and challenges

3.3.5 Phase five: Production of draft report and contrast results with main experts

As part of the fifth methodological phase, the consortium processed all information and produced this current strategic report with the following outline:

1. Introduction

2. Methodological research approach to the report - Objective of the study and research phases of the methodology

3. Representative Sample and Status Quo of Current Water Reuse Treatment Technologies in Operation: Final Water Application analysis and operational cost analysis of Technologies

4. Overview of DEMOWARE water reuse technologies: Based on Technology profile, overview and future perspectives

5. Benchmark analysis: based on types of technologies and technology management

6. Highlights and major conclusions

4 Representative Sample and Status Quo of Current Water Reuse Treatment Technologies in Operation

A representative European sample of current water reuse scheme operations was surveyed to gain a baseline understanding of current water reuse technology implementation. A representative analysis of current operations gives us a starting point from where we can gain a greater understanding of the desired technology requirements and how the innovations undertaken in DEMOWARE can potentially attend to these needs.

In reviewing treatment plants that are currently using technologies to treat wastewater for reuse applications, it was important to have an understanding of: which technologies are currently being used; what is the treatment capacity of those technologies; what mechanism drove the selection for choosing the technology; the advantages of the chosen technology; the implementation cost (CAPEX) and on-going operational costs (OPEX) as well as the mechanisms that would drive the treatment scheme operators to implement new technologies. Therefore a survey was designed and sent to treatment operators.

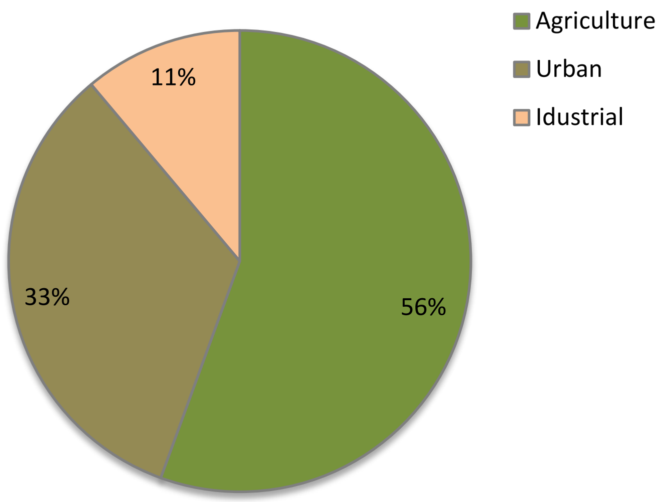

Figure 5 Water Reuse Final Application of the Surveyed Treatment Plants

Of the nine (9) companies surveyed the overwhelming reuse application was for agricultural practices, five (5), with four (4) treatment works applying reuse applications to Urban (park irrigation, salt water intrusion barrier and toilet flushing) and one (1) to Industrial (cooling water make-up) applications. It is interesting to note that the agricultural reuse applications have been in place for many years (from the 1970s), meanwhile reuse applications for urban and industrial applications are far more recent (mid 1990s to the current day). This circumstance dramatically influences the type of treatment technologies that are used in these treatment works, not only for the years that the technology has been in use and the types of technologies that were available at that time, but for the type of water quality required for application (Agricultural application in principle requiring less quality than Urban or Industrial applications).

4.1 Final Water Application analysis

Following, is a brief description of the considerations for each one of the final reuse application uses: agricultural, urban and industrial.

4.1.1 Water Reuse for Agricultural Application

Of the surveyed treatment plants, technologies for agricultural water reuse application go from low technology solutions (SAT) to high technology solutions (UF-RO schemes). Although both of these extremes are for agricultural irrigation, the water production for irrigation differs significantly from 350,000m^3/day to 15m^3/day respectively. Therefore not only the final application needs to be factored in, but aspects such as land footprint, water production and costs all need to be considered when reviewing current water reuse treatment schemes for agricultural irrigation. The reason given for the choice of using the UF – RO scheme for agricultural irrigation was related to the smaller land footprint that this technology allows.

Two (2) of the surveyed treatment plants use sand or UF filtration followed by UV treatment, this is a fairly common treatment method as a number of water reuse treatment plants in Europe (especially in Spain) follow this treatment scheme. The reason for this was stated to be the lower OPEX costs compared to other technological options and that UV does not produce potentially carcinogenic disinfection by-products while achieving the quality aims.

4.1.2 Water reuse for urban applications

The three (3) DEMOWARE plants that have their final applications in the urban sector use tertiary treatment of UV - Hypochlorite, MBR – GAC - Hypochlorite and MBR – UV – Hypochlorite respectively. The reasons given for the why these particular technologies were chosen in each case, was that in addition to the small spatial footprint afforded by the MBRs and Hypochlorite combinations, the combinations provide the water quality requirements and more importantly in one case the company had previously implemented the technology combination at another plant and therefore they stayed with the technology that they knew. The use of conventional treatment methods followed by UV treatment, and in the case of Urban application the addition of hypochlorite, is a fairly common technology chosen in Europe. The reason for the surveyed plants choosing this technology was stated that this technology, as in the agricultural case, offers lower OPEX while achieving the quality aims required for Urban water reuse.

4.1.3 Water reuse for industrial applications

Water reuse for Industrial application in general requires water of higher quality (depending on the exact use of the final application). The surveyed treatment plant uses sand filtration and RO. The reason that this technology was chosen was that it achieves the quality aims required while reducing its OPEX costs. However further optimisation of OPEX savings is currently being considered in the DEMOWARE project through UF-RO or MF-RO treatment schemes.

4.2 Operational cost analysis of technologies

The principle reason that the technologies were chosen was to reduce OPEX costs while still achieving the quality aims for the reuse application. In certain cases reducing land footprint was a deciding factor in the choice of technology. The four main suppliers favoured by these treatment plants were: DOW, General Electric, Kubota and Veolia.

At the moment, no treatment plant benefits financially from the treatment by-products. In the three cases where the by-products (digested sludge) was re-used, the treatment plant either gives it to the farmers for free or they cover the full costs of getting the digested sludge to the farmers. In the industrial case they have not looked into this aspect, but it is something they would like to assess.

4.2.1 Costs Analysis of technologies

The current treatment scheme operators were also surveyed in terms of their capital (CAPEX, see Table 5) costs for implementing the treatment technologies as well as their on-going yearly costs (OPEX - see Table 6). The results of these surveys allow us to gain an understanding of the capacity of the treatment plants and their related costs. As OPEX costs are one of the main issues that current operators would like to reduce, the baseline survey acts as an important benchmark to current technology OPEX costs.

Table 5 CAPEX Cost Range for Water Reuse Technology Implementation

	Low ≤ 5 €/m^3/day	Medium 6 €/m^3/day – 99 €/m^3/day	High ≥ 100 €/m^3/day
Sand Filtration – UV – Hypochlorite (4,500m^3/day)	X		
Conventional with no tertiary treatment (55,000m^3/day)	X		
Sand Filtration and RO (150m^3/day)			X
UF – UV (360 m^3/day)		X	
SAT (350,000 m^3/day)	X		
UF – RO (17,000 m^3/day)	X		
UV – Hypochlorite (500 m^3/day)		X	
MBR – GAC – Hypochlorite (574 m^3/day)		X	
MBR – UV – Hypochlorite (15,000 m^3/day)	X		

Table 6 OPEX Cost Range for Water Reuse Technology Operation

	Low ≤ 0.5 €/m^3	Medium 0.6–2 €/m^3	High ≥ 2.1 €/m^3
Sand Filtration – UV – Hypochlorite (4,500 m3/day) (Agricultural)	X		
Conventional with no tertiary treatment (55,000 m3/day) (Agricultural)		X	
Sand Filtration and RO (150 m3/day) (Industrial)			X
UF – UV (360 m3/day) (Agricultural)			X
SAT (350,000 m3/day) (Agricultural)	X		
UF – RO (17,000 m3/day) (Agricultural)	X		
UV – Hypochlorite (500 m3/day) (Urban)		X	
MBR – GAC – Hypochlorite (574 m3/day) (Urban)			X
MBR – UV – Hypochlorite (15,000 m3/day) (Urban)	X		

4.2.2 Aspects that will Drive Technology Changes in Current Operations

All treatment works were asked if they would change their current technology for technology that was "better" or "cheaper" (see Table 7 Pull factors). Of all treatment works surveyed only one mentioned that they would look to change their technology that they are currently using (SAT) to upgrade to better technology, this was mainly to reduce the land footprint and brine production. As this technology was first implemented in the 1970s, it is logical that an upgrade would be investigated, as improved technologies (AOP-SAT) would achieve their required reduction in the land footprint and brine production.

The treatment plants were also asked the main factors that would force them or allow them to change the current technologies they are using (see Table 8 Push factors). The answers to these questions were divided into Technology pull factors (i.e. factors that the treatment scheme operators require) and Technology Push Factors (i.e. factors that will force the treatment scheme operators to make changes) each factor was ranked in terms of the importance placed on it by the treatment scheme operators.

Table 7 Ranking of the Technology Pull Factors

Rank	Technology Pull Factor
1	Achieving CAPEX and OPEX cost reductions
2	Advancements in Technology
3	The potential for new clients in the future

Table 8 Ranking of the Technology Push Factors

Rank	Technology Push Factor
1	Changes in legislation resulting in treatment works being forced to improve their current treatment schemes
2	Better risk management techniques in reducing risks from non-potable water

As can be seen from the two tables above, the main pull factors to implement new technologies in their treatment plants is to reduce their CAPEX and especially their OPEX expenditures. These factors supersede technology advancements or the potential for new clients in the future.

The main push factors that would influence the treatment plants in changing their current technology would be through the change in water reuse legislation which would essentially force the treatment plants to implement advanced treatment schemes. It was also noted that improved risk management techniques would assist in reducing the risk of non-potable supply and thereby drive lower quality standards and subsequent energy reduction.

Interestingly, potentially important technology pull factors that we tend to assume will change the technology landscape, were not mentioned by the treatment plant companies. Climate change, resulting in dryer periods in areas that are already water scarce, which potentially leads to greater water reuse demand, was not considered a factor for technology pull from the treatment scheme operators. Social acceptance potentially resulting in a pull for water reuse was also not mentioned in terms of being forced to change to "newer" and "better" technologies than they currently use.

5 Overview of DEMOWARE water reuse technologies

This section presents an analysis of the treatment technologies selected by DEMOWARE which has been performed through (i) an extensive review of the main literature on each technology, (ii) the analysis of questionnaires sent to experts and suppliers and (iii) a series of interviews to relevant experts as detailed in section 2.

The chosen technologies are as follows:

1. Membrane schemes combining Microfiltration/Ultrafiltration pretreatment with Reverse Osmosis
2. Anaerobic Membrane Bioreactor Technology
3. Forward Osmosis Membrane Bio Reactors
4. Modular Wastewater Treatment Plants
5. Soil Aquifer Treatment for indirect potable reuse
6. Advanced oxidation for pretreatment in Soil Aquifer Treatment
7. Struvite

Each technology is presented through the same analysis structure which focuses on (i) the technological aspects of the technology and (ii) its main market characteristics before providing (iii) an overview of its main perspectives for further development. For each of these three sections, the following key components have been analysed thoroughly (see Figure 6).

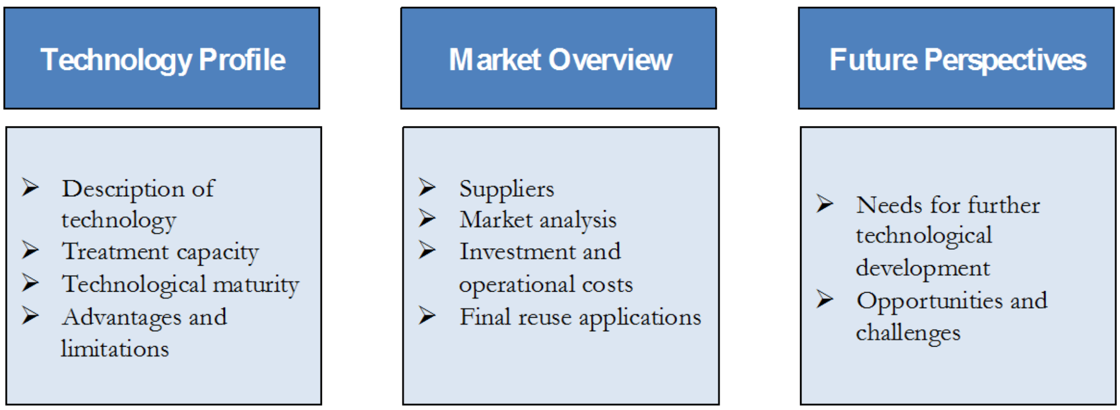

Figure 6 Structural approach of technology analysis

(i) Technology Profile

a) Description of the technology
b) **Treatment capacity (m3/day)** – This parameter indicates the filtration capacity of the selected technology and how many cubic meters of used water it can filter over a 24 hours period. Despite the result depends on the treatment plant size and capacity, it sill gives a good indication of the potential of the technology compared to other ones.
c) **Technological Maturity** – The technological maturity indicates whether the water reuse technology analysed has been validated and can be used widely at industrial, urban or agricultural levels, or, on the contrary, whether it remains at the pilot phase implying further development and pilot testing before being able to be introduced to the market.
d) **Advantages and limitations** - where the specific technological advantages and limitations characterising the water reuse technology are presented

(ii) Market overview

a) **Suppliers** – This section presents the main suppliers that manufacture and offer the technology to the market and their geographical origin.
b) **Market analysis -** Overview of the water reuse market for the given technology in terms of demand for industrial, urban or agricultural applications and perspectives of the technology at a market level in Europe and globally.
c) Investments and operational costs

- **CAPEX** – A key factor for deciding which technology to use is the initial investment and capital expenditures (CAPEX) it requires. Important variations can be observed at this level regarding the level of technology it implies, the infrastructures needed, etc. A segmentation has been applied between the technologies that need high (superior to 100M€), medium (from 10M€ to 99M€) or low investments (inferior to 9 M€).
- **OPEX**: Similarly, the operational costs (OPEX) are key for taking a technological decision as they vary dramatically among different technologies and can balance the initial investment. While some technologies might be relatively inexpensive in terms of investment, they might imply high operational costs. Major operational costs in the water reuse sector are linked to energy consumption, maintenance (use of chemicals for cleaning the processes) and replacement needs (directly linked to the lifespan of the technology). Operational costs have been classified for the purpose of the study between "high" (superior to 2.1 € per cubic meter treated), "medium" (from 0.6€ to 2 € per cubic meter treated), and "low" (inferior to 0.5 € per cubic meter treated).

d) **Final reuse applications** – Water reuse technologies, especially in their probing phase or early years, are usually used for specific applications, either agricultural, urban or industrial that often can be extended to other applications when they are more technolgically mature.

(iii) Future perspectives

a) **Needs for further technological development**- this section presents an overview of the principal areas for technological improvement in the coming years.
b) **Opportunities and challenges**: summarizing the market perspectives for the technology.

5.1 UF/MF - RO membrane treatment schemes

5.1.1 Technology Profile

The combination of Reverse Osmosis (RO) and Membrane filtration technology, whether Microfiltration (MF) or Ultrafiltration (UF), are very suitable technical solutions for wastewater treatment and potable water production. RO technology has already been successfully applied for water treatment (municipal and industrial) for many decades, treating a wide range of water sources such as tap water, groundwater, surface water, or waste water or the treatment of the domestic industrial effluents for internal reuse or for compliance with the existing discharge regulations. However, an appropriate pre-treatment is the most critical factor to warrant the successful performance of these RO systems.

5.1.1.1 Description of the technology

Reverse Osmosis: RO employs a hydrostatic pressure greater than the osmotic pressure to reverse the direction of osmosis flow so that the water moves from a higher to lower solute concentrate. It is possible to use RO to remove dissolved and colloidal materials (particles smaller than 0.1 µm) which include aqueous salts, organic matter, pesticides and herbicides. RO removes 98%+ of monovalent ions. RO filters use membrane technology, and more specifically cross-flow membrane separation process that provides a level of filtration down to ionic levels allowing filtering impurities (minerals, calcium, chloride, sodium, chlorine, etc) from the water down to ionic levels. Permeate is produced from the membrane with the majority of the dissolved content of the feed transferred to the waste concentrate stream. Main operating cost of an RO system are related to fouling and include power requirement, power cost, membrane life and replacement cost, membrane cleaning costs and scale inhibition costs.

Membrane filtration technology: As far as pretreatment for RO is concerned, there are two main types of membrane filtration technology for water and wastewater treatment, namely ultrafiltration (UF) and microfiltration (MF).

Microfiltration (MF) - MF for water treatment usually uses pores between 0.04 µm and 0.10 µm although coarser MF pore sizes of 0.2 and 0.4 µm can be used. Microfiltration can be implemented in many different water treatment processes when particles with a diameter greater than 0.1 mm need to be removed from a liquid. Usual applications include separation of bacteria from water (biological wastewater treatment), effluent treatment, separation of oil/ water emulsions or pre-treatment of water for nano filtration or Reverse Osmosis.

Ultrafiltration - In recent years, hollow fibre Ultrafiltration (UF) technology has gained acceptance in the treatment of waters with high contamination levels, among other benefits, due to its higher efficiency– compared to other conventional filtration technologies– in the removal of suspended solids, microorganisms, and colloidal and organic matter. Ultrafiltration is a pressure-driven purification process in which water and low molecular weight substances permeate a membrane, while particles, colloids, and macromolecules are rejected. Flow through the semi-permeable membrane is achieved by applying a pressure gradient between the inner and outer walls of the membrane structure. UF membranes typically have pore sizes in the range of 0.01 – 0.05 µm and have a high removal capability for bacteria, most viruses, colloids and silt, thereby effectively achieving separation and purification. UF applications include potable water, reverse osmosis (RO) pretreatment for seawater desalination applications and wastewater reclamation.

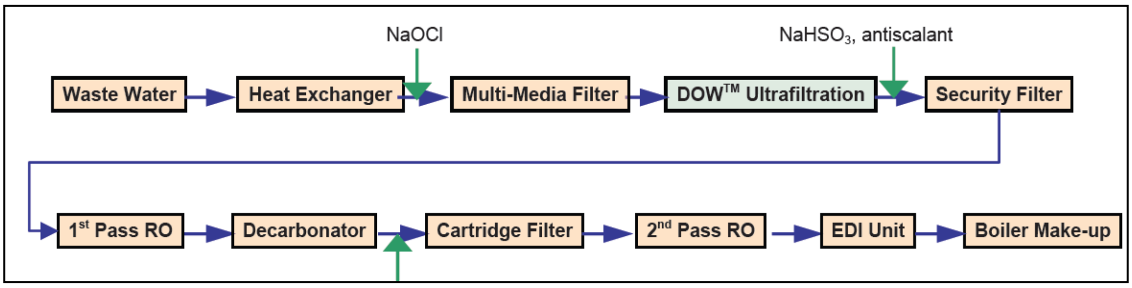

Figure 7 Example of UF-RO Scheme. Source: Dow Chemical

5.1.1.2 Treatment capacity

The treatment capacities are estimated to go up to 55,000 m3/day worldwide and 24,000 m3/day in Europe.

5.1.1.3 Technological Maturity

The technology is mature although the potential for improvement in the field of membranes is very promising. RO has been used for a long time in desalination of seawater (the use of desalination technologies for municipal water supplies is a commonplace since the 1990's, predominantly with RO technology*)*, however it is fairly new in Wastewater treatment for water reuse applications. In the past decades, ultrafiltration (UF) has become more popular for RO pretreatment in the municipal and lately in the industrial sector too.

5.1.1.4 Advantages and limitations of UF/MF – RO schemes

The RO process is characterized by two main limitations:

- Fouling - High fouling on RO membranes implies frequent downtime for cleaning and maintenance leading to significant operational costs and shorter membrane life time.
- Energy cost - A major drawback of RO membranes is the relatively high energy cost as a certain pressure has to be achieved in order to reverse the osmotic potential.

In this context, applying a pretreatment through MF or UF allows reducing significantly the chemical cleaning requirement of RO membranes. Reduction in cleaning frequency has a number of benefits including reduced chemical costs and extended membrane life, as each time a RO membrane is cleaned, membrane integrity is slightly reduced. Other advantages of UF/MF include increasing the permeate production per unit membrane area. The result is a requirement for less membrane area, which means potentially lower RO capital costs. Less membrane area in RO systems also means less chemical is required to clean the membranes, also reducing costs.

The main specific benefits of microfiltration are as follows:

- Compared to UF, MF offers higher permeability with relatively clean water quality, due to their bigger pore size
- Some micro filters are capable of effectively removing 98% of suspended solids above 3µm, making them very suitable for RO membrane pre-filtration applications.

As regards to ultrafiltration, specific benefits include:

- Ultrafiltrate water is virtually free of particles, colloids, and suspended solids. Therefore, plugging of RO feed channels is minimized and the RO cleaning frequency can be noticeably reduced.

- In comparison with conventional filtration (e.g. sand filtration), UF requires significantly lower footprint, produces a higher and more consistent water quality regardless of variations in the feed quality, and usually needs less power and chemicals.
- Compared to MF systems, UF tend to foul slower than UF and therefore need slower chemical consumption for cleaning.

Main advantages and limitations of UF/MF RO schemes can be summarised as follows:

Advantages	Limitations
• MF/UF pretreatment for RO allows reducing significantly the chemical cleaning requirement of RO membranes which implies reduced chemical costs and extended membrane life. • It increases the permeate production per unit membrane area allowing for less membrane area, which means potentially lower RO capital costs. • In comparison with conventional filtration, UF requires significantly lower footprint, produces a higher and more consistent water quality regardless of variations in the feed quality, and usually needs less power and chemicals. • Ultrafiltrate water is virtually free of particles, colloids, and suspended solids. Therefore, plugging of RO feed channels is minimized and the RO cleaning frequency can be noticeably reduced.	• Compared to UF systems, MF tend to foul faster and therefore need higher chemical consumption for cleaning.

5.1.2 Market overview

5.1.2.1 Suppliers

Dow accounts for the largest RO supplier with an estimated 35% market share, followed by Toray, Hydranautics and Nitto Denko. The top three producers account for 85% of the market approximately.

For UF, there are different technologies and not all products are completely interchangeable. Pentair is the market leader followed by other players such as Inge, Pall, Siemens, GE and Dow. Dow is a new entrant in UF since it only started in 2006 with the acquisition of Omex (Chinese).

As regards to microfiltration (MF), similarly there are a number of different technologies adapted to different applications and schemes. Main suppliers include Toray, Koch, General Electric, Hydranautics (Nitto Denko), Siemens-Memcor, Amiad and AMI.

5.1.2.2 Market analysis

UF/MF and RO technologies have been in Market for more than 20 years. The estimation of the actual market for Europe is 20-25 million €, including municipal and industrial waste water treatment[1]and is expected to grow by 5 to 10% in the next few years[2].

[1] Estimation provided by DOW Chemicals

[2] Estimation by CAGR

This technology is widely spread in advanced countries where wastewater treatment and wastewater reuse is a priority. Some countries, like in central Europe, where water scarcity might not be a big issue, are still heavily promoting water reuse in order to increase the respect for the environment. In other countries, like in the Mediterranean region, Israel, Cyprus, Greece or even in Middle East, Water Reuse is becoming more and more popular given the limited availability of fresh water.

Historically, the technology has been widely used to tackle water shortages issues in draught areas. Thus, largest desalination plants have been built in countries like Spain, Israel, Australia and Middle East, being KSA the largest desalination market in the world, to provide citizens with drinkable water. Nonetheless, it has been implemented all across the globe for industrial applications, but usually at much smaller scales.

The most promising markets today appear to be the Asia Pacific region, the Middle East and South Africa.

Compared to MF, UF is the preference for most of the suppliers, and it is becoming the dominant technology. Improving the quality of drinking water and the water that is critical to essential industrial processes like chemical processing, power generation and the manufacturing of food and pharmaceuticals will be increasingly important. The technology will also be vital to desalination and water reclamation efforts in communities with severe water shortages.

5.1.2.3 Investments and operational costs

CAPEX -The investments needed for UF– RO and MF-RO schemes are similar and vary in a scale ranging from 10M€ to 99M€ depending on the size of the treatment plant and the choices made in terms of technical configurations. Submerged systems require more complicated and expensive civil works and higher membrane area. There are also differences in equipment needs depending on factors such as hollow fibre membrane flow pattern (i.e. Out/In vs In/Out) rather than pore size. E.g. In/Out membranes require bigger backwash pumps while Out/In typically require a blower for air scour.

OPEX – Operating costs are relatively low with an estimated cost inferior to 0.5€ per cubic meter treated but can vary significantly depending on the system design and operation regime. Main costs are linked to energy consumption and cleaning processes. MF tend to have higher operating cost due to differences in membrane morphology and fouling mechanism (i.e. pore blocking prevails in MF versus surface deposition in UF). MF systems tend to foul quicker than UF and therefore need higher chemical consumption for cleaning. On the other hand there are other process-related factors that have a higher impact on OPEX rather than pore size, e.g. whether the system needs coagulation in line.

5.1.2.4 Final reuse applications

In the past decade, Ultrafiltration (UF) has become more popular for RO pretreatment in the municipal and lately in the industrial sector. The share between UF-RO onsite industrial treatments versus UF-RO treatment at centralised WWTP, either for urban or agricultural purpose, is 35% versus 65%.

So far it is used for treating sea and brackish water, waste water that will be used for indirect potable use (such as groundwater recharge), surface water augmentation, cooling towers or high-pressure boilers in industrial water reuse applications.

5.1.3 Future perspectives

5.1.3.1 Future Needs

Water consumption is linked to agriculture, population growth, energy and other aspects such as climate change that will continue demanding additional water resources, either by desalinating brackish or seawater or recycling and reusing water. UF/ MF - RO membranes systems are a proven technology to all these challenges and will be used for new plants but there will also be a significant demand required for replacement of existing installations due to their nature as consumables.

Continuous development for this membrane based systems are making the technology even more attractive, driven by innovations to reduce energy consumption, extend lifetime and enhance pollutants rejections. There is still a large field for development. Potential developments include large UF modules (compact footprint); low fouling membranes (UF and RO), high permeability UF membranes, high pressure and temperature resistance, the use of non-oxidizing chemicals for fouling control in integrated UF-RO systems, cleaning processes optimization or ceramic UF membranes. There is no reason to consider that this technology can be likely displaced by any other new one able to cost-efficiently deliver equal or better performances: the development perspectives appear very promising.

5.1.3.2 Opportunities and challenges

The main opportunities and challenges for the future development of the technology can be summarized as follows:

Opportunities	Challenges
• UF/MF pre-treatment is essential to reduce the operating cost of the RO and have lower energy costs than MBR RO. • UF/MF is a suitable treatment technology for various water types from surface waters to wastewater, and the more fluctuating or challenging the feed water source is, the better the benefits of UF are seen compared to conventional pretreatments. • UF/MF-RO schemes are increasingly popular for water treatment uses • There is still a large field for development both for RO and UF/MF membranes	• Lack of standardization among the different suppliers. • Legislation and public acceptance of re-used water. • Commoditization would certainly lead to a significant reduction on R&D expense due to lack of attractiveness for continuous innovation.

5.2 Anaerobic Membrane Bioreactor Technology

5.2.1 Technology Profile

5.2.1.1 Description of the technology

The Anaerobic Membrane Bioreactor Technology (AnMBR) is an integrated system combining anaerobic bioreactor with low pressure membrane ultrafiltration or microfiltration. Since MF/UF membranes can physically retain suspended solids, including suspended biomass and inert solids, the AnMBR can achieve complete separation of the solid retention from the hydraulic retention, independently from the characteristics of the wastewater, biological process conditions, and sludge properties. The membrane filtration can be integrated with anaerobic bioreactors in three different forms: internal submerged membrane filtration, external submerged membrane filtration, and external cross flow membrane filtration.

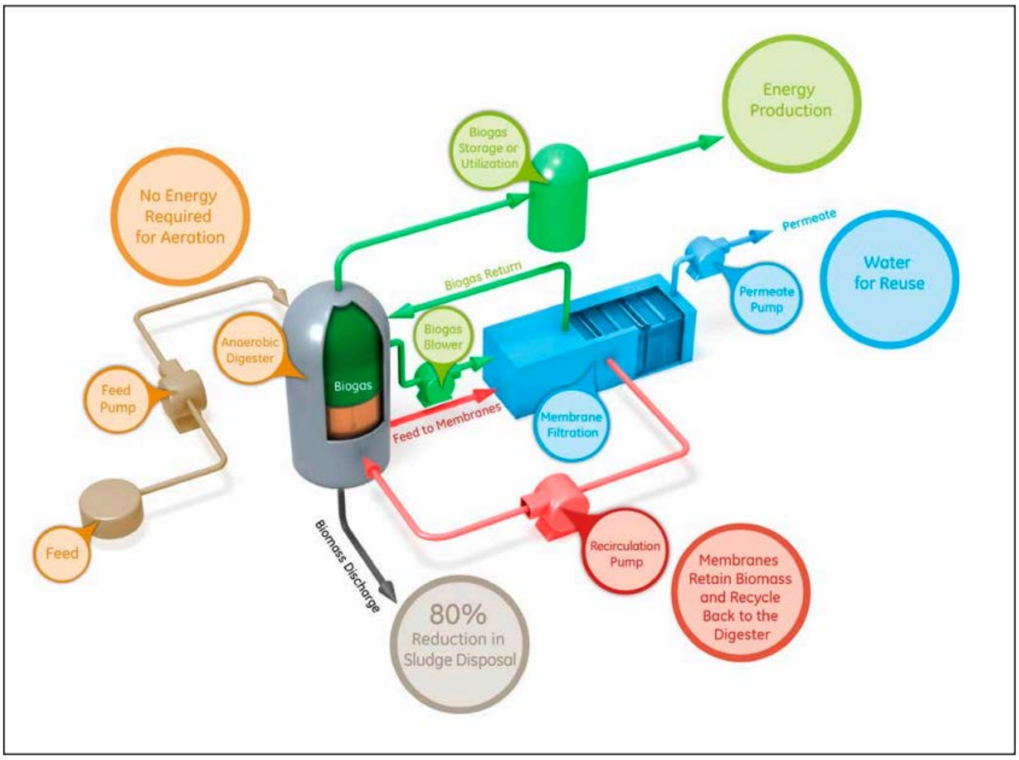

Figure 8 Example of AnMBR process Source: General Electric

5.2.1.2 Treatment capacity

The treatment capacities of AnMBR are estimated to go from 100 m3 up to 2.000 m3 per day.

5.2.1.3 Technological Maturity

Although the concept of AnMBR was developed in 1980s, large scale applications of the anaerobic membrane technology have been limited due to membrane fouling in the anaerobic environment, energy consumption of the membrane processes, and the technological limitations of large-scale wastewater treatment membrane filtration. However, large-scale membrane filtration systems have improved significantly in the recent years. These progresses, combined with the potential of energy recovery from the AnMBR and the capacity to handle wastes with very high concentrations of chemical oxygen demand

(COD) have contributed to the emergence of AnMBR as a potential technology for high-rate anaerobic treatment. However, the maturity of the technology is still limited and it is considered that at least ten years will be necessary before operating large-scale centralized AnMBR. As of today 100% of the use is industrial.

5.2.1.4 Advantages and limitations

The main technological benefits and limitations of AnMBR can be summarized as follows:

Advantages	Limitations
• Nearly absolute biomass retention with the potential to generate a high quality effluent • Low nutritional requirements • Allows for operation at high sludge retention time (SRTs) • Low energy requirements as no aeration energy is required for mineralizing the organics • Ability of producing biogas • Produces mineralized nutrients in the form of ammonia and orthophosphate enabling direct agricultural use of the effluent for ferti-irrigation	• Needs further research efforts on membrane technology at higher scales to be scaled up from laboratory to real plant. • Membrane fouling seems much more severe under anaerobic conditions than aerobic ones. Cake formation on the membrane surfaces is a key parameter that governs the applicable membrane fluxes. • WWT by AnMBR systems in more temperate climates is still considered a challenge. Under low temperature (<20 C) conditions, hydrolysis of particulate matter into dissolved molecules becomes the rate-limiting step, which results in the accumulation of suspended solids (SS) in the reactor and a decrease in organic matter conversion efficiency together with a decrease in methanogenic activity • After treatment by MBR systems, substantial amounts of oestrogens and their conjugates still pass through treatment systems and enter the aquatic environment

5.2.2 Market overview

5.2.2.1 Suppliers

Main suppliers include GE Water Technologies, Kubota (Japan), Wehrle AG (Germany) or Beijing Origin Water (China), Veolia and ADI systems Inc. being the main technology integrators in Europe.

5.2.2.2 Market analysis

While the size of the MBR market has been assessed extensively, there is still no proper information giving a full picture of the AnMBR market and whether the market has taken off. It is estimated that less than ten side stream sites and six immersed sites are operating globally and they are all industrial.

There is no clear tendency for the AnMBR Market as the technology still cannot be applied for large scale plants. An important question is to know whether the MBR market will move towards AnMBR with the same tendencies (highly concentrated and dominated by suppliers from Japan, USA, Germany and Singapore) as it is now for MBRs? Similarly, will the lead suppliers be vertically integrated, producing membranes and membrane filtration modules and providing customers with complete AnMBR treatment plants in the form of Build-Operate-Transfer (BOT) projects?

5.2.2.3 Investments and costs

AnMBRs imply medium initial capital investment (considered between 10 and 99 million euros depending on the dimension of the application) but low operating costs (less that 10 million euros operational cost) as the energy requirements are very low (no aeration) and as it has the ability of producing net energy within the MBR (biogas). This information however, has to be validated by Veolia but they did not respond to the information requirements.

5.2.2.4 Final reuse applications

AnMBR has only been used for industrial applications and it is estimated that a minimum of ten years will be necessary before operating centralized large-scale AnMBR. AnMBR is especially suitable for warm climates. It is particularly indicated for strong, concentrated wastes, solid and semi-solid wastes and slurries, and wastewaters with poor settling characteristics, including chemical production, distillery, food and organic waste residuals, etc. AnMBR technology is expected to be used in the future in the peri-urban to rural context to recover water, nutrient and biogas for combined heat and power generation.

5.2.3 Future perspectives

5.2.3.1 Future needs

There is a growing need in the rural and peri-urban zones for water and nutrient recovery as well as for the production of biogas for combined heat and power generation. In this context, AnMBR technology appears as a very attractive technology as it provides a solution for integral municipal waste water treatment with pathogen free but nutrient rich effluent for re-use in irrigation while enabling energy recovery with the production of biogas. This represents an important opportunity especially in the regions suffering from water shortage.

However, the adoption and commercialisation of this technology at industrial scale is still pending due to a number of reasons. As of today, the state-of-the-art in AnMBRs is not appropriate for municipal wastewater treatment to reach reuse quality due to too high costs and high shear stress in the biology. Solutions should also be found for slowing down cake formation and treating waste water at low temperatures (<15ºC).

5.2.3.2 Opportunities and challenges

The main opportunities and challenges for the future development of the technology can be summarized as follows:

Opportunities	Challenges
• Use in the peri-urban to rural context to recover water, nutrient and biogas for combined heat and power generation. • Suitable for high loads (ability to treat water of poorer quality) • Provides a possibility for the agricultural use of the treated effluent for non-potable purposes in many regions suffering from water shortage . • Integral municipal waste water treatment with pathogen free but nutrient rich effluent for re-use in irrigation and enable energy recovery	• Cake formation - AnMBR technology will not develop significantly until cake formation is solved • High cost of membranes: membrane costs appear to be up to 10 times higher than the energy consumption costs per m3 of treated water. • Treatment of domestic waste water at low temperatures (<15ºC) • High shear stress in the biology •

5.3 Forward Osmosis MBRs

5.3.1 Technology Profile

5.3.1.1 Description of the technology

The Membrane Bio-reactors (MBR) is a biological treatment process that integrates membrane systems to separate the treated effluent from the biomass in the reactor. Although usually based on microfiltration (MF) or ultrafiltration (UF), novel MBR system utilizing submerged forward osmosis membrane (OMBR) are becoming a new alternative.

Forward Osmosis - FO for water application capitalises on the natural phenomenon of osmosis by exploiting an osmotic-pressure gradient generated by a concentrated solution (known as “draw” solution) to allow water to diffuse through a semi-permeable membrane from saline feed water with lower concentration. Consequently, it produces a less concentrated draw solution, which may be further treated to extract freshwater. FO is comparable to RO; in both processes water moves through a semi-permeable membrane while the membrane retains salts. However, the concentration differences between the feed and the draw solutions across the membrane, in contrast to the high pressure applied in the RO process naturally creates the driving force in the FO process. Thus, FO requires less energy.

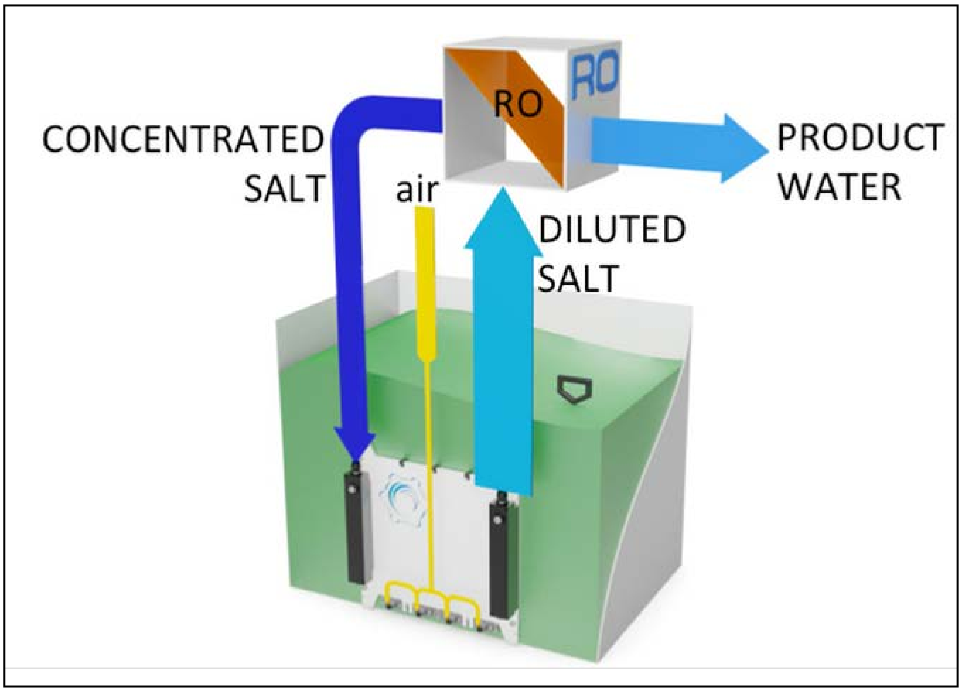

Figure 9 Example of Forward Osmosis MBR process Source: Porifera

5.3.1.2 Treatment capacity

The treatment capacities of the OMBRs are estimated at 200 cubic meters per day.

5.3.1.3 Technological maturity

The Forward Osmosis Membrane Bioreactor technology (OMBR) cannot be considered as a mature technology as it is only tested on laboratory and remains at pilot scale. According to experts interviewed for the purpose of this study, OMBRs have not risen above academic interest.

5.3.1.4 Advantages and limitations

Compared to the MF or UF process in a conventional MBR, the FO process in the MBR offers the advantages of much higher rejection (semi-permeable membrane versus micro porous membrane) at a lower hydraulic pressure. FO processes are also likely to have lower fouling propensity than pressure-driven systems, and therefore, require less frequent backwashing. However, there are still a number of limitations to the technique that need to be addressed before full technological implementation. Main limitations include low water flux resulting in large FO membrane areas and cost; high salt leakage resulting in a salinization of bioreactor; large sludge bleed which contains salts or the high energy demand linked to the need for re-concentration.

5.3.2 Market overview

5.3.2.1 Suppliers

Despite several companies such a HTI, Oasys, Modern Water, Porifera, Aquaporin, offer FO membranes, there is today no supplier of FO MBR systems.

5.3.2.2 Market analysis

Similarly there is still no market for OMBR as the scheme remains more expensive than common schemes, such as MBR followed by RO. Yet, the potential market remains important as all countries and regions where re-use of wastewater is needed will be potential markets.

5.3.2.3 Investments and operational costs

Initial investments for OMBR are expected to be higher compared to state of the art MBR-RO processes, prominently caused by the FO process. The CAPEX for OMBR is expected to be superior to 100M€. As regards to operating costs (OPEX), the energy requirements of the FO part in the process is low, but the re-concentration part (e.g. reverse osmosis) to re-concentrate the diluted draw solution is (very) high. Alternative re-concentration systems all share a high energy demand and therefore the OPEX remains at Medium levels with an estimated cost establishing between 0.6€ and 2€ per cubic meter treated.

5.3.2.4 Final reuse applications

If OMBR becomes cost effective and competitive compared with MBR-RO schemes, it is expected that on-site industrial FO MBR treatment schemes will dominate over centralised wastewater treatment plants for urban uses.

Recent research conducted focuses on the combination of MBR and OMBR systems. In this way accumulation of salts into the bioreactor can be controlled and two water qualities can be produced from this system.

5.3.3 Future perspectives

5.3.3.1 Future needs

There is a need for higher rejection (semi-permeable membrane versus microporous membrane) at a lower hydraulic pressure (compared to the MF or UF processes in a conventional MBR). Conventional MBRs are prone to higher fouling propensity, which needs to be lowered. FO processes can provide these needs, in addition, when comparing an OMBR system (OMBR followed by RO) with a conventional

MBR followed by RO, the high rejection of the FO membrane will result in an RO influent with lower fouling propensity.

Although it combines a number of significant advantages such as a higher rejection rate or lower fouling propensity, forward osmosis membrane bioreactor is not a mature technology and needs further research efforts. It is only tested so far on laboratory and pilot scale and the industrialization of the process still appears remote. More worryingly, it seems that this technique has not risen above academic interest which represents a serious challenge for its development. Therefore, further research should be promoted to identify or demonstrate the unique advantages of the process before considering industrial development.

5.3.3.2 Opportunities and challenges

The main opportunities and challenges for the future development of the technology can be summarized as follows:

Opportunities	Challenges
• Compact wastewater treatment concept • Effective in treating difficult wastewaters • Produces high quality effluents which can be re-used directly • Higher rejection rate or lower fouling propensity	• More expensive than MBR-RO schemes • High energy requirements of the re concentration • Limited performance of the FO membrane. • Lack of academic interest

5.4 Modular Wastewater Treatment Plants

5.4.1 Technology profile

5.4.1.1 Description of technology

By definition, a packaged wastewater treatment plant is a sewage treatment module or series of linked modules that are constructed in a factory and subsequently transported to site for connection and installation. In terms of the size of the plants that are available as packaged plants, they typically range from a four-person population equivalent to larger than a 9,000 population equivalent, although the size can vary according to geographic conditions and customer requirements and the nature of the effluent required to be treated. The technologies that are most often used in packaged plants are biological wastewater treatment methods, which are ideally suitable for small-scale operations. Solutions range from Moving Bed Biological Reactors (an expensive option), activated sludge, Rotating Biological Contractors, the SAF treatment process, sequencing batch reactors and Membrane bioreactors that are becoming increasingly popular.

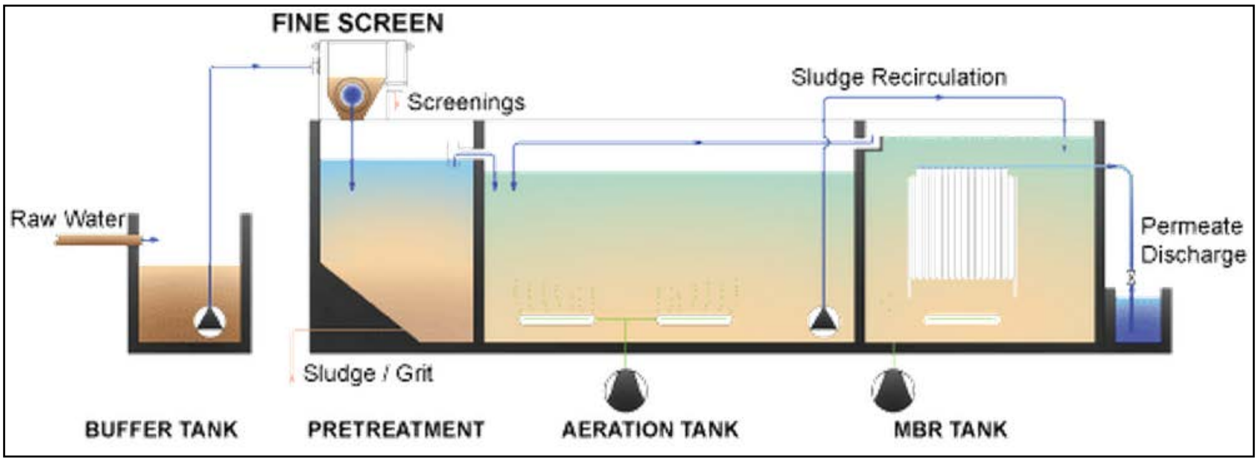

Figure 10 Example of modular wastewater treatment plant Source: DMB Mena Water

5.4.1.2 Treatment capacity

The treatment capacities of the Modular Wastewater Treatment Plants vary significantly depending on the size of the WWT plant. They can go up to 4.500 m3 treated per day.

5.4.1.3 Technological Maturity

MBBR has been used for approximately 15-20 years and MBRs of external tubular Airlift type approximately 10 years. Cross flow type MBR's have been used for more than 30 years for industrial wastewater treatment.

5.4.1.4 Advantages and limitations

Modular Wastewater treatment plants combine a series of benefits:

- They are portable and easy to install,
- Designed for use in projects with time, space, and budget constraints.
- Their units can be placed strategically to generate reclaimed water at the point of reuse, minimizing distribution networks, and can be installed incrementally to meet growing wastewater demands.

- They better handle the availability of municipal/industrial effluent and the re-use of this effluent

However, this technology also implies a series of limitations:

- Typically, they have higher OPEX than conventional technologies (see below) due to the higher effluent quality required for reuse, the high maintenance and energy costs
- Getting rid of the sludge can be a challenge in some cases
- They require a high operator knowledge

5.4.2 Markets overview

5.4.2.1 Suppliers

The European market is very competitive, and is currently dominated by numerous small local manufacturers. Some of the key players include Kruger, Veolia, GE Zenon, A3, Alfa Laval, Aqua Aerobics, Huber, Koch, Kubota, Ovivo, Siemens, Smith & Loveless or Bioprocess H20 etc. Larger companies have moved out of this market because they found it increasingly difficult to compete in such a niche market where local competitors are able to be more effective in terms of lower prices and cheaper solutions.

5.4.2.2 Market analysis

Modular Wastewater Treatment plants have been in the market for more than ten years and there is today a clear and growing market for packaged plants. The European market has important opportunities for packaged wastewater treatment plants linked to the local-specific conditions. Packaged plants have gained popularity in countries such as Germany where the industrial end-user in particular has responded favourably to this technology. The most widespread version of the packaged plant however has been in segments where rapidly expanding installations base has prompted the entry of a large number of small local companies.

One of the growing trends within the market is the development of Membrane Bioreactor Systems. Key companies offering this type of packaged solution include Enviroquip, Zenon and US Filter. For example US Filter offers its MemJet MBR system as a complete, pre-engineered, membrane bioreactor system in a compact skid-mounted design.

5.4.2.3 Investments and operational costs

Modular WWT investments vary significantly regarding the size of the installation. They generally establish at a medium level with CAPEX ranging from 10M€ to 99M€. Similarly, the OPEX establish at medium level between 0.6€ and 2 € per cubic meter treated mainly due to the high effluent quality required for reuse and high maintenance and energy costs.

5.4.2.4 Final reuse application

Applications for packaged plants can be classified into four main categories: municipal, industrial, commercial and residential. The packaged plants are typically used for treatment of domestic effluents. However, they can also be used for treatment of industrial wastewater in which biodegradable constituents are encountered. In either case, the effluent of this treatment can be safely discharged or further treated in a polishing loop and then recycled or reused in the plant operation. Users may dispose of treated effluent using either subsurface or above-ground discharge depending on the local legislation.

5.4.3 Future perspectives

5.4.3.1 Future needs

Many wastewater treatment works in Europe are old and require upgrades, especially if they want to move to treating water for reuse, which can be quite expensive. Industrial water reuse is also a growing area due to the need for industries to reduce their water related costs. In this context, modular WWT plants can provide relevant technological solutions at a competitive price.

The packaged plant market is proving interesting, with new applications and technologies becoming increasingly popular, such as modular MBRs. Package plants are also attractive for emergency water and wastewater treatment. They allow companies to provide expanded services for municipal and industrial customers who need immediate assistance in treating their wastewater supply. These pre-engineered, packaged systems provide the end-user willing to treat their waste water with an economical approach to treatment of wastewater, and the modular approach provides customers with an efficient, compact, easy to operate, and cost effective method of wastewater treatment.

5.4.3.2 Opportunities and challenges

The main opportunities and challenges for the future development of the technology can be summarized as follows:

Opportunities	Challenges
• Change in legislation (i.e. polluter pays principle, hydraulic footprint etc.) might force a lot more industries to install modular wastewater treatment plants to treat effectively their wastewater and reuse the treated water. • Growing trend in compound recovery, where compounds of economic value can be recovered from certain industries from treating their wastewater. • Wide range of applications ranging from emergency wastewater treatment and off grid applications.	• Larger international corporations (Chinese, Korean, US) might encroach on the European Market outcompeting European SMEs .

5.5 Soil Aquifer Treatment (SAT) for indirect potable reuse

5.5.1 Technology Profile

5.5.1.1 Description of the technology

Managed Aquifer Recharge (MAR) refers to different recharge techniques that release the reclaimed water from above the ground, percolating through unsaturated soil, or from below the ground, by injection or recharge wells. **Soil Aquifer Treatment (SAT)** is one of many MAR methods, which is receiving growing attention because it features advantages such as inherent natural treatment, inbuilt storage capacity to buffer seasonal variations of supply and demand as well as mixing with natural water bodies, which promotes the acceptance of further uses, particularly indirect potable use.

Soil Aquifer Treatment (SAT) is an artificial groundwater aquifer recharge option. Water is introduced into the groundwater through soil percolation under controlled conditions. SAT is either used to artificially increase the groundwater in order to withdraw freshwater again at a later stage or as a barrier to prevent saltwater or contaminants from entering the aquifer. During percolation, natural soil filtration occurs and the water enters the aquifer where mixing and possibly some other physical and chemical reactions may occur. This method can be used with reclaimed water (treated blackwater) or relatively little polluted water (e.g. pre-treated greywater or stormwater) which is typically entered through a recharge basin or an injection well. Effluent is intermittently infiltrated through infiltration ponds to facilitate nutrient and pathogen removal in passage through the unsaturated zone for recovery by wells after residence in the unconfined aquifer.

Depending on the wastewater quality, land availability and intended water supply usage, SAT can be complemented by various pre-treatment technologies such as horizontal, vertical and free-surface constructed wetlands, waste stabilisation ponds, Upflow Anaerobic Sludge Blanket (UASB) reactor or advanced treatments such as activated sludge, membrane filtration, or advanced oxidation process (see section 4.6 below).

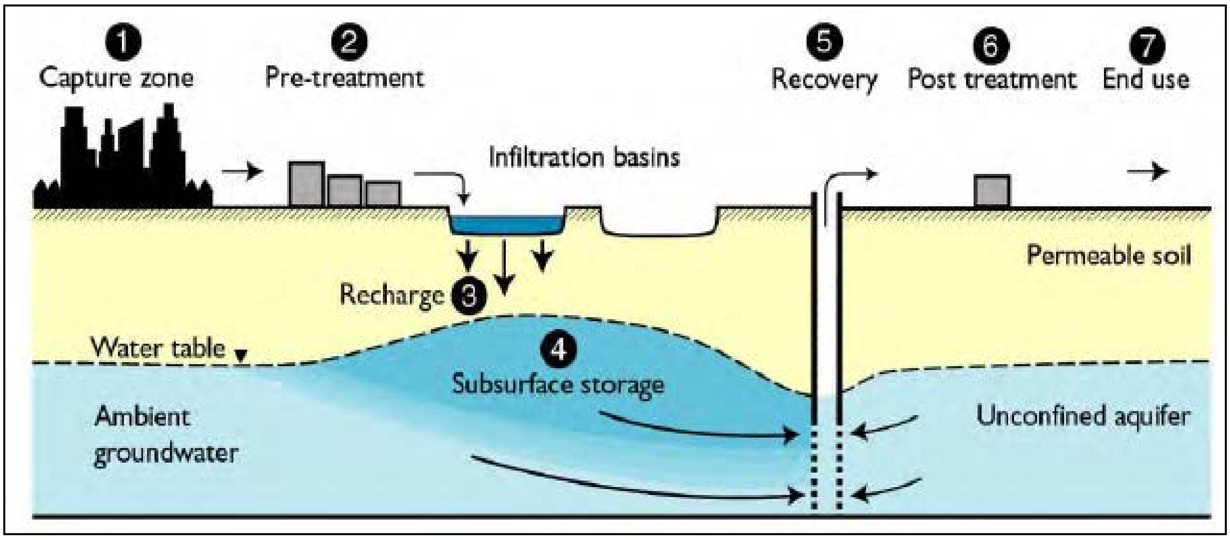

Figure 11 Example of SAT system for pre-treated wastewater Source: Miotlinski et al. (2010)

5.5.1.2 Treatment Capacity

Although it depends largely on the characteristics of the site, SAT has a very important treatment capacity going up to 350.000 cubic meters of treated water per day.

5.5.1.3 Technological Maturity

SAT is a mature technology that has been used for many years at global level.

5.5.1.4 Advantages and limitations

While the process is considered as mature, more research is needed to demonstrate the multiple advantages of SAT. Among other benefits already recognized, SAT is a natural pretreatment system that allows securing and enhancing water supplies while mitigating floods and flood damage. It is a low cost and a fitting option for wastewater reclamation. SAT can contribute to improve the aquifer water while preserving water levels in wetlands, mitigating contaminant intrusion and freshening saline aquifers or preventing aquifer salinization creating a buffer against salt water intrusion. Other benefits include enhancing environmental flows in water supply catchments and augmenting water supplies and improving coastal water quality by reducing urban discharges.

However, although the soil can act as a filter for a variety of contaminants, groundwater recharge should not be viewed as a treatment method. Introducing pollutants into groundwater aquifers may have long-term negative impacts and SAT could change the soil and groundwater hydrological properties. Surface soil aquifer treatment requires a big area for the infiltration basin which adds to the cost of the project and may increase the risk of flooding in areas where groundwater levels are already high.

5.5.2 Market overview

5.5.2.1 Suppliers

There is no supplier of SAT as such as it represents a technique rather than a technology.

5.5.2.2 Market analysis

Main sites using SAT today include the Tula valley (Mexico), Phoenix (USA), Adelaide (Australia), Windhoek (Namibia), Atlantis (South Africa), Porquerolles island (France) and Shafdan (Israel) amongst others. The market for SAT has not been estimated so far and depends largely on the characteristics of the site.

At European level, due to the economic crisis, several of the existing schemes have been closed. South of Europe, especially Mediterranean Islands and Mediterranean coastline of Spain are the most promising markets. In other regions of the world, South Africa (and surrounding countries), Australia, Singapore and China seem to have the strongest potential for development.

The best water reuse projects in terms of economic viability and public acceptance are those that substitute potable water with reclaimed water for use in irrigation, environmental restoration, cleaning, sanitation and industrial uses. SAT adds to the Ecosystem Services through augmenting the water supply of a catchment, this in turn has an indirect economic gain to all operators in the catchment.

5.5.2.3 Investments and operational costs

In terms of investments and costs, SAT is a very low budget technique and it is worth mentioning that several SAT are implemented without investments. On the other hand, other sites imply important investments including advanced treatments technologies and costs related to social aspects, technical counsels, analytical facilities, research, land for recharge, distribution systems, recovery systems, etc.

5.5.2.4 Final reuse application

In Europe, much of the municipal wastewater reuse has only occurred in the coastline and islands of the semi-arid southern regions so far, and in the highly urbanised areas of the wetter northern parts. In southern Europe reclaimed wastewater is predominantly used for agricultural irrigation, whereas in northern Europe it is mainly used for urban application.

SAT can be applied when facing issues with the quantity and the quality of groundwater aquifers. It can be an option where groundwater levels are declining due to overexploitation, where a substantial part of the aquifer has already been desaturated (e.g. when regeneration of water in wells is slow), or where groundwater from wells is inadequate during the dryer months.

5.5.3 Future perspectives

5.5.3.1 Future needs

One of the main concerns about SAT is the introduction of pollutants into groundwater aquifers that may have long-term negative impacts. In a context of increased contamination of water effluent due to global industrialization and population growth, there is a need for ozone treatments to deal with manganese dissolution problems and to increase the biodegradability of micro pollutants in the SAT. AOP has a strong potential for current and future removal of recalcitrant organic compounds such as dyestuffs, pesticides, pharmaceuticals, phenolic compounds, and endocrine disrupting chemicals and therefore increases the potential safe use of SAT for water reuse.

Despite further development of the AOP + SAT scheme which is still at pilot phase, and the need for further research on the toxicology of contaminants "cocktails", the AOP SAT appears as an interesting solution, especially for arid areas that need subsurface storage due to seasonal demand.

5.5.3.2 Opportunities and challenges

The main opportunities and challenges for the future development of the technology can be summarized as follows:

Opportunities	Challenges
• SAT implies a better knowledge on the use of natural systems in its entirety • A number of cities and agricultural areas rely on the combined use of surface water and groundwater • SAT reclaimed water such as treated blackwater, greywater or stormwater not to be just discharged into other surface waters, but also reused as water for irrigation in agriculture or to intentionally recharge groundwater aquifers via MAR.	• Need to develop evaluations that integrate SAT wide range of direct and associated costs and benefits versus current narrow sector-base evaluations of alternative supplies • Lack of operator and regulator training • Cost or unavailability of required lands in urban areas • Concern about introducing pollutants into groundwater aquifers that may have long-term negative impacts and further investigation reducing those risks appear necessary today.

5.6 Advanced oxidation for pretreatment in SAT

5.6.1 Technology Profile

5.6.1.1 Description of the technology

Advanced oxidation process (AOP) refers to a set of chemical treatment procedures designed to remove organic (and sometimes inorganic) materials in water and waste water by oxidation through reactions with hydroxyl radicals (OH•). The advanced oxidation process is of great importance as, unlike conventional oxidation, it can completely destroy trace constituents of concern for public health and the environment, such as endocrine disruptors.

The process is therefore particularly suitable for water pretreatment in managed aquifer recharge (MAR) techniques such as Soil Aquifer Treatment (SAT).

Many systems are qualified under the broad definition of AOP. Most of them use a combination of strong oxidants, e.g. O_3 and H_2O_2, catalysts, e.g. transition metal ions or photocatalyst, and irradiation, e.g. ultraviolet (UV), ultrasound (US), or electron beam.

Reactors used for water treatment by chemical oxidation include batch Fenton reactors, ozone transfer reactors, reactors using hydrogen peroxide or UV reactors.

AOPs may be used in wastewater treatment for (i) overall organic content reduction (COD), (ii) specific pollutant destruction, (iii) sludge treatment, (iv) increasing bioavailability of recalcitrant organics, and (v) color and odor reduction.

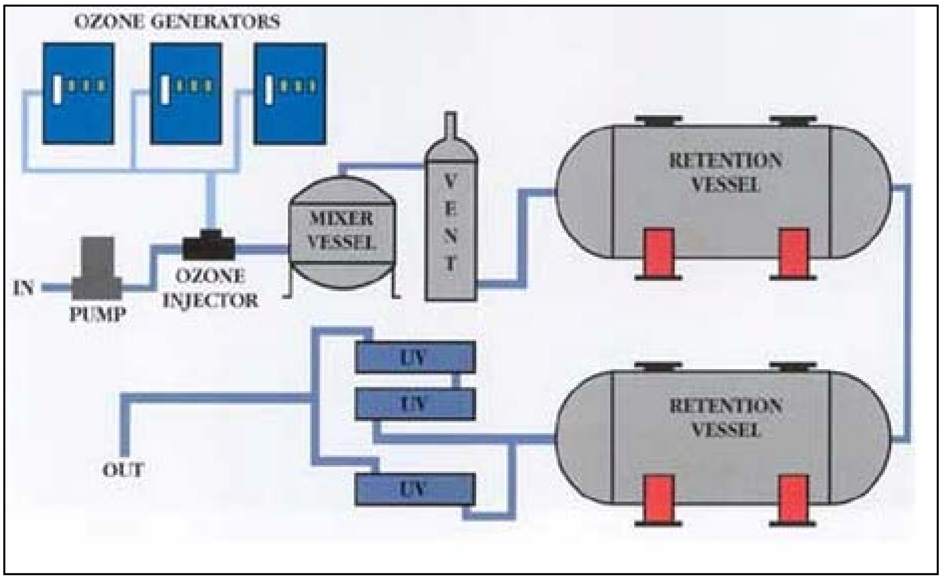

Figure 12 Example of advanced oxidation process
Source: www.wateronline.com - pilot plant as installed at the EBMUD site.

5.6.1.2 Treatment capacity

The capacities of the AOP for pretreatment in SAT are estimated to 40.000 cubic meters per day at pilot phase but should be able to obtain the same treatment capacity of SAT, i.e. 350,000 cubic meters per day.

5.6.1.3 Technological maturity

The maturity of the AOP + SAT scheme is low as the scheme is only at pilot phase in one site (Shafdan, Israel) for irrigation purpose. No AOP+SAT pilot has been developed so far for drinking water purpose.

As regards to Advanced oxidation process on itself, it has been used so far to treat wastewater from groundwater remediation pump-and-treat systems, manufacturing facilities, domestic wastewater treatment plants, and others. However, AOP has not been widely applied so far as the chemical processes behind advanced oxidation require deeper research.

5.6.1.4 Advantages and limitations

The strength of advanced oxidation lies in the hydroxyl radical (HO·), one of the most active oxidants, which can break down most organic components into carbon dioxide, water and mineral acids. A number of AOPs exist that can function at normal temperatures and pressures. Compared to other oxidants, the hydroxyl radicals in the AOP are non-selective towards different classes of reduced compounds. No secondary waste stream is generated, so there are no costs related to stream management. Moreover, AOP can be operated with equipments of small dimensions. AOP has the capacity to remove micro pollutants favouring the biodegradability of effluents in the SAT treatment and avoiding aquifer clogging. Moreover, it has the ability to deal with manganese dissolution problem due to reductive conditions (Petrunic et al., 2005) and to increase the biodegradability of micro pollutants in the SAT system.

A disadvantage of AOPs is their capacity to generate by-products of concern such as brominated by-products, various oxygenated by-products, carboxylic acids and halogenated acetic acid. The performance of the process is affected by high concentrations of bicarbonate (HCO3–) and carbonate (CO_3^{2-}) ions, which react with the hydroxyl radical. Some metal ions (like Fe(II) and Mn(II)) or suspended material can also interfere with the AOP. Free hydroxyl radicals (HO·), in spite of their great oxidizing power cannot be used effectively for disinfection due to their short half life which disables high radical concentration. However, an AOP coupled with high dosages of UV energy might be sufficient for disinfection but this needs to be tested on pilot and full-scale installations. AOP also implies relatively high treatment costs and special safety requirements because of the use of very reactive chemicals and high-energy sources (UV lamps, electron beams, and radioactive sources).

5.6.2 Market overview

5.6.2.1 Suppliers

AOP technology is an area that sees a high level of technology innovation, with many start-ups seeking to commercialize a wide variety of processes that generate hydroxyl radicals. Main suppliers of AOP include MIOX, ULTROX, WEDECO, UVOX, AquaMost, Ecosphere Technologies. However, none provides advanced oxidation processes for soil aquifer treatment purposes so far.

5.6.2.2 Market analysis

There is no existing market for AOP + SAT scheme so far as the scheme is still at pilot phase. Markets with more potential are the arid zones with needs for subsurface storage due to seasonal demand and as such the Mediterranean and countries with pronounced seasonal demand-supply gap seem the most indicated.

5.6.2.3 Investments and operational costs

Setting up an advanced oxidation process for pretreatment in SAT implies significant investments with an estimated CAPEX ranging from 10M€ to 99M€ depending on the size of the site. As regards to operational costs they remain low with OPEX inferior to 0,5€ per cubic meter treated.

5.6.2.4 Final reuse application

The AOP SAT scheme offers a wide range of possible applications whether for industrial, urban or agricultural purposes. It appears particularly adapted to highly populated areas with difficulties for (tap) water supply. It can be used through treated wastewater discharged to rivers when there is the possibility to indirectly reuse such water for drinking purposes.

5.6.3 Future perspectives

5.6.3.1 Future Needs

AOP offers strong potential for current and future removal of recalcitrant organic compounds such as dyestuffs, pesticides, pharmaceuticals, phenolic compounds, and endocrine disrupting chemicals.

There is a need for ozone treatments to deal with manganese dissolution problems and to increase the biodegradability of micro pollutants in the SAT system.

There are many opportunities for the development of AOP SAT schemes in a context of increased contamination of water effluent due to global industrialization and population growth. AOP SAT scheme appears as a highly effective treatment for the removal of organic contaminants from water and could apply to small and medium facilities if the technological aspects can be simplified in the future. Further research should also be promoted to analyse the real toxicology of cocktails (effect of all by-products as a whole, not one by one studies).

This potential to remove emergent compound pollutants increases the potential safe use of SAT for water reuse.

5.6.3.2 Opportunities and challenges

The main opportunities and challenges for the future development of the technology can be summarized as follows:

Opportunities	Challenges
• Increased contamination of water effluents implies the development of adapted solutions for SAT pretreatment • AOP potential to remove emergent compound pollutants increases the potential safe use of SAT for water reuse • Need for subsurface storage due to seasonal demand in arid zones • Highly populated areas with difficulties for (tap) water supply • AOP + SAT makes unused water sources available for irrigation	• Public acceptance of indirect potable reuse • Legal framework with EU Groundwater directive: impairment of groundwater quality is likely but forbidden • Further research should be promoted to analyse the real toxicology of cocktails (effect of all by-products as a whole, not one by one studies).

5.7 Struvite

5.7.1 Technology Profile

5.7.1.1 Description of the technology

Struvite crystallization is a new and high-efficiency technique to remove ammonia nitrogen and phosphorus from wastewater. Nitrogen and phosphor are the main reason for water eutrophication which often causes aquatic ecosystems disorder, aquatic species decreased and diversity damaged. Struvite crystallization method is a novel efficient wastewater nitrogen phosphorus removal technology developed in recent years. Its principle is that NH4 + PO43 - and Mg2 +, under the condition of metastable zone, can generate undissolved magnesium ammonium phosphate (MgNH4PO4 • 6H2O), commonly known as Struvite to remove nitrogen and phosphorus from wastewater in water systems. The Struvite generated can be recovered and used as slow-released fertilizer or industrial chemical, and the wastewater recycling is achieved by this method. The process operates in the sludge treatment line using a combination of Anaerobic Digestion with Enhanced biological phosphorus removal through a reactor. There are two process options: either Struvite is extracted in the sludge before centrifuge, or in centrifuge centrates.

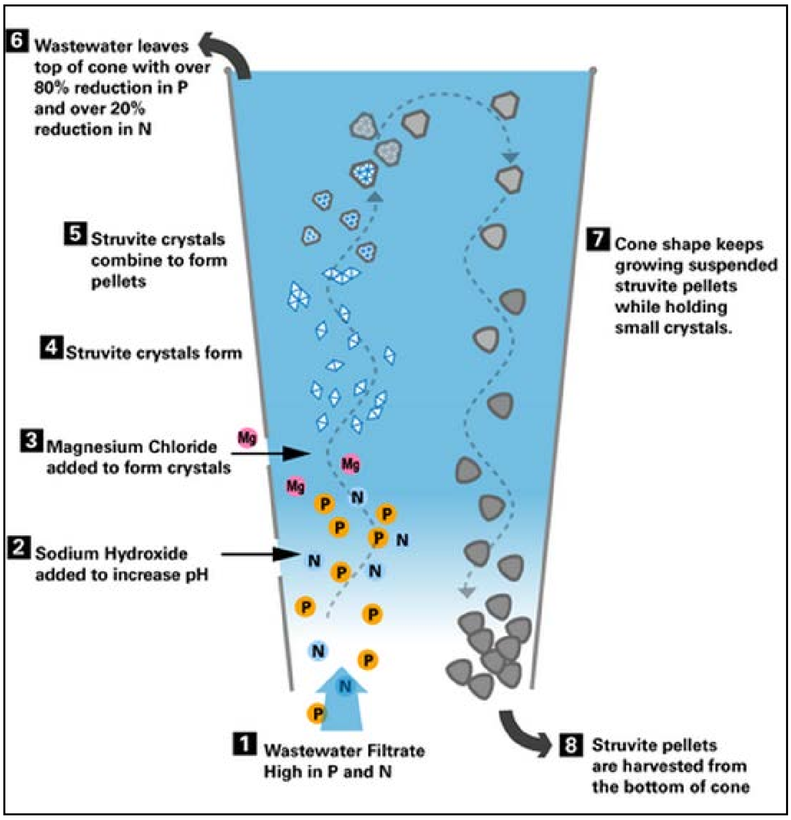

Figure 13 Example of struvite crystallisation process Source: Multiform Harvest

5.7.1.2 Treatment capacity

Commercial references with capacities up to 4.000 m^3 per day for WWTP up to 300,000 p.e.

5.7.1.3 Technological maturity

Struvite recovery is considered as mature technology as it has been validated and is used at large scale level globally.

5.7.1.4 Advantages and limitations

Struvite combines an important number of benefits. It improves the performance of the WWTP as it reduces pipeline incrustations, the return load, the sludge volume and the consequent disposal costs, and need for chemicals. Moreover, it allows recycling part of the nutrients present in the wastewater, together with the clean water. It can be recovered to use as agricultural slow release fertilizer which has the advantage to stop nitrogen and phosphate in fertilizer entering into water and therefore prevent the occurrence of eutrophication. Struvite can also be used as chemical reagent, fireproof agent, cement adhesive, etc. It increases the recovery rate of nutrients through the water reuse scheme. Another interesting aspect is that crystallisation reactors used for struvite have low energy consumption and produces a fast reaction with crystallisation products with a high selectivity. On the other hand, the key limitation is enhanced biological phosphorus removal with anaerobic digestion (AD) to provide enough phosphorus in the sludge water and moderate recovery rates (up to 15%) of the phosphorus eliminated at the WWTP. Another limitation is the need of stable climate conditions (rather warm than cold).

5.7.2 Market overview

5.7.2.1 Suppliers

Main suppliers for struvite include NuReSys,Royal Haskoning DHV (Crystal Reactor), Task Industriële Milieutechnieken Bvba, Ostara, CNP (ex-PCS) and Veolia.

5.7.2.2 Market analysis

The Netherlands, where the production of energy from WWT plants has significantly increased in the last years, have been the first European country to adopt struvite precipitation. Today in Europe, struvite recovery units are also operated in Germany, Belgium Denmark, Sweden, United Kingdom, and Spain. Main sites outside of Europe include the USA, Canada, and China (planned).

The development of the market for struvite is linked to the technical advantages of the technology that allow improving the WWTP performance (and especially the reduction of pipeline incrustations) and the potential market for struvite derivatives. As for the market potential for struvite derivative, it depends on the interest of the agriculture sector in slow-released fertilizer. Most countries with live stock are currently limiting the amount of manure that can be spread on the land by P. In this context, slow-released fertilizers offer the possibility to reduce the P in the manure so that more volumes of manure can be spread on the land. The market seems rather promising.

5.7.2.3 Investment and operating costs

The investment costs (CAPEX) for Struvite directly depend on the size of the treatment plant and can vary from 250.000€ (5m^3 treated/h) to 1.500.000€ (125m^3/h). Similarly, the OPEX depends directly on the throughput (m^3/day) and initial PO4-P concentration but is high, establishing at a level superior to 2€/m3 treated.

5.7.2.4 Final reuse application

Struvite applications include Waste Water Treatment Plants for municipal applications and industrial applications. In principle it can be applied on any liquid waste stream with an interesting PO4-P concentration.

5.7.3 Future perspectives

5.7.3.1 Future needs

Phosphorus is an essential element of life for the role it plays as a plant nutrient. In the EU, the capability of feeding populations directly depends from a secure and affordable supply of phosphorus as the EU depends for more than 90% on imports of Phosphorus minerals. Phosphate rock was declared a critical raw material by the European Commission in 2014. On the other hand, human activities have doubled the amount of nitrogen in the environment and are responsible for a ten-fold increase in phosphor input to the environment. Nitrogen and phosphor are the main reason for water eutrophication which causes aquatic ecosystems disorder, aquatic species decreased and diversity damaged.

In this context, Stuvite crystallization offers a very suitable combination of waste water treatment with the production of slow release fertilizer which is characterized by its ability to stop nitrogen and phosphate in fertilizer entering into water through the slow release of nutrient. It is estimated that technical recovery and recycling from the wastewater stream has the potential to triple the European mineral phosphorus supply from 8% to 23%.

5.7.3.2 Opportunities and challenges

The main opportunities and challenges for the future development of the technology can be summarized as follows:

Opportunities	Challenges
• Struvite offers the possibility to decouple nutrients management from the water management in the agriculture (the seasonal nutrients needs of the plant do not coincide with the water needs) • Need for reducing the amount of phosphorus in the manure linked to the increase of sales of slow-released fertilizer • Municipal wastewater represent a relevant phosphorus reserve and have the potential to cover about 20% of the demand • Phosphorus is considered as a critical raw material by the EU	• Competition with primary fertilizers could jeopardize market development. • As of today, phosphorus recovery is not a motivation for installing Struvite WWT units as the main operational benefits come from the WWT • Indecisive policies and non-reliable regulation could also hamper investment significantly. The downstream use of recovered nutrients still need to be harmonised, a regulation would be needed at this level.

6 Benchmark analysis

Based on the information processed through the research study, a specific benchmark analysis has been performed considering different comparative variables. Such variables can be appreciated below (see Figure 14).

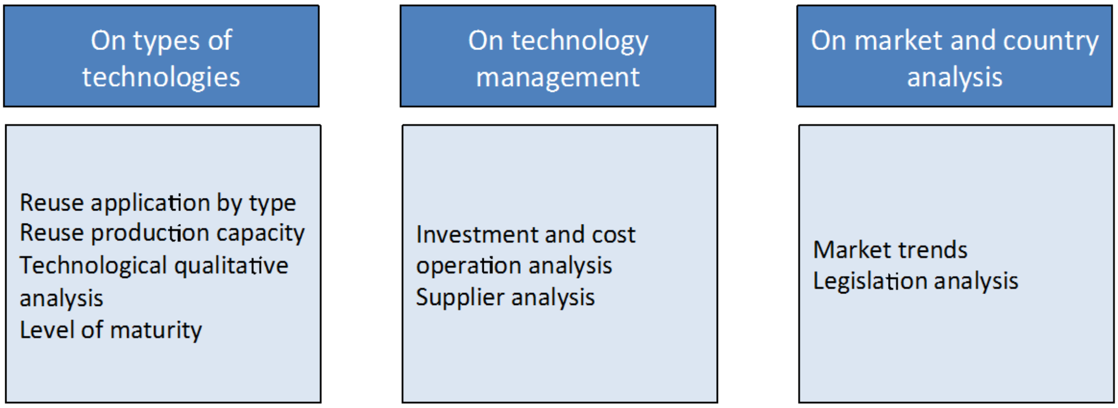

Figure 14 Variables considered to perform the benchmark analysis of technologies identified

Other than the aspects analysed in Chapter 4, the benchmark has also included a comparative analysis of the legal framework needed to create enabling environments to promote the technology. Thus, the benchmark study has analysed the main barriers for an extensive implementation of the technology, identifying the key legislative changes that would be necessary for mainstreaming the uptake of the technology.

6.1 Benchmark analysis of the types of technologies

When benchmarking the types of technologies, the study considered the different applications (either urban, industrial or agricultural), its reuse production capacity, the qualitative analysis capacity, its technological maturity based on variables assigned to high, middle and low maturity, and basic advantages and disadvantages of the technology.

6.1.1 Reuse application by type

The following reuse applications have been identified for each one of the technologies (see Table 9).

Table 9 Final Reuse application by type of technology

Applications / Technologies	Agricultural irrigation	Urban Application	Industrial
1.UF MF RO	✔	✔	✔
3. AnMBR			✔
4. FO MBR		✔	✔
5.Modular WWT	✔	✔	✔
6. SAT	✔	✔	
7. AOP for SAT		✔	✔
8. Struvite	✔	✔	✔

6.1.2 Reuse production capacity

In terms of capacities of reuse production, it has not been possible to perform accurate analysis of production capacity due to the different level of technological maturities, however, based on expert feedback, the following reuse capacities have been assigned (see Figure 15).

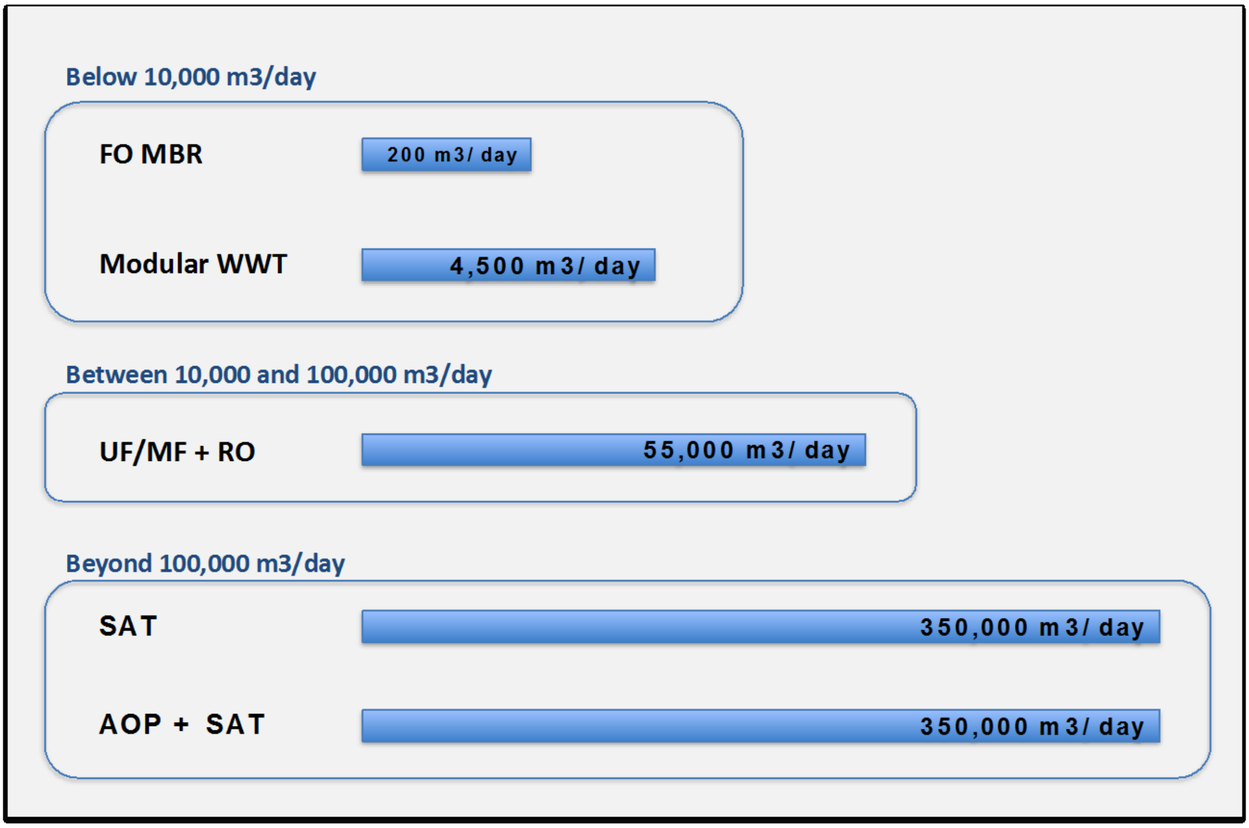

Figure 15 Reuse production capacity according to the feedback from interviews

6.1.3 Technological qualitative analysis

In terms of technological qualitative analysis the following investigation has been performed to compare technologies according to the main wastewater quality parameters that at the end of each treatment train, the technology can remove. The parameters below have been included:

BOD	Biological Oxygen Demand: is the amount of dissolved **oxygen** needed by aerobic **biological** organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. Measured in Parts Per Million (PPM)
COD	Chemical Oxygen Demand: test is commonly used to indirectly measure the amount of organic compounds in water.
Coliforms	**Coliform bacteria** are a commonly used **bacterial indicator** of sanitary quality in water. Measured in milligarms per liter (mg/l)
Faecal Coliforms (E-Coli)	Faecal Coliforms provide a warning of failure in water treatment, a break in the integrity of the distribution system, possible contamination with pathogens. When levels are high there may be an elevated risk of waterborne gastroenteritis. Measured in Coliform count

	per 100ml.
Suspended Solids	**Suspended solids** refers to small **solid** particles which remain in **suspension** in water as a colloid or due to the motion of the water. It is used as one indicator of water quality. Measured in miligrams per liter (mg/l)
N_{total}	**Total Nitrogen** is the sum of nitrate (NO3), nitrite (NO2), organic **nitrogen** and ammonia (all expressed as **N**). Ntotal is measured to know the amount of nutrients in water which can be cause of Eutrophication. Measured in milligrams per liter (mg/l)
P_{total}	Phosphorus in natural waters is divided into three component parts: soluble reactive phosphorus (SRP), soluble unreactive or soluble organic phosphorus (SUP) and particulate phosphorus (PP) (Rigler 1973). The sum of SRP and SUP is called soluble phosphorus (SP), and the sum of all phosphorus components is termed total phosphorus (TP). Ptotal Ntotal is measured to know the amount of nutrients in water which can be a cause of Eutrophication. Measured in milligrams per liter (mg/l)
Fats and Oils	Fats and Oils consists of a group of related constituents that are of special concern in wastewater treatment due to their unique physical properties and highly concentrated energy content. They are hydrophobic and thus have low solubility in wastewater, resulting in relatively low biodegradability by microorganisms. Measured in milligrams per liter (mg/l)
Nematodes	Nematode removal can play an important role in evaluating the degree of efficiency of wastewater treatment systems. Nematode eggs are a direct threat to human health and are an indication of organic enrichment in wastewater. Measured as egg count per liter
Turbidity	Measuring Turbidity (the amount of particles in a water body), is important for water reuse purposes as Turbidity gives a quick and momentary indication of a problem with the integrity of the water treatment technologies as there are direct correlations between Turbidity and Pathogenic Organisms including viruses. Measured as Nephelometric Turbidity Units (NTUs)

Based on these above defined parameters, an "x" has been placed next to each parameter that the water reuse technologies can remove (Table 9). Primary and/or secondary treatment would be required before the implementation of most of the technologies below, therefore Table 10 represents the parameters that are removed, in some instances, in the entire treatment train.

Table 10 Qualitative characterization by defined technology

Parameter	Technologies						
	(MF/UF RO)	AnMBR	FO - MBR	Modular Waste-water Treatment	SAT	AOP + SAT	Struvite
BOD	X	X	X	X	X	X	
COD	X	X	X	X	X	X	
Coliforms	X	X	X	X	X	X	
Faecal Coliforms (E-Coli)	X	X	X	X	X	X	
Suspended Solids	X	X	X	X	X	X	
N_{total}	X		X	X	X	X	X
P_{total}	X		X	X	X	X	X
Fats and Oils	X	X	X	X	X	X	
Nematodes	X	X	X	X	X	X	
Turbidity	X	X	X	X	X	X	

6.1.4 Level of maturity

In terms of the technological maturity, which implies the level to which the technology has been tested in terms of its implementation, the benchmark performed provided the following comparative analysis (see Figure 16). Levels of maturity are defined according to the following distribution:

Low Maturity: Low maturity level indicates that the technology is still at pilot phase and needs further research to be used at large-scale.

Mid Maturity: Mid maturity corresponds to technologies that have been pilot tested and have already been developed at scale but are not yet mainstreamed.

High Maturity: High maturity corresponds to technologies that are validated and can be used at large-scale at industrial, urban or agricultural levels.

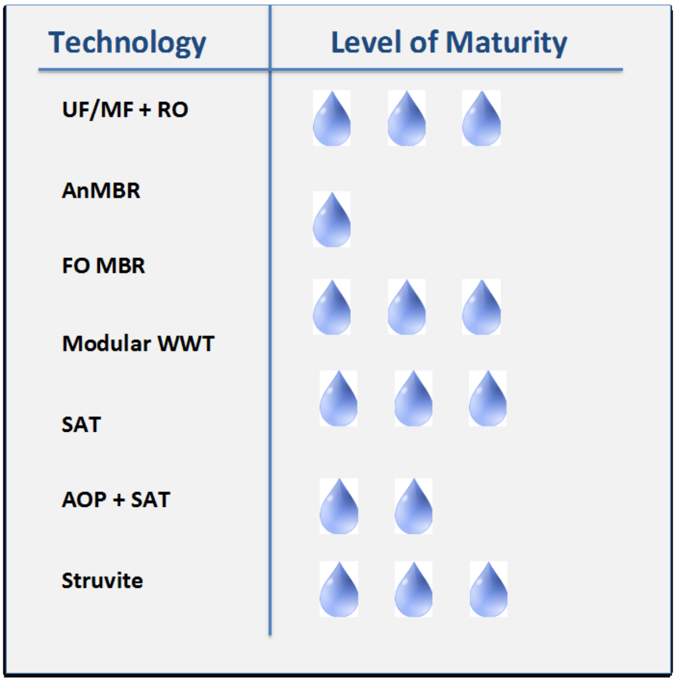

Figure 16 Comparative analysis of technology maturity

6.2 Benchmark analysis of technology management

When performing a comparative analysis of the management and operations among the different technologies studied, the following variables have been considered: investment and cost management analysis (considering OPEX and CAPEX) and supplier analysis.

6.2.1 Investment and cost operation analysis

Considering the investment and operational costs of technologies, an assignation strategy has been done based on the linkages between CAPEX and OPEX (see Figure 17).

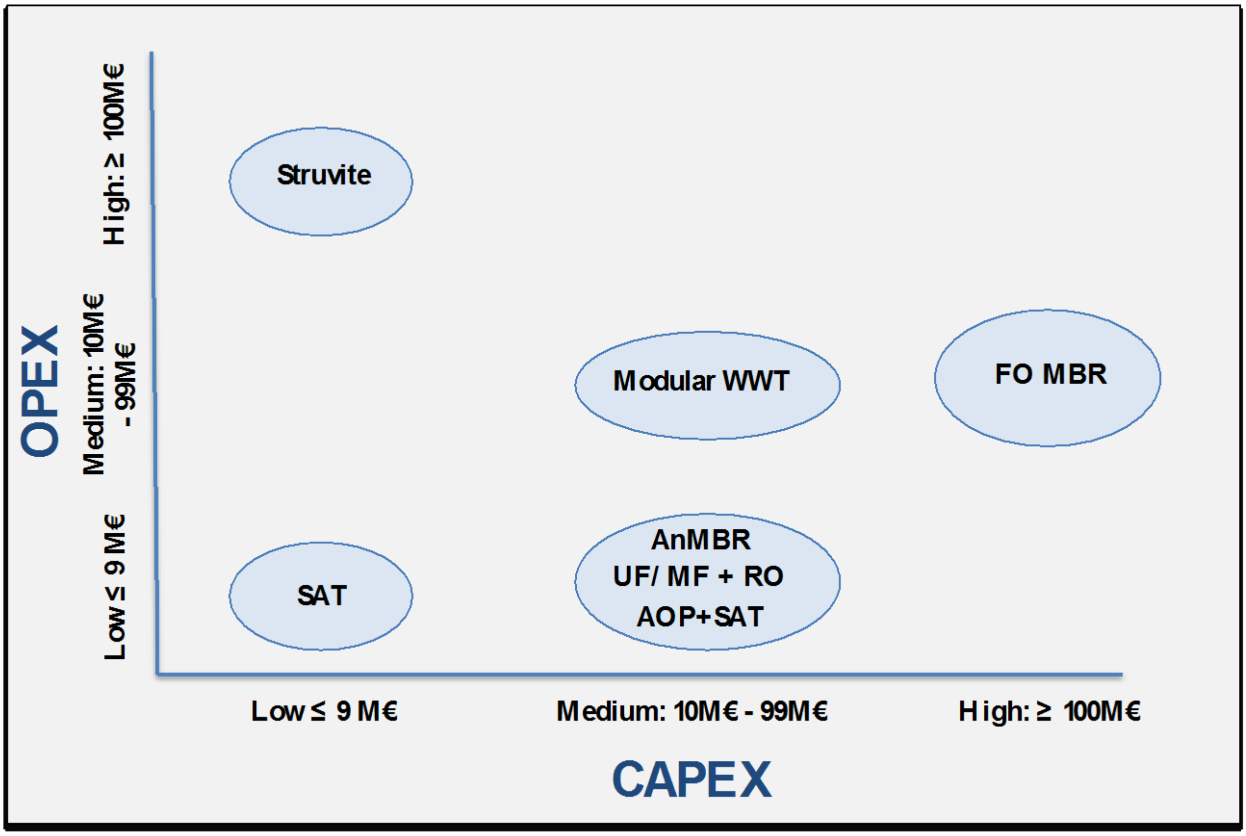

Figure 17 Correlation between CAPEX and OPEX technology costs

According to this analysis, we have the following characterization of technologies:

- Low investment and low operational costs: SAT
- Low investment and high operational costs: Struvite
- Medium level of investment and low operational costs: AnMBR and UF/MF+RO
- Medium level of investment and medium operational costs: Modular WWT
- High investment and medium operational costs: FO MBR

6.2.2 Supplier analysis

In order to further analyse the context and circumstances of each technology, a study has been performed to consider the number and type of suppliers for each technology (see Figure 18).

Based on this, three different categories have been created:

- Category 1: Technologies that are in a pilot test stage currently and don't have any supplier
- Category 2: Technologies that have a supplier structure formed by few suppliers or few suppliers cover the majority of the market supply
- Category 3: Technologies that have a broad number of suppliers and access to technology is open market driven

SAT and AOP SAT not included because they are process methodologies and as such, they do not have formal suppliers.

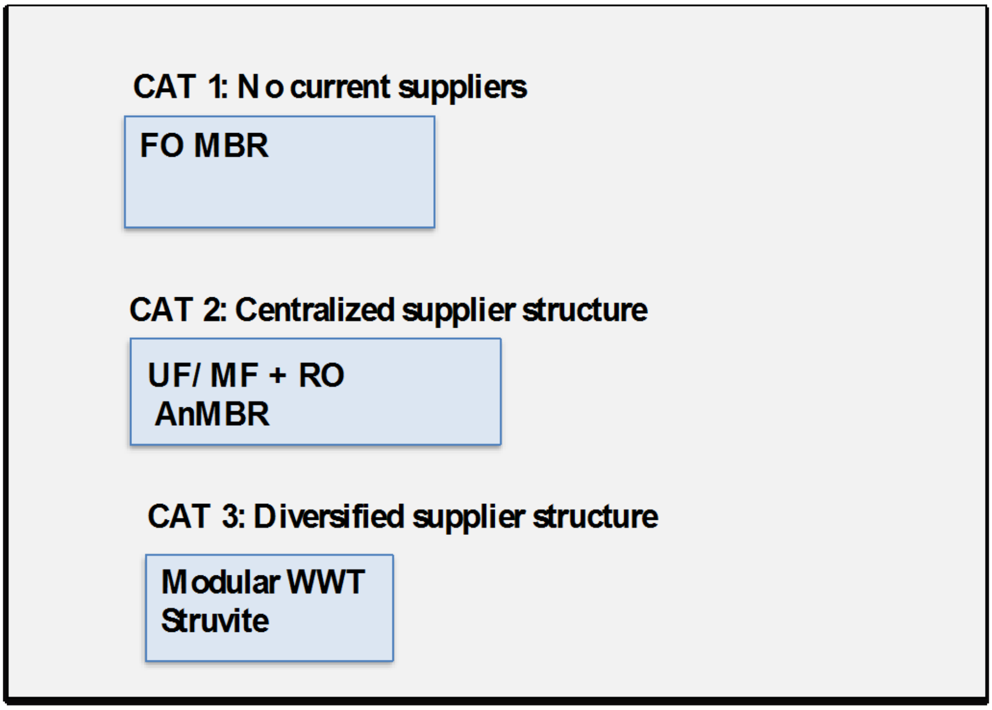

Figure 18 Technologies distributed according to their supplier structure

6.3 Market and country analysis

6.3.1 Market trends

The research process benchmarked the different markets and country analysis among the technologies based on the years they have been in the market (see Figure 20).

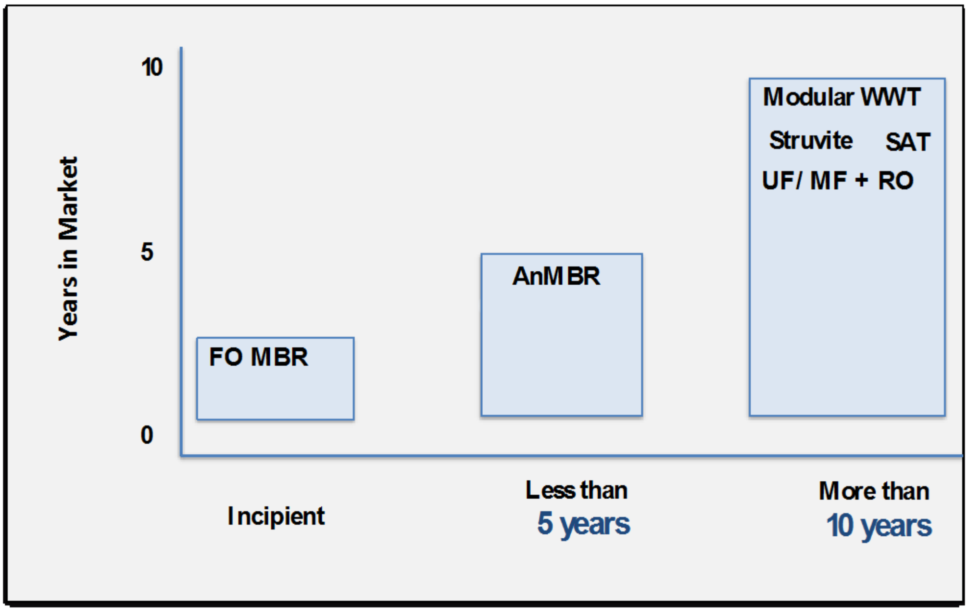

Figure 19 Years in market of each technology analysed

Technologies on non-mature markets

From the seven technologies analysed, the most incipient one is the Forward Osmosis MBRs. Currently, there is still no market for OMBR as the scheme remains more expensive than common schemes, such as MBR followed by RO. Yet, the potential market remains important as all countries and regions where re-use of wastewater is needed will be potential markets.

Furthermore, AnMBR technology has been in the market for more than five years, as an urban application, although as an industrial application it has been in the market for more than 20 years. However, while the size of the MBR market has been assessed extensively, there is still no proper information giving a full picture of the AnMBR market and whether the market has taken off. It is estimated that less than ten side stream sites and six immersed sites are operating globally and they are all industrial. Thus, there is no clear tendency for the AnMBR Market as the technology still cannot be applied for large scale plants. An important question is to know whether the MBR market will move towards AnMBR with the same tendencies (highly concentrated and dominated by suppliers from Japan, USA, Germany and Singapore) as it is now for MBRs.

Technologies from mature markets

As it can be appreciated, four of the technologies analysed are considered mature in the sense that they have been more than ten years in the market and have been broadly tested and proved.

In the case of UF/MF and RO technologies, the estimation of the actual market for Europe is of 20 to 25 million euros, including municipal and industrial waste water treatment[3], and it is expected to grow by 5 to 10% in the next few years[4].

This technology is widely spread in advanced countries where wastewater treatment and wastewater reuse is a priority. Some countries, like in central Europe, where water scarcity might not be a big issue, are still heavily promoting water reuse in order to increase the respect for the environment. In other countries, like in the Mediterranean region, Israel, Cyprus, Greece or even in Middle East, Water Reuse is becoming more and more popular given the limited availability of fresh water.

In the case of Struvite, recovery units are operated in Germany, Netherlands, Belgium Denmark, Sweden, United Kingdom, Canada, USA, and are planned in China and Spain. The Netherlands have adopted properly the production of energy with the sludge from WWT plants. They have high concentrations of PO4-P and this is the first EU country to adopt the Struvite precipitation. But the most promising countries are the one with high-energy consumption such as Europe, USA and Canada, and therefore where there is a higher tendency to spread anaerobic digestion

In the case of modular wastewater treatment plants, the technology has been in the market for more than ten years and there is today a clear and growing market for packaged plants. The European market has important opportunities for packaged wastewater treatment plants linked to the local-specific conditions. Packaged plants have gained popularity in countries such as Germany where the industrial end-user in particular has responded favourably to this technology. The most widespread version of the packaged plant however has been in segments where rapidly expanding installations base has prompted the entry of a large number of small local companies. One of the growing trends within the market is the development of Membrane Bioreactor Systems. Key companies offering this type of packaged solution include Enviroquip, Zenon and US Filter.

Finally, the main sites using SAT today include the Tula valley (Mexico), Phoenix (USA), Adelaide (Australia), Windhoek (Namibia), Atlantis (South Africa), Porquerolles island (France) and Shafdan (Israel). The market for SAT has not been estimated so far and depends largely on the characteristics of the site. At European level, due to the economic crisis, several of the existing schemes have been closed. South of Europe, especially Mediterranean Islands and Mediterranean coastline of Spain are the most promising markets. In other regions of the world, South Africa (and surrounding countries), Australia, Singapore and China seem to have the strongest potential for development. In the advanced oxidation for pretreatment in SAT, there is no existing market for AOP + SAT scheme so far as the scheme is still at pilot phase. Markets with more potential are the arid zones with needs for subsurface storage due to seasonal demand and as such the Mediterranean and countries with pronounced seasonal demand-supply gap seem the most indicated.

6.3.2 Legislation analysis

In Europe, there are no current or specific guidelines nor regulations at the European Union (EU) level for water reuse. However, the “Blueprint to Safeguard Europe's Water Resources” (COM 2012), makes it clear that boosting water reuse in Europe is a specific objective of the EU, with a proposal for the development of a regulatory instrument for water reuse by 2015. In order to achieve the objective of new water reuse regulations for Europe, the European Commission launched a public consultation in 2014,

[3] Estimation provided by DOW Chemicals

[4] Estimation by CAGR

where the aim of the consultation was to publically evaluate the most suitable EU-level instrument/s to foster water reuse, while ensuring the health and environmental safety of water reuse practices and the free trade of food products.

There are, however, several environmental Directives that need to be taken into account when considering water reuse applications at EU level (Gawlik & Alcalde Sanz, 2014). The Water Framework Directive (WFD, 2000/60/EC) is the main directive followed by European entities interested in water reuse, as it establishes a legal framework to guarantee sufficient quantities of good quality water across Europe for the different water uses and environmental quality.

The other directives that relate to water reuse in Europe, taken from (Gawlik & Alcalde Sanz, 2014) are:

- The Urban Wastewater Treatment Directive (91/271/EEC) concerns the quality of the urban wastewater discharged into receiving waters that can be reused if it is additionally treated by reclamation technologies. The major concerns are chemical and/or biological hazardous substances.
- The Sewage Sludge Directive (86/278/EEC) deals with the use of treated wastewater for agriculture regarding the major concerns of contamination of soil, groundwater and agricultural produce with chemical and /or biological hazardous substances, and the health risk for workers and consumers.
- The Nitrates Directive (91/676/EEC) concerns water reuse for agricultural irrigation and for groundwater recharge with respect to the health and environmental impacts of nitrates, especially in vulnerable zones. It is necessary to avoid over-fertilisation.
- The Groundwater Directive (2006/118/EC) refers to water reuse for agricultural irrigation and aquifer recharge with respect to the contamination of groundwater by hazardous chemical substances.
- The Thematic Strategy for Soil Protection (COM(2006) 231) and the future Soil Protection Directive address the use of reclaimed water for irrigation and soil-aquifer recharge with a view to protecting soils from deterioration.
- The Drinking Water Directive (98/83/EC) addresses the indirect reuse of drinking water, for example through the recharging of aquifers used for the abstraction of water intended for human consumption and the augmentation of surface waters for human consumption, with respect to chemical and biological contaminants.
- The Bathing Water Directive (2006/7/EC) concerns the use of treated wastewater in recreational impoundments with/without public access (e.g. fishing, boating, bathing areas). The main concern is the risk to public health caused by pathogens.
- The Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC) address the application of water reuse for environmental enhancement, such as wetlands improvement.
- The Industrial Emissions Directive (2010/75/EU) and the Environmental Quality Standards Directive (2008/105/EC) address the application of reclaimed water in industrial uses and uses that may affect the environmental matrices of surface- and groundwater, such as artificial aquifer recharge, stream augmentation, and irrigation.

Can water reuse legislation drive water reuse technology implementation?

With the impending introduction, in 2015, of water reuse legislation at European level, it generates a potential for this legislation to bring about changes in technology choice and potentially drive the EU water reuse technology market

According to Judd (2006), legislation often drives the specification of both potable and discharge water quality, through demand management or reuse and therefore influences the choice of water and wastewater treatment technologies. He goes on to mention that legislation and associated regulatory functions exert the greatest influence on the global MBR market. The focus of his study was of course on MBRs. However the same notion can be extended to the entire reuse market as Bennett (2009), concurs with Judd where he mentions that in general terms, economic viability is likely to depend on regulatory restrictions on supply and discharge, balanced with the technical and financial risk at an individual site. While economic profitability is obviously important, he mentions that this is an insufficient driver in its own right. Instead, legislative or water scarcity issues will be the main driving forces that then impact on economics and technology choices.

Analysing the individual technologies of this study in terms of how legislative changes could potentially influence the market to move towards an uptake of a particular technology, it is important to keep in mind Table 9 as one of the most important aspects of a technology is the water quality parameters that the technology is able to remove.

Table 11 lists the technologies focussed on in this study and the potential legislative drivers that can force this technology to be taken up in the European Water Reuse market. Interviews were conducted, Phases III and IV of the Methodological Study Process, with experts and suppliers for each technology to gain an understanding of what legislative changes, if any, would help drive the technology implementation, their views have been included in the table.

Table 11 Legislative analysis per Technology

Technology	Legislation
UF/MF + RO	Advances in membrane technology over the last decade and significant improvements in its efficiency, and thus cost effectiveness, have greatly increased the competitiveness of wastewater reuse processes over discharging directly to the environment. Given that UF/MF RO treatment schemes are able to eliminate all major wastewater treatment parameters, these schemes therefore offer the best option for impending legislative changes with ever increasing threat of stricter parameter quality levels. Expert/Suppliers view: Harmonization of legislation and technology standardisation across all EU Countries will assist European companies implement their technologies across Europe without having to have a deep understanding of each individual countries water reuse legislation which speeds up technology implementation.
AnMBR	The trademark of an AnMBR, is the ability to produce consistently high-quality effluent, whereas conventional anaerobic digestion technologies are often sensitive to system upsets that affect reliability and efficiency. Given the fact that AnMBR systems do not remove Phosphorous nor Nitrogen, their final reuse application is restricted, mainly to Industrial Applications. Expert/Suppliers view: With the ability to treat water of poorer quality, it opens up the possibility of further industrial reuse expansion and to treat difficult high load urban wastewaters with impending legislation for industrial and urban wastewater reuse. If legislation demands improved or increased energy recovery from treated wastewaters, this can drive the introduction of AnMBR systems of high load wastewaters where energy recovery will be more worthwhile.

Technology	Legislation
FO MBR	More stringent regulations and the potential to produce high quality effluent make membrane bioreactors (MBRs) an attractive process for domestic wastewater treatment. FO-MBRs systems are able to eliminate all the main wastewater parameters (Table 9) thereby making FO-MBR systems a viable option for impending water reuse legislation for mainly for Industrial wastewater but for urban wastewaters as well. Expert/Suppliers view: As FO MBRs have better efficiency of TOC removal, if legislation and regulations become more stringent in the TOC wastewater quality parameter, this will drive the introduction of FO MBRs over conventional MBRs and MBR RO systems. FO MBRs given their design and process configurations are also able to run using less energy than conventional systems and MBR RO systems and therefore if the legislation was to demand that industrial companies treat their wastewater at lower energy, this would drive the uptake of FO MBR.
Modular WWT	Modular wastewater treatment systems can be built according to the wastewater that it has to treat. It is for this reason that modular wastewater treatment systems are able to eliminate all major wastewater quality parameters, as they are built on an adhoc and made to measure basis. Change in legislation (i.e. polluter pays principle, hydraulic footprint etc.) might force a lot more industries to install modular wastewater treatment plants to treat effectively their wastewater and reuse the treated water Expert/Suppliers view: If new legislative rules demanded that wastewater, that has to be reused onsite, be treated onsite to save energy and piping infrastructure costs, this would then drive the market to uptake more modular wastewater treatment works.
SAT	SAT is one of the most mature technologies for water reuse with un-controlled SAT being used for decades in many countries. SAT is shown to remove all major wastewater quality parameters and therefore, given sufficient land availability it is a good treatment option to achieve the impending water reuse legislation. Expert/Suppliers view: The current legisltion covers well the aspects of water reuse through SAT application. However with potentially stricter European environmental legislation (EU Groundwater Directive) it could drive further innovation in SAT which in turn could result in further SAT update. If legislation demands for reduced costs in water reuse, SAT could be a viable economic option if land availability was not a concern, this would drive further implementation of SAT.
AOP + SAT	One of the major drawbacks of SAT is the amount of land required to treat the water to sufficient water reuse quality. However, with the addition of AOP, short SAT is possible, thereby the ability to treat water to reuse standards requires less land. Expert/Suppliers view: We would need to propose new legislation in order to allow for shorter SATs. Current legislations requires, one day of flooding 2-3 days of rest, therefore if we can shorten this time given the AOP pre SAT, this would allow for reduced time for treatment.
Struvite	Struvite recovery is a growing application to wastewater and water reuse schemes as nutrient legislation limits are becoming ever stricter and at the same time nutrient sources are becoming more expensive, implementation of nutrient recovery technologies and strategies could help in increasing the economic feasibility of water reuse schemes. Expert/Suppliers view: As a way of example, Netherlands have changed their legislation recently to allow Struvite to be used in agricultural applications. However at European level there is no common legislation to allow this. In addition, if all member states where required by legislation to recover struvite from urban and industrial wastewater treatment works this would result in less reliance on phosphorous imports. Therefore common legislation and enforced struvite recovery would drive the uptake of struvite technology across Europe.

7 Highlights and major conclusions

Given the increasing level of water consumption, population growth and the growing scarcity of water resources, water reuse technologies can only become more relevant and will be applied every time more in agricultural, industrial and urban sectors. This implies the need of understanding the advantages and disadvantages of current technologies and developing joint strategies to enhance the opportunities they provide and address the challenges they may generate.

Thus, as a final conclusion of this research process, the research team has identified major advantages and disadvantages of each technology, and highlighted the major opportunities and challenges associated with each one of them.

7.1 Technological advantages and disadvantages

In terms of specific advantages and disadvantages for each one of the technologies analysed, the research identified the following major key points:

Technology	Advantages	Disadvantages
1.UF/MF + RO	• MF/UF filtration allows for the chemical cleaning requirements and power consumption for RO membranes to be reduced significantly and increases the permeate production per unit membrane area	• Fouling and Energy cost of RO
2. AnMBR	• Nearly absolute biomass retention • Low nutritional requirements • Allows for operation at high sludge retention time (SRTs) • low energy requirements • Ability of producing net energy (biogas) • Produces mineralized nutrients (ammonia, orthoP) for agricultural use	• Cake formation: membrane fouling more severe than under aerobic conditions • WWT in lower temperate climates (<20ºC) is still a challenge
3. FO MBR	• Much higher rejection than MF/UF RO scheme at a lower hydraulic pressure • Lower fouling propensity than pressure-driven systems meaning less frequent backwashing.	• Low water flux resulting in large FO membrane areas/cost • Accumulation of salts into the bioreactor resulting in salt leakage • High energy demand linked to the need for re-concentration
4. Modular WWT	• Portable and easy to install • Designed for use in projects with time, space, and budget constraints • Can be placed strategically to generate reclaimed water at the point of reuse • Can be installed incrementally to meet growing demand	• Getting rid of the sludge can be a challenge in some cases • They require a high operator knowledge

Technology	Advantages	Disadvantages
5. SAT	• • Natural pretreatment system • Allows securing and enhancing water supplies while mitigating floods and flood damage. • Low cost and a fitting option for wastewater reclamation. • Can contribute to an improvement of the aquifer water while preserving water levels in wetlands • mitigates contaminant intrusion and freshens saline aquifers or prevents aquifer salinization • Enhances environmental flows in water supply catchments • Augments water supplies and improving coastal water quality by reducing urban discharges.	• Groundwater recharge should not be viewed as a treatment method. Introducing pollutants into groundwater aquifers may have long-term negative impacts and SAT could change the soil and groundwater hydrological properties. • Requires a large area for the infiltration basin which adds to the cost of the project and may increase the risk of flooding in areas where groundwater levels are already high.
6. AOP + SAT	• Hydroxyl radical (HO•) can break down most organic components into carbon dioxide, water and mineral acids • A number of AOPs exist that can function at normal temperatures and pressures and can be operated with equipments of small dimensions • HO•in the AOP are non-selective towards different classes of reduced compounds. • No secondary waste stream is generated, reducing costs • Capacity to remove micro pollutants favouring the biodegradability of effluents and avoiding aquifer clogging. • Ability to increase the biodegradability of micro pollutants in the SAT system. • Land reduction: with AOP before SAT, it results in less land needed to treat the water to reuse standards.	• Capacity to generate by-products of concern such as brominated by-products, various oxygenated by-products, carboxylic acids and halogenated acetic acid. • Performance of the process affected by high concentrations of bicarbonate (HCO3–) and carbonate (CO32–) ions, which react with the hydroxyl radical. • HO•, in spite of their great oxidizing power cannot be used effectively for disinfection due to their short half life which disables high radical concentration. • Relatively high treatment costs and special safety requirements because of the use of very reactive chemicals and high-energy sources (UV lamps, electron beams, and radioactive sources)
7. Struvite	• Increase overall WWTP performance due to reduction of pipeline incrustations, return load, sludge volume and the consequent disposal costs. • Struvite can be recovered to use as agricultural SRFS (slow release fertilizer). • Can also be used as chemical reagent, fireproof agent, cement adhesive, etc. • Increases the recovery rate of nutrients through the water reuse scheme.	• The key limitation is enhanced biological phosphorus removal with anaerobic digestion (AD) to provide enough phosphorus in the sludge water. • Needs stable climate (better warm than cold).

7.2 Major challenges and opportunities of each technology analysed

In terms of challenges and opportunities, the research identified the following major key points:

Technologies	Challenges	Opportunities
UF/MF + RO	• Lack of standardization among the different suppliers; • Legislation and public acceptance of re-used water; • Commoditization would certainly lead to a significant reduction on R&D expense due to lack of attractiveness for continuous innovation.	• Demand for replacement; • General interest for membrane technologies which have a number of applications; • Increasing investments and investigation; • Large field for development and innovation:
AnMBR	• As of today, not appropriate for municipal WWT to reach reuse quality due to too high costs and high shear stress in the biology. • Legislation and public acceptance of re-used water; • Will not develop significantly until cake formation is solved • High cost of membranes still impedes a faster commercialisation (both MBRs and AnMBRs). • Membrane costs appear to be up to 10 times higher than the energy consumption costs per m3 of treated water. • Treatment of domestic waste water at low temperatures (<15ºC).	• Use in the peri-urban to rural context to recover water, nutrient and biogas for combined heat and power generation. • Suitable for high loads (ability to treat water of poorer quality) and provides a possibility for the agricultural use of the treated effluent for non-potable purposes in many regions suffering from water shortage • Integral municipal waste water treatment with pathogen free but nutrient rich effluent for re-use in irrigation and enable energy recovery.
FO MBR	• No market so far as more expensive than MBR-RO schemes • Legislation and public acceptance of re-used water; • High energy requirements of the re concentration • Limited performance of the FO membrane.	Potential opportunities linked to characteristics: • Compact wastewater treatment concept • Effective in treating difficult wastewaters • Produces high quality effluents which can be re-used directly.
Modular WWT	• Larger international corporations (Chinese, Korean, US) might encroach on the European Market outcompeting European SMEs. • Legislation and public acceptance of re-used water;	• Change in legislation (i.e. polluter pays principle, hydraulic footprint etc.) might force a lot more industries to install modular wastewater treatment plants to treat effectively their wastewater and reuse the treated water. • Growing trend in compound recovery, where compounds of economic value can be recovered from certain industries from treating their wastewater. • Wide range of applications ranging from emergency wastewater treatment and off grid applications.

Technologies	Challenges	Opportunities
SAT	• • Need to develop evaluations that integrate SAT into a wide range of direct and associated costs and benefits versus current narrow sectoral evaluations of alternative supplies. • Legislation and public acceptance of re-used water; • Lack of operator and regulator training • Cost or unavailability of required lands in urban area • Concern about introducing pollutants into groundwater aquifers that may have long-term negative impacts and further investigation reducing those risks appear necessary today.	• In a context where many cities and agricultural areas rely on the combined use of surface water and groundwater, SAT appear as a promising option for integrated water resource management. • It allows reclaimed water such as treated blackwater, greywater or stormwater not to be just discharged into other surface waters, but also reused as water for irrigation in agriculture or to intentionally recharge groundwater aquifers via MAR. • SAT implies a better knowledge on the use of natural systems in its entirety
AOP + SAT	• Further research should also be promoted to analyse the real toxicology of cocktails (effect of all by-products as a whole, not one by one studies). • Legislation and public acceptance of re-used water;	• Many development opportunities for AOP SAT schemes in a context of increased contamination of water effluent. • AOP SAT scheme appears as a highly effective treatment for the removal of organic contaminants from water and could apply to small and medium facilities if the technological aspects can be simplified in the future. • Highly populated areas with difficulties for (tap) water supply.
Struvite	• Competition with primary fertilizers could jeopardize its market development. • Legislation and public acceptance of re-used water; • Indecisive policies and non-reliable regulation could also hamper investment significantly. The downstream use of recovered nutrients still need to be harmonised, a regulation would be needed at this level.	• Phosphorus is considered as a critical raw material by the EU since 2014 as its availability has been identified as a globally relevant bottleneck for fertiliser and food supply. Europe has an import dependency above 90% with regards to mineral phosphorus. • Strong potential for new WWTP treatment schemes with integrated nutrients recovery steps • As to municipal wastewater, they represent a relevant phosphorus reserve and have the potential to cover about 20% of the demand.

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9 Annexes

9.1 Annex 1. Participants

DOW®	VEOLIA	PUB Water for All: Conserve, Value, Enjoy
KWR Watercycle Research Institute	bioprocessH2O a CLARCOR company	KOMPETENZZENTRUM Wasser Berlin
Cranfield UNIVERSITY	UB Universitat de Barcelona	Fiordelisi
MEKOROT ISRAEL NATIONAL WATER CO.	Abwasserverband Braunschweig	WssTP The European Water Platform
NuReSys	IWVA Kring-Lopend Water is ons Ambacht	acciona Agua
WATEREUSE ASSOCIATION Sustainable Solutions for a Thirsty Planet	NETWORK FOR WATER IN EUROPEAN REGIONS AND CITIES netwerch2o	A NEW STANDARD IN WASTE WATER TREATMENT verdygo

9.2 Annex 2. Example of the Questionnaire sent to Water Reuse Treatment Scheme Operators

<table>
<tr><th>Question</th><th>Answer</th></tr>
<tr><td>What is the current reuse application of your treated water?</td><td></td></tr>
<tr><td>What is the m3/day of water available for reuse?</td><td></td></tr>
<tr><td>Which technologies are you currently using to treat the water for reuse?</td><td></td></tr>
<tr><td>Do you know about any other sites/companies using this technology? Please be specific (number and name)</td><td></td></tr>
<tr><td>Do you plan to use any other technologies in the future? If so, why?</td><td></td></tr>
<tr><td>Did you specifically choose to use this technology for water reuse, if so, why? If not, please explain why not.</td><td></td></tr>
<tr><td>What are the unique advantages of this technology?</td><td>
<table>
<tr><th>Advantages</th><th>Yes/No</th></tr>
<tr><td>Technologically it achieves our quality requirements</td><td></td></tr>
<tr><td>Lower CAPEX costs compared to other technologies</td><td></td></tr>
<tr><td>Lower Opex Costs</td><td></td></tr>
<tr><td>Low Maintenance costs</td><td></td></tr>
<tr><td>It opens up new possible revenue streams (product recovery, new reuse customers…). Which?</td><td></td></tr>
<tr><td colspan="2">Another reason, please explain</td></tr>
<tr><td colspan="2"></td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>For how long have you been using this technology?</td><td></td></tr>
<tr><td>Where did you buy the technology from? What were the approximate costs of implementation and operation?</td><td></td></tr>
<tr><td>Would you like to use another type of Technology? If so, which technology would you like to use, and why would you choose that technology?</td><td></td></tr>
<tr><td>What would force you to use a new type of technology?</td><td>
<table>
<tr><th>Advantages</th><th>Yes/No</th></tr>
<tr><td>To reduce CAPEX costs</td><td></td></tr>
<tr><td>To reduce OPEX costs</td><td></td></tr>
<tr><td>You need to reduce your maintenance costs on the current technology</td><td></td></tr>
<tr><td>Changes in legislation, increasing the quality requirements</td><td></td></tr>
<tr><td>New clients that would need to use reclaimed water</td><td></td></tr>
<tr><td>Technology has advanced and you want to improve your treated product</td><td></td></tr>
<tr><td>If you had a new use for your treated wastewater</td><td></td></tr>
<tr><td colspan="2">Another reason, please explain</td></tr>
<tr><td colspan="2"></td></tr>
</table>
</td></tr>
<tr><td>Are you using any of the by-products? If so, how are you using those by-products exactly (e.g. sales, given free to farmers, etc)?</td><td></td></tr>
</table>

9.3 Annex 3. Example of a Questionnaire sent to the Water Reuse Experts

WP4: Benchmark of technologies

Questions to Simon Judd

Anaerobic Membrane bioreactor

Questions	Answers
Market overview	
How mature is this technology? For how many years has AnMBR been available?	
How many treatment plants worldwide, that you are aware of, are currently using AnMBR for WWT?	
In your estimation what is the size of the actual market of AnMBR for WWT in Europe?	
What is your estimation of the share between AnMBR onsite industrial treatment vs AnMBR treatment at centralised wastewater treatment plants?	
Which countries/regions appear to be the most promising markets for AnMBR? Please Explain why.	
Are there new market trends for AnMBR?	
Please list the main challenges to further technology development or application	
Please list the principal opportunities for the development of this technology in your opinion	

Forward Osmosis MBRs (FO MBR)

Questions	Answers
Technical Characteristics	
How mature is this technology? Please Elaborate	
What are the main limitations of this technique?	
Market overview	
Are there currently any plants worldwide that are using this technology?	
Are you aware of any FO MBR manufactures worldwide?	
What kind of investment does this system represent compared to (MF/UF) MBR scheme?	
Would there be high operational costs? Please Elaborate	
What is your estimation of the potential size of the actual market of FO MBR scheme for WWT?	
What would be the principle use of FO MBR? Modular Urban Wastewater treatment? Industrial treatment? Etc.	
Which countries/regions appear to be the most promising markets for FO-MBRs in WWT? Please Explain why.	
What are the market trends for FO MBR (FO MBR) scheme?	
Please list the main challenges to further technology development or application?	
Please list the principal opportunities for the development of this technology in your opinion?	

9.4 Annex 4. Example of a Questionnaire sent to Technology Suppliers

WP4: Benchmark of technologies

Questions to NuReSys

Struvite crystallization

Questions	Answers
Technical Characteristics	
Can we consider Struvite as a mature technology for Waste Water Treatment?	
Questions	Answers
Market overview	
Do you know how many sites globally (and in Europe) that use Struvite crystallization at WWTW?	
What are the investments needed? (CAPEX) for scheme operators	
What are the Operational costs (OPEX) for scheme operators?	
Is there any estimation of the size of the actual market of Struvite crystallization worldwide?	
Is there any estimation of the size of the actual market of Struvite crystallization in Europe?	
Are there geographical tendencies: which countries/regions appear to be the most promising markets for Struvite crystallization? Please Explain.	
Please list the main challenges to further technology development or application?	
Please list the principal opportunities for the development of this technology in your opinion?	