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Membrane technologies for water applications

Highlights from a selection of European research projects

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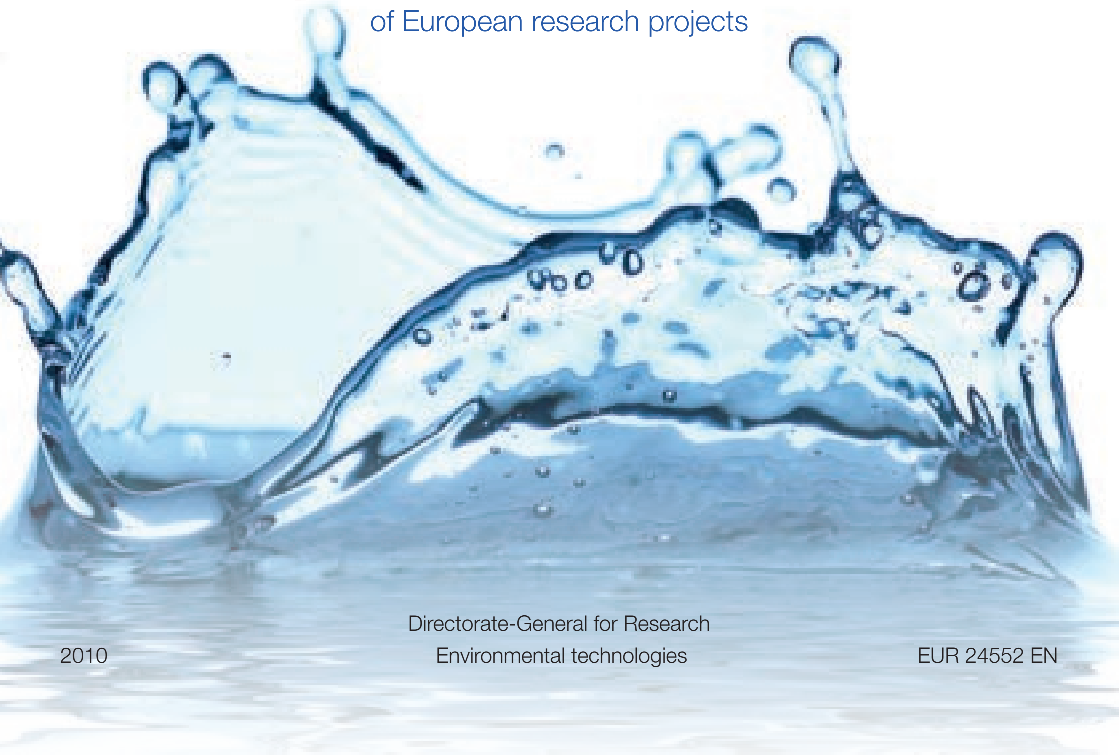
Membrane technologies for water applications

Highlights from a selection of European research projects



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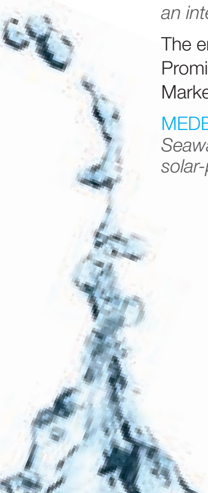

Water: a grand challenge for EU research

As an essential resource for life, sustainable growth and healthy ecosystems, water has been high on the European research agenda since the early years of the Community's research, technological development (RTD) Framework Programmes (FPs).

Increasing population numbers, a changing climate, intensive agricultural practices, economic growth and urbanisation will undoubtedly continue to make the issue of water scarcity a global priority for years to come.

With average economic growth, the 2030 Water Resource Group reports that the worldwide water supply-to-demand gap is likely to reach approximately 40% by 2030 unless significant efficiency gains can be made. The Intergovernmental Panel on Climate Change (IPCC) predicts that by the year 2050, around 60% of the world's population could experience severe water shortages, with 33% thought to be already under stress. In Europe, competing demands for limited and sometimes over-exploited water resources concern more than a few Member States: water scarcity and droughts already affect one third of the EU territory across different latitudes.

Tackling the water gap challenge while achieving good status of all water bodies in Europe – as targeted by the EU Water Framework Directive (Directive 2000/60/EC) for 2015 – will require a transformation of the sector based on the combination of new technological, organisational and management approaches to supply, conservation, reuse and recycling in agricultural, industrial, urban and domestic contexts.

As part of the solution, **membranes for water applications** – the focus of this publication – are arousing great interest as potentially cost-effective answers to a growing range of purification and separation needs.

A series of Community research projects administered by the European Commission's Research Directorate-General (DG Research), under the Environment Theme of the RTD Framework Programmes has investigated and tested new membrane technologies from lab-scale to full-scale for municipal and industrial wastewater treatment, as well as for drinking water production by routes including the desalination of seawater and brackish water.

These have adopted a holistic problem-solving stance, typically involving large-scale collaborative and multidisciplinary efforts to innovate at the interfaces between membrane technologies and other fields such as biotechnology, advanced materials, nanotechnologies, information communication technology (ICT) and low energy processes.

The following pages outline some of the notable successes to date, and consider the future directions for research and development (R&D) and their translation into exploitable innovations.

Dr Andrea Tilche, Head of Unit
Dr Michel Schouppe, Scientific Officer
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Unit I.3 'Environmental Technologies and Pollution Prevention'

Why membrane separation for water?

Membrane filtration technologies form a promising avenue of research and innovation being pursued by Europe to provide effective and lasting solutions for adequate supplies of water of suitable quality to meet human, environmental and industrial needs.

Traditional water treatment methods include physical separation techniques for particle removal; biological and chemical treatments to remove suspended solids, organic matter and dissolved pollutants or toxins; and evaporative techniques and other physical and mechanical methods. Membrane separation replaces or supplements these techniques by the use of selectively permeable barriers, with pores sized to permit the passage of water molecules, but small enough to retain a wide range of particulate and dissolved compounds, depending on their nature.

Already used for niche applications, usually involving high-value liquid streams, membrane filtration was introduced in drinking water treatment in the 1950s, mainly for desalination of seawater, brackish

water and groundwater. Since that time, advances in materials, system designs and process combinations have opened the door to affordable implementation in more aspects of the overall water cycle, including production of drinking and process water; industrial process and wastewater treatment; municipal sewage treatment; product recovery from aqueous streams; water loop closure; and treatment of groundwater, agricultural waste streams and percolation waters.

Matching the application

Membrane filtration processes are classified according to the membrane pore sizes, which dictate the size of the particles they are able to retain (see table).

The membranes are made from materials such as thin organic polymer films, metals or ceramics, depending on the application. They are manufactured in different forms such as hollow fibres or flat sheets, which are incorporated into housing modules designed to produce optimal hydrodynamic conditions for separation. Complete systems comprise arrangements of modules, together with the interfaces and control systems needed to integrate them into the various process configurations.

Multi-stage treatment

Purification typically begins with a pre-treatment stage to remove contaminants that would otherwise affect the downstream equipment. Methods such as activated carbon filtration may be used for chlorine removal, cartridge or deep-bed filters for particle removal, and softening agents to remove minerals that cause hardness in the water.

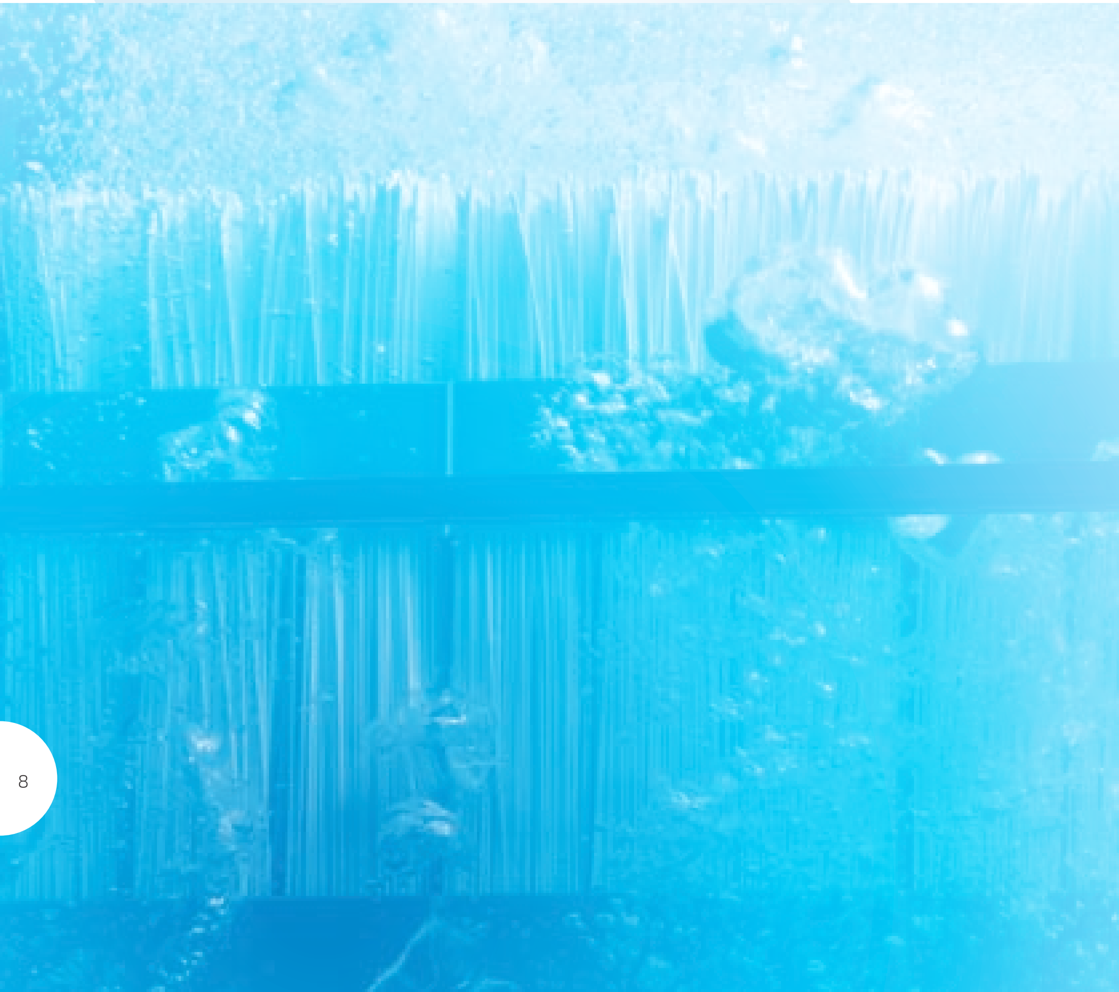
Following the membrane filtration, 'polishing' systems can be employed to deliver ultra-pure water by removing trace levels of any residual contaminants. Post-treatment can also be enhanced by the addition of

Filtration class	Particle capture size	Typical contaminants removed	Typical operating pressure ranges
Microfiltration (MF)	0.1-10 µm	suspended solids, bacteria, protozoa	0.1-2 bar
Ultrafiltration (UF)	ca.0.003-0.1 µm	colloids, proteins, polysaccharides, most bacteria, viruses (partially)	1-5 bar (cross-flow) 0.2-0.3 bar (dead-end and submerged)
Nanofiltration (NF)	ca.0.001 µm	viruses, natural organic matter, multivalent ions (including hardness in water)	5-20 bar
Reverse osmosis (RO)	ca.0.0001 µm	almost all impurities, including monovalent ions	10-100 bar

ultraviolet (UV) radiation or other features to suit specific circumstances.

Although some membrane systems incur higher capital or operational costs than conventional processes (such as evaporation, deep-bed filtration or chemical treatment), they are generally able to achieve superior product water quality, while imposing a smaller footprint at plant level.

▼ *Membrane air scouring*



Problems to be overcome

Membrane performance is generally defined in terms of two factors:

- **Flux** – the amount of water passing through the membrane per unit of time and surface area. This has a strong impact on the capital costs of the process and hence influences the economic feasibility.

- **Selectivity** or **retention** – the concentration ratio of a component between the filtered 'permeate' and the input feed water, which is a main determinant of the technical feasibility of a process.

Reductions in separation efficiency are mainly due to two effects: **concentration polarisation**, caused by a concentration increase near the membrane surface, and **membrane fouling**. Fouling is the greater problem; its remediation is thus the focus of much research effort.

Fouling results from complex phenomena linked to the deposition of components at the surface and inside the pores of the membrane. Major fouling phenomena are particulate and colloidal fouling, scaling (precipitation of inorganic salts), bio-fouling and adsorption. Methods to reduce these effects include pre-treatment of the feed solution, judicious selection of membrane material, appropriate setting of operational parameters and the use of turbulence promoters.

Growing research support

Water research has received considerable attention in the European Commission's RTD Framework Programmes since the 1980s, with EU-funded research covering a broad area embracing:

- ecological quality assessment and aquatic ecosystems functioning;
- social, environmental and economic aspects of integrated water resource management;
- mitigation of global change impact on water resources;
- the definition of environmental quality standards and objectives to support EU legislation.

Since the adoption of the Environmental Technologies Action Plan (ETAP) in January 2004, new emphasis has been put on water technologies for supply and sanitation, pollution prevention and monitoring and surveillance, with a view to fostering eco-innovation and contributing to the Lisbon objectives of sustainable growth and European competitiveness.

From the start of FP6 (2002-2006), the thrust of membrane studies has been to develop, integrate and validate technological solutions with a potential for up-scaling from micro to macro level. The ultimate objective was to reach maturity in terms of cost-effectiveness in various operational water treatment contexts, as well as appeal to public and private customers.

A round of FP6 Calls for Project Proposals, published in 2004 under the Global Change and Ecosystems Priority, included three topics of specific relevance to membrane separation technologies:

- integrated urban water management within the context of global change in Europe and developing countries;

- advances in membrane bio-reactor technologies for municipal wastewater treatment;
- technologies and systems for drinking water production and distribution.

In 2005, a further Call under that same FP6 Priority added two more subject areas:

- new concepts and processes in wastewater treatment;
- advances in desalination.

Under the subsequent FP7 (2007-2013), a joint Call in 2008 between the Environment and NMP (Nanosciences, Nanotechnologies, Materials and new Production Technologies) Themes specifically addressed:

- Nanotechnologies for water treatment.

Although membranes for water applications have also been the subject of more recent FP7 Calls under the Environment and NMP Themes, this brochure looks particularly at more mature projects resulting from the above Calls of the period 2004-2008.

European Technology Platform guides strategy

In order to steer continued development of the water technologies necessary to realise Europe's sustainable growth and competitiveness goals, FP6 also fostered the establishment of the Water Supply and Sanitation Technology Platform (WssTP – http://www.wsstp.eu/site/online/home). This is one of several European Technology Platforms (ETP) created soon after the launching of ETAP. The Platform is led by industry and consists of a partnership of all major European stakeholders in the water technology sector: manufacturers, water utilities, research institutes, universities, consultant engineering companies and large water users.

To achieve its goals, WssTP set out to define a vision and Strategic Research Agenda (SRA) for future research and innovation. The first version of the SRA (October 2005) formed a major input to the FP7 Call.

In 2010, the priorities were updated following extensive stakeholder consultations. The latest revision underlines the need for cross-cutting research topics, such as 'Climate Change', 'Sensors and Monitoring', 'Water and Energy' and 'Millennium Development Goals'. Its integrated approach considers research on water technologies in a social and economic context across all users and their supply chains.

Membrane bioreactors for wastewater treatment

Membrane bioreactors (MBRs) represent a mature technology for industrial wastewater treatment. Ongoing research to improve system designs and reduce energy consumption is making them an increasingly attractive option for municipal applications.

MBR technology combines biological activated sludge processes with MF/UF (microfiltration/ultrafiltration) membrane separation for biomass retention in the treatment of industrial wastewaters and municipal sewage. The membrane provides an effective barrier to suspended solids and can replace conventional secondary clarification and potential tertiary sand filtration.

Technology transition

MBR technology was first commercialised in the 1970s and 1980s for specialist applications such as the treatment of ship-board sewage, landfill leachate and highly loaded industrial effluents. At that time the systems were based on cross-flow membranes installed in units placed outside the activated sludge tank and equipped with high-flow circulation pumps. These required high energy to generate sufficient feed velocities across the membrane surface, so they were considered uneconomical for treating municipal wastewater.

Schilde hybrid MBR-CAS plant

More recently, a new generation of 'immersed' systems emerged, with the membrane units submerged in the activated sludge tank itself and working at a low transmembrane pressure difference. These are less costly to install and operate, making the technology more viable for the treatment of both municipal and industrial wastes.

Other advantages over conventional processes include a small footprint, easy retrofittability for the upgrade of old treatment plants, complete solids removal, effluent disinfection, operation at higher suspended biomass concentrations (resulting in long sludge retention times), low sludge production and no problems with sludge bulking.

The fact that aeration, necessary for biological sludge degradation and membrane scouring, accounts for approximately 80% of the total energy demand continues to be seen as a limiting factor – but ongoing research is eroding the cost barriers to MBR.

Research targets municipal take-up

A survey of the European MBR market conducted in 2005 by the Berlin Centre of Competence for Water as part of the AMEDEUS project confirmed the near-total predominance of immersed MBR, which accounted for 99% of the membrane surface area installed over a 3 year period.

From a start-up in the late 1990s, the number of MBR installations increased rapidly and was forecast to reach about 700 installations in 2009, of which one third would be for municipal applications. Moreover, the average capacity of municipal plants was found to be 10 times greater than that of industrial units, with respective median flow rates of 2 500 m^3/d and 180 m^3/d.

While the industrial market can now be considered as mature and stabilised, the municipal market is expected to witness further growth over the next few years, with an acceleration of plant construction and increasing capacities. In the period from 2003 to 2005, it was found to represent 75% of market volume – and the survey foresaw a short-term prospect for an additional 70 MBR plants annually.

Research launched under FP6 therefore focused on stimulating advances in the process engineering aspects of municipal plants, aiming to reduce both capital investments and operating costs, e.g. through the increase of permeate fluxes, extension of membrane life-times, minimisation of the need for chemical cleaning and optimisation of energy-efficiency.

Thanks to several research efforts, notably at Community level, the technology of aerobic submerged MBR is becoming acknowledged as the best available technology for wastewater treatment, especially where high effluent qualities are required and when water recycling is an option. A clear trend can be observed of MBR technology becoming competitive at much larger scales, as illustrated by the biggest plant so far (in Brightwater, USA), which will have a capacity of 495 000 m^3/d when it is commissioned in 2010/2011.

Challenge for Europe

The challenge for AMEDEUS and its fellow projects EUROMBRA, MBR-TRAIN and PURATREAT, which together make up the MBR network, was to build European expertise in MBR as a foundation for renewed competitiveness in a global membrane market that is currently in the hands of a few non-European manufacturers.

Together, the 4 initiatives united the resources of 50 European and international companies and institutions in generating new knowledge and achieving significant technological breakthroughs. All aspects of MBR were covered: membrane fouling characterisation and monitoring, membrane fouling control and cleaning, process modelling and control, novel European MBR technologies, process integration and new processes, economics and market studies and full-scale implementations.

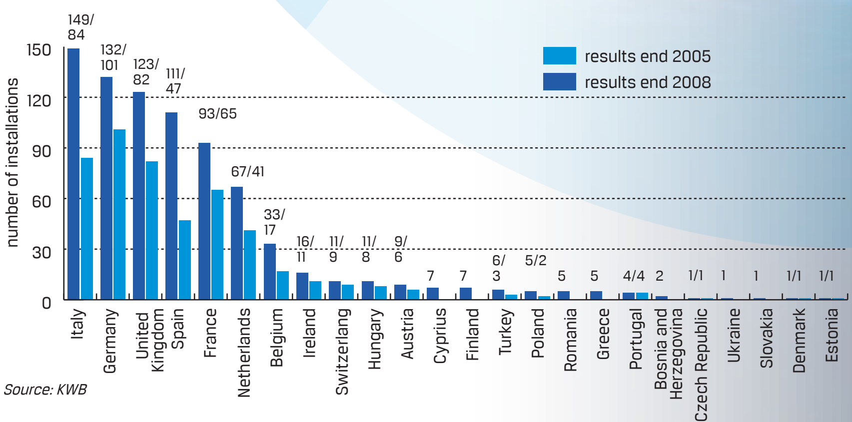
Dissemination drive

In order to maximise the integration of results across their projects, the partners created six liaison groups to facilitate exchanges and discussions, both between themselves and with external specialists on selected topics.

A shared website (http://www.mbr-network.eu) launched in 2006 provides a common portal giving details of the projects and also serves as a valuable information source for others with interests in MBR. The site includes reports, articles, news, events and a regularly updated literature survey covering all related matters. In August 2009, after 3 years of operation, it counted over 1 000 members representing more than 70 countries.

To encourage the entry of new competitors in the MBR market and aid acceptance of new MBR modules and systems, AMEDEUS published a White Paper on the establishment of common standards for MBR technology in Europe. After discussion and endorsement by the industry, this has formed the basis for initiation of a formal procedure of standardisation together with the Centre Européen de Normalisation (CEN).

Geographical distribution of MBR market in Europe



Source: KWB

AMEDEUS

Accelerate membrane development for urban sewage purification

AMEDEUS sought to reduce the capital and operating costs of MBR technology and to minimise its environmental impact in order to make it more competitive for municipal wastewater purification.

A model of the biological process was used to evaluate design concepts and operating parameters.
Individual developments included dual MBR/activated sludge configurations, recommendations on submerged filtration module positioning, new chemical cleaning techniques, online sensors and an advanced control system.

Turnkey containerised MBR units were engineered for small communities of 50 to 2 000 persons, while a further study examined the potential for retrofits to larger plants.

More information:
http://www.mbr-network.eu

▼ *Schilde hybrid MBR-CAS plant*

EUROMBRA

Membrane bioreactor technology (MBR) with an EU perspective for advanced municipal wastewater treatment strategies for the 21st century

Working in close collaboration with AMEDEUS, EUROMBRA proposed improvements in MBR system configurations based on detailed studies into the influence of factors such as reactor geometry, the hydrodynamics and placement of membrane modules and the overall operating parameters.

Because fouling is an inherent phenomenon in all membrane filtration systems, the partners conducted an in-depth investigation ranging from the characterisation and monitoring of key foulants, to the mechanisms of fouling and the degree to which it can be predicted.

Aeration as a key operating parameter for fouling mitigation was also thoroughly explored, as were strategies for membrane cleaning and chemical waste management.

A model relating feedwater quality to cost for specific membrane configurations is available as a freeware spreadsheet package on the MBR Network website.

More information:
http://www.mbr-network.eu

Photograph of bench scale flat-sheet MBR pilot plant for laboratory studies ▶

Advances in membranes for desalination

Although the oceans hold Earth's most abundant reserves of water, their desalination remains too energy-hungry for universal adoption. However, membrane technologies are becoming increasingly competitive, and new research continues to lower the cost barrier.

The original method for large-scale desalination of seawater by collecting the condensed vapour after thermal evaporation (boiling) demands a very high energy input. Its initial use in the 1950s and 1960s was therefore confined to desert areas, mainly in the Middle East, which lacked water but had ample stocks of fuel to burn.

Even with subsequent efficiency improvements, advances in heat recovery and the use of concentrated solar energy, process costs have remained too high – although the gap is narrowing.

Scientists in the 1940s first realised that, with the application of sufficient pressure, it was possible to reverse the natural process of osmosis (in which a solvent flows through a semipermeable membrane from a dilute solution to a more concentrated one until pressure equilibrium is reached). Thus, reverse osmosis (RO) was born and by the 1970s it began to be incorporated into new desalination plants.

The development of thin-film composite membranes and optimised module hydrodynamics has since improved performance and reduced capital and operating costs to the point that, since the 1990s, RO has become the fastest growing method of seawater desalination. It is now a viable option even for applications such as the desalination of marginal or brackish groundwater, for which it would not previously have been considered.

Despite this, research continues to look for more improvements in terms of water quality, recovery rates, unit water cost and mitigation of the environmental and economic difficulties associated with concentrated brine disposal.

A good example of research covering the end-to-end integration of RO is the FP6 project MEDINA, which carried out a study embracing:

- the characterisation of saline feed waters;
- the effects of different pre-treatment sequences on the efficiency of RO and its propensity to fouling;
- new membrane materials and module designs;

- the relative effectiveness of membrane cleaning protocols;
- post-treatment methods for reducing brine effluent volumes and increasing salt recovery.

The activities also included environmental and life-cycle assessments to inform designers, regulators and decision makers about the benefits of fully integrated membrane desalination systems.

MEDINA

Membrane-based desalination: an integrated approach

In MEDINA, a range of analytical tools was deployed to evaluate seawater and brackish water qualities as the starting point for selection of the most appropriate integrated RO-based treatment sequences. Comparison of various pre-treatment combinations showed that MF/UF without use of coagulants or adsorbents could be effective, but led to higher organic fouling of the RO module. MBR offered a means to reduce organic content and limit the fouling potential.

With the aid of computational fluid dynamics, optimisation of the membrane module characteristics further increased mass transport rates, limited fouling/scaling tendencies and lowered the energy demand. Methods tested to improve salt extraction and water recovery from process effluents included membrane crystallisation, wind-assisted evaporation and vacuum membrane distillation (VMD). A semi-industrial scale VMD plant using solar collectors has been constructed in Tunisia.

More information:
http://medina.unical.it/

Wind-aided intensified evaporation (WAIV™) was used by the MEDINA project for treating reverse osmosis desalination brine. Brine is pumped over large arrays of vertically mounted surfaces packed in a small area so that wind blows across the vertical surfaces to evaporate the water. More concentrated brine is collected at the bottom. The illustrated unit was constructed near the Dead Sea in Israel under licence of technology from Ben Gurion University of the Negev. WAIV is registered trademark by Lesico Ltd.

The energy dimension

In recent years, the drive to save energy has given rise to hybrid desalination systems combining RO with thermal technologies, such as multi-stage flash and multi-effect distillation.

These hybrid systems have been applied in a number of existing and new commercial desalination plants, which are often sited alongside power stations where they are able to utilise a portion of the plants' waste heat output for their processes.

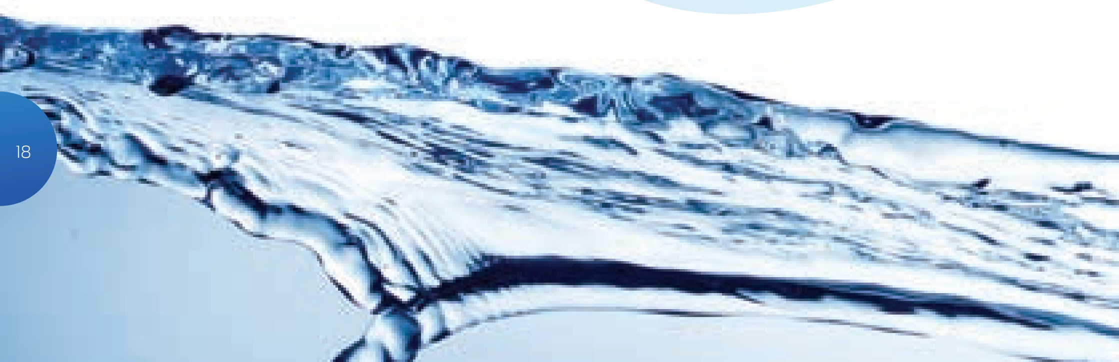
Pre-treatment by nanofiltration (NF) has also been shown to reduce the formation of mineral scale deposits from the seawater, allowing high temperature operation of the thermal processes and further increasing water productivity.

Another interesting line of research focuses on salinity gradient power (SGP) production. This technology exploits the ability to convert the osmotic pressure difference between solutions of differing salinity into mechanical or electrical energy.

Promising new technique

Under FP6, the MEDESOL project took up the examination of membrane distillation (MD), a technique that combines membrane technology and evaporation processing in a single system. The appeal of MD is that it functions at atmospheric pressure and requires only relatively low feed temperatures of 70º-90ºC. Prior to this initiative, industry's interest in MD had been limited due to the low productivity obtainable with current membrane systems. MEDESOL's proposed remedy was to develop an innovative multi-stage distillation process using commercially available MD modules powered by solar energy. The results fell somewhat short of expectations, as even the state-of-the-art modules supplied to the partners were unable to match the required performance levels. There are nevertheless clear indications that the multi-stage concept has significant potential for further improvement.

As mentioned above, MEDINA also considered the use of MD, among other methods, to recover more of the salts from the brine, which reduces the ecological impact and provides a source of revenue to offset the treatment costs.



Market growth

Forecasters see a bright future for membrane separation in general, and MD in particular. A 2010 Desalination Market survey by Global Water Intelligence (GWI) notes that 'three areas of new technology are likely to be the focus of commercialisation over the next four years. These are: improved membrane materials (both nano-engineered and biomimetic), forward osmosis, and membrane distillation. Improved membranes are very much a continuation of the kind of technology development we have seen over the past 45 years in desalination. Forward osmosis and membrane distillation represent new paradigms. They face two challenges: one is overcoming the innate conservatism of water customers, and the other is finding a business model which fits the existing market'.

There is no doubt that the challenge will be worth taking up. The collapse of the market following the recent global financial crisis cast doubts on earlier estimates, but GWI still expects an average growth of 10% pa until end-2013. With much activity centred around the Mediterranean rim, Europe is well placed to win a share.

MEDESOL

Seawater desalination by innovative solar-powered membrane-distillation system

With the goal of developing more affordable desalination technology to supply fresh water in arid and semi-arid regions of the EU and third countries, MEDESOL designed and produced prototypes for a multi-stage membrane distillation system powered by an advanced parabolic solar concentrator. The concept was that heated water from each stage would contribute energy to the following stage, while the collected permeate could serve as a condensing coolant.

While distillate production rates with proprietary MD modules were below the levels required to permit further scale-up, the partners made valuable progress in the performance of concentrators and heat exchangers. Technical and economical feasibility studies for industrial, small-capacity and stand-alone systems were also completed.

More information:

http://www.psa.es/webeng/projects/medesol

Nanotechnologies for water treatment

In addition to nanofiltration itself, nanotechnologies' contribution to water purification include the modification of membrane characteristics with nanomaterials and processes that fine-tune performance for specific pollutant types or improve resistance to fouling.

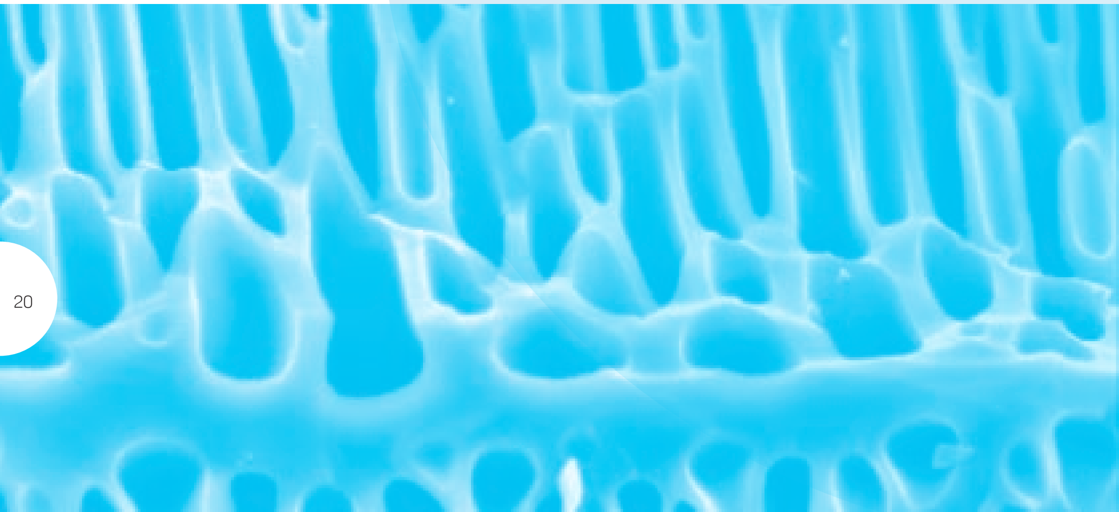
Nanofiltration (NF) for water purification was first introduced in the 1970s, and the introduction of thin film composite membranes triggered rapid growth through the 1990s.

NF finds application in polishing at the end of conventional processes. It cannot be used alone for seawater desalination, but is an effective means of softening as the main contributors to hardness are divalent ions. NF is also capable of separating bacteria, viruses, pesticides, other organic contaminants and disinfection residuals, making it a very cost-effective option for producing drinking water from impaired surface and ground water sources.

Because multivalent ions are retained and monovalent ions are not, NF membranes can be tailored to specific applications. In fact, their ability to selectively remove problematic compounds and ions while retaining some hardness in the permeate is a desirable property for many municipal applications, since this makes the water less aggressive to distribution piping materials.

Many sectors of the industry – chemicals, pharmaceuticals, paper, foodstuffs etc. – also use NF for closing the water loop, improving process yields and recovering valuable compounds from waste streams.

SEM cross-section of a Hollow fiber membrane used in Reverse Osmosis_2



Wider role for nanotechnologies

More ways in which nanotechnologies can play a role in water treatment are the functionalisation of MF and UF membranes by engineered nanoparticles deposited on their surfaces or embedded into the matrices, and the use of nanomaterials to bind specific contaminants or catalyse degradation reactions.

Examples of the former include the incorporation of nanosilver (Ag) into filters to gain anti-microbial properties, and of titanium dioxide (TiO_2) to degrade retained compounds reactively. TiO_2 nanoparticles also show photocatalytic effects; when exposed to UV radiation, they are capable of decomposing many different organic compounds.

A number of FP7 projects launched following a Joint Call in 2008 between the Environment and NMP Themes are grouped into the NANO4WATER cluster (http://nano4water.eu/), which is pursuing research into these areas. The membrane development projects are mainly utilising known nanomaterials such as carbon nanotubes, TiO2 and Ag to modify membranes (CLEANWATER, NAMETECH, NEW ED). Molecular imprinting is another method being evaluated for the design of membranes with defined retention capacities by creating molecule-specific receptor sites (WATERMIM).

CLEAN WATER

Water detoxification using innovative vi-nanocatalysts

To eliminate highly toxic chemicals that can pose serious health hazards even when occurring at very low concentrations in drinking water, CLEAN WATER is investigating the use of membrane reactors incorporating doped titanium oxide (TiO_2) photocatalysts activated by sunlight.

The nanostructured catalysts are stabilised on nanotubular membranes or carbon nanotubes, exploiting their high surface area and unique electron transport properties to achieve high levels of photo-activation.

Comparative evaluations of the UV-visible and solar light efficiency of the process focus mainly on the cyanobacterial toxin MC-LR and endocrine-disrupting compounds, as well as on classical pollutants such us phenols, pesticides and azo-dyes. The final goal is to scale up the technology for application in lakes, tanks and continuous flow systems for public water distribution.

More information:

http://www.photocleanwater.eu

NAMETECH

Development of intensified water treatment concepts by integrating nano- and membrane technologies

NAMETECH is following two distinct routes to process intensification to produce nano-activated membranes (NAM) via the addition of nanoparticles:

1. Incorporation of particles such as Ag and TiO_2 (which have anti-bacterial properties) into UF membrane structures to reduce fouling, leading to enhanced flux.

2. Adaptation of UF membrane structures to improve micro-pollutant removal and detoxification.

Main expected advantages include:

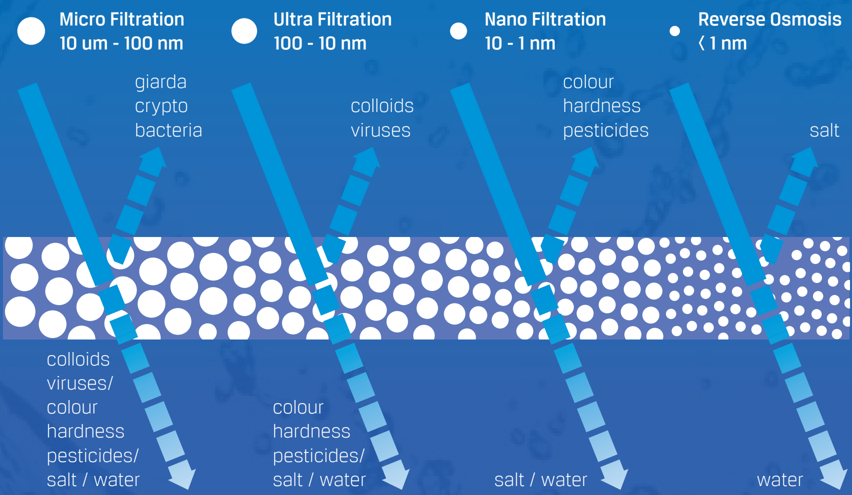
- a reduction of biofouling of the membranes, reducing the use of cleaning chemicals and improving stability over time;
- improved mechanical properties and resistance (increased porosity, together with reduced breakage and abrasion damage);
- better flux control and extended cleaning intervals.

All developed NAMs are being tested at laboratory scale before selecting the most promising for pilot trials, complemented by a toxicological study and life-cycle analysis to assess all environmental impacts. At the end of the project, one or more NAMs will be proposed for the production of drinking water and/or process water.

More information:

http://nametech.eu/

▼ *Norit principle pressure driven filtration processes*



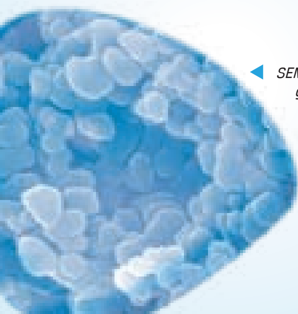
NEW ED

Advanced bipolar membrane processes for remediation of highly saline wastewater streams

NEW ED is striving for cost-performance breakthrough in the relatively new process of bipolar membrane electrodialysis (BPMED), or 'water splitting', which produces acids and bases from their corresponding salts without requiring the addition of chemicals.

BPMED is based on membrane stacks comprising bipolar ion exchange membranes in conjunction with cation- and anion-exchange membranes, in which the separation of ions is driven by the application of a direct electrical current. The absence of electrochemical transformations makes this an energy-efficient process. It is also less subject to fouling than conventional systems, minimises the generation of by-products and avoids costly downstream purification steps.

The great interest of industry in this project and its products can be seen in the participation of the two large industrial end-users Bayer Material Science, Germany, and Prayon S.A., Belgium, in the consortium. The value lies in the possibility of exploiting the salt content of waste streams by transforming them into valuable recoverable products, while also conferring the environmental benefits of water recycling and minimal effluent discharge. But the feasibility of BPMED for large-scale applications has so far been constrained by shortcomings in the available membrane and process technologies.



SEM image focusing on the g-alumina layer of a ceramic nanofiltration membrane

To make BPMED economical enough for processing large industrial waste volumes, higher current densities and greater product purity must be realised. NEW ED is aiming to achieve these goals by developing a new type of bipolar membrane featuring a revolutionary water transport concept.

Novel materials and material combinations are being investigated, together with the necessary manufacturing and module design concepts. Integration and scale-up of these advances will be essential elements of a thorough evaluation, intended to make this a key technology for the treatment of highly saline waste streams stemming from a broad range of industrial production processes.

The outcomes should enable end-users in the chemicals sector, in particular, to make their processes greener and more resource-efficient – thus securing the sustainability of European manufacturing plants.

More information:

http://www.new-ed.eu/

Weighing the risks

As industry moves ahead to take advantage of the new opportunities and prospects offered by nanotechnology, it is necessary to ensure that the developments take place in a safe and sustainable manner.

During the life-cycle of nanomaterials, workers and consumers can be exposed at various stages of production, processing, use and recycling or disposal – and sooner or later, nanoparticles may be released into the atmosphere or water system. Given the present knowledge gaps regarding possible health and ecological hazards, caution therefore needs to be exercised in deploying nanoparticles in the aqueous environment.

Several FP7 projects have been launched to study the 'cradle-to-grave' evolution of the chemical and physical properties of nanoscale materials, with particular emphasis on size-related particle characterisation, potential toxicological effects and acceptable exposure levels. A large data-gathering effort is required to assemble meaningful information on escape routes, degradability and mechanisms for transport, transformation and accumulation in living organisms. New strategies for the recycling of nanocomposites and the immobilisation of their nanocomponents must also be pursued.

Open discussion and information exchange between researchers, industries and communities will be vital to ensure global adherence to ethical and safe practices.

Process integration and life-cycle management

Integrated and coordinated water management strategies considering the full life-cycle from extraction to discharge or reuse offer the only sustainable long-term solution. In cities, especially, growing populations, industrialisation and urban sprawl are placing increasing pressures on authorities to become more environmentally responsible.

The variety of demands made on water supplies can only be met by reconciling diverse, and often conflicting, stakeholder interests. Integrated water management must thus consider three interrelated aspects: the availability and accessibility of the water itself in terms of both quantity and quality; its interactions with land and the environment; and the effects on social and economic development.

Complex interactions

More than half of the world's rising population already lives in cities, and growth over the next two decades is likely to take place very largely in urban areas. Municipal authorities thus face major challenges in delivering water and sanitation services to meet citizens' lifestyle expectations and in disposing of increasing volumes of wastewater while minimising negative impacts on the environment. In many cases, their task is rendered more difficult by ageing and deteriorating distribution infrastructures, which are costly to maintain and repair.

Making balanced and acceptable decisions about the level of need for intervention, the best available choices for action and the eventual consequences of their implementation requires the assembly of knowledge from many different disciplines – from the physical, social, economic and life sciences.

Enhancing the contribution of membrane separation to this process thus goes beyond the search for innovative technologies and the optimisation of individual processes. EU-funded research also addresses a wide spectrum of topics related to its assimilation onto the overall water treatment chain, from feed water quality monitoring to novel effluent quality upgrading and reuse strategies.

Combination technologies

Developing the most promising combinations of technologies and processes can set new standards for water treatment, as well as providing greater flexibility to offer sustainable tailor-made solutions to end-users, both for new installations and for the upgrading of existing plants.

Emerging systems use multi-membrane barriers or couple membrane separation with other biological, chemical or physical treatments to improve separation efficiency, deal with difficult contaminants, cut costs and energy consumption and boost ecological performance.

When the objective is to produce water of potable quality, for example, a multi-barrier approach links membrane filtration to a subsequent disinfection stage. And, as membranes can deliver higher water quality than conventional processes, they are often employed to upgrade wastewater by removing particulates (MF/UF) and dissolved substances such as salts and organics (NF/RO).

TECHNEAU

Technology enabled universal access to safe water

TECHNEAU takes a world view in considering the problems of resource shortages, emerging contaminants and ageing infrastructures. An exploration of technologies to protect against a broad spectrum of chemical and microbiological contaminants has shown promising results for ceramic MF/UF membranes in combination with coagulation for drinking water production.

The combination of a PAC (powdered activated carbon) pre-coat with ceramic membranes is being investigated, as are the fouling properties of the various membranes.

Online monitoring techniques are also under development to provide early warning of water quality threats such as malicious interference and deterioration in defective pipelines.

A third thread of research addresses predictive computer modelling for optimisation of existing water supply systems with respect to quality, reliability, environmental impact and cost.

More information:

http://www.techneau.org/

Winning ways with waste

Two parallel FP6 projects, NEPTUNE and INNOWATECH, have explored the application of sustainable combination techniques to municipal and industrial wastewater treatment, respectively.

The premise of NEPTUNE was that, while improving contaminant removal, modern sewage treatment plants can increasingly become providers of valuable renewable resources, ranging from biogas fuel to phosphates and biopolymers. The major objectives of the project were to shift wastewater treatment towards water reuse, from nutrient removal towards nutrient recycling, from energy optimisation towards energy production and emissions reduction, and from sludge disposal towards reuse of sludge and its constituents.

NEPTUNE

New sustainable concepts and processes for optimization and upgrading municipal wastewater and sludge treatment

NEPTUNE sought to transform sewage treatment from being an 'end-of-pipe' necessity to an interface between sanitation and environment, capable of yielding reusable resources for human and ecological activities – including reservoir replenishment, nutrient recycling and energy production.

Two new technologies were developed for the removal of persistent micropollutants such as pharmaceuticals, human care products and polymer additives. Ferrate (Fe(VI)) oxidation permitted the simultaneous removal of pharmaceuticals and phosphates, while the application of biogenic manganese oxides enabled pharmaceuticals to be removed by both chemical and biological mechanisms.

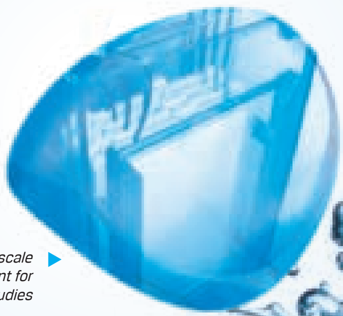
Phosphorus and heavy metal recovery with ultra-high-temperature pyrolysis, and biopolymer production from sewage were further techniques explored for sludge revalorisation.

Combining dynamic modelling with life-cycle assessment allowed the optimisation of a control strategy based on quality and cost targets.

More information:
http://www.eu-neptune.org

With a focus on industrial wastewaters, INNOWATECH researched the integration of membranes with aerobic sludge granulation, advanced oxidation and biological methods for process intensification and the elimination of expensive downstream polishing. Parallel activities addressed sectors such as the food, pesticides, pharmaceuticals and chemicals industries, with a view to proposing solutions having broad cross-sectoral application. Mature landfill leachates were also included, because their inherent treatment difficulty provided a 'benchmark' of process effectiveness.

When treating complex streams, the integration of biological, chemical and membrane treatments was shown to produce synergistic effects that generate cost savings and increased efficacy. By using solar light in photochemical reactors, chemical and energy savings were also achieved, without detriment to the effectiveness of the process for the treatment of wastewaters containing toxic pollutants such as pharmaceutical residues and pesticides



Photograph of bench scale flat-sheet MBR pilot plant for laboratory studies

INNOWATECH

Innovative and integrated technologies for the treatment of industrial wastewater

In its extensive investigation of industrial wastewater remediation, INNOWATECH examined technology combinations suitable for incorporation into customised solutions for diverse end-user sectors.

The coupling of advanced oxidation processes (AOP) with biological treatment was successful for the removal of bio-recalcitrants, while AOP plus MBR and ozonation proved comparable in performance to polishing (tertiary ozonation).

A key aspect of this work was the examination of membrane-based hybrid systems for process intensification. Two novel approaches were studied for the treatment of hazardous pollutants:

- a membrane chemical reactor combining a photocatalytic reactor with a membrane filtration unit to retain photoactivated TiO2 catalyst for the degradation of persistent organic pollutants;

- a membrane contactor, which incorporates a coated membrane for the reactive extraction of phenols with caustic soda.

Conceptual models of existing and new treatment systems permitted life-cycle cost comparisons of the investigated technologies.

More information:

http://www.innowatech.org

Cross-fertilisation

Alongside such technological progress, information dissemination, demonstration and user involvement are key activities of all projects to promote take-up of the best identified practices by public authorities, utility companies and other associated businesses.

With ready access to new knowledge, many small suppliers in Europe and developing countries that are currently lacking up-to-date treatment and surveillance systems could benefit by moving directly to the latest technologies, leap-frogging the methods of long established centralised facilities. The more flexible small plants could, in turn, share experiences with their large-scale counterparts.

Coordination is also important to eliminate wasteful duplication of research effort, and to avoid situations where an ad hoc solution applied in one geographical location can have unconsidered knock-on effects in others (e.g. for downstream users in shared river basins).

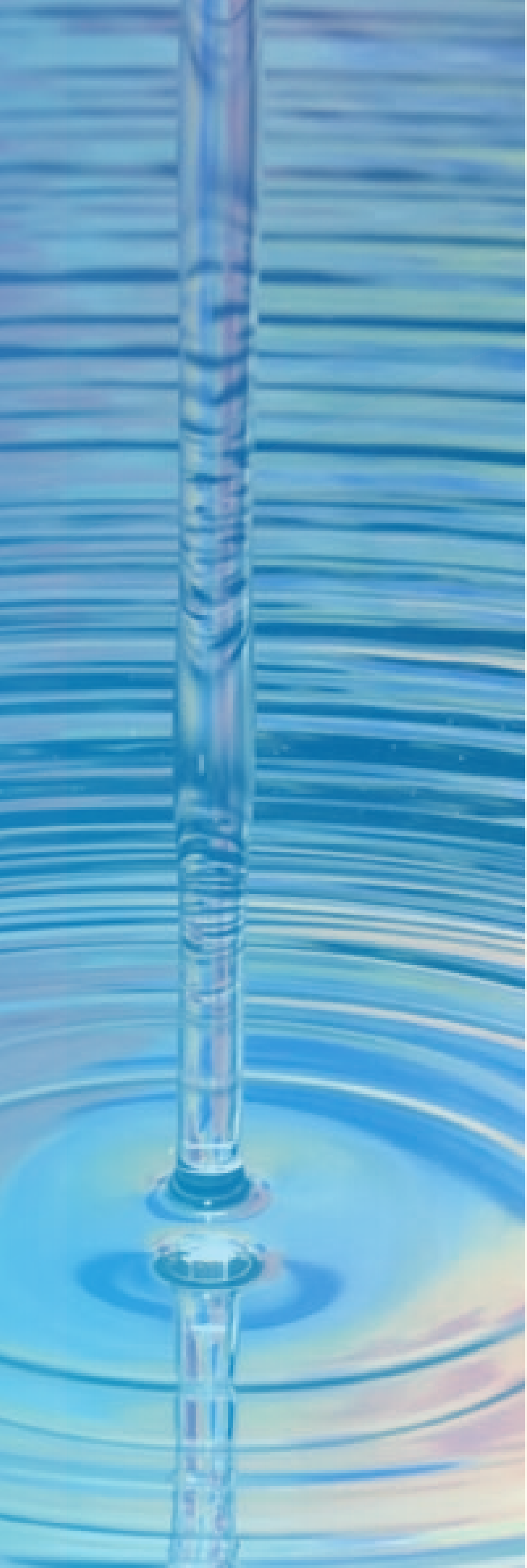
SWITCH

Sustainable water management improves tomorrow's cities' health

SWITCH is seeking to bring about a paradigm shift in urban water management from today's piecemeal solutions towards more efficient and interactive systems for the 'City of the Future'. To accelerate the sharing and adoption of new concepts, the partners are engaging directly with civil society through 'Learning Alliances' in a network of 10 demonstration cities across Europe and Israel, Africa, Asia and South America. Their planning approach is based on creative visioning, scenario identification and strategic planning, followed by method development for implementation via governmental and non-governmental sectors.

More information:

http://www.switchurbanwater.eu/



Conclusions

Membrane technology is a strategic sector in which the EU is well positioned in terms of scientific and technical (S&T) excellence, albeit still under-represented in manufacturing presence. Innovation derived from world-class research can provide a springboard for future growth in market share.

Europe has a solid reputation in water sciences and technologies. In the domain of water treatment membranes, its strengths lie mainly in the competitiveness of its engineering industry, especially with regard to system integration for desalination and wastewater treatment.

In particular, the EU benefits from a network of small and medium-sized enterprises (SMEs) that are active in this field and are often well connected to experienced academic centres, which together form a wide and world-class research community. Building on this S&T base is crucial, not only to meet Europe's own water needs, but also – in line with the Europe 2020 strategy – to contribute to the overall greening of the European economy, and to boost the share of manufacturing industry in a global market worth over EUR 300 billion.

From lab to market

Projects described in this publication have shown some of the results being achieved through collaborative research on a European and broader international scale. Taking these discoveries forwards from the laboratories to the marketplace is equally important in capitalising on the substantial investments that have been made and also in maintaining the momentum for further innovation.

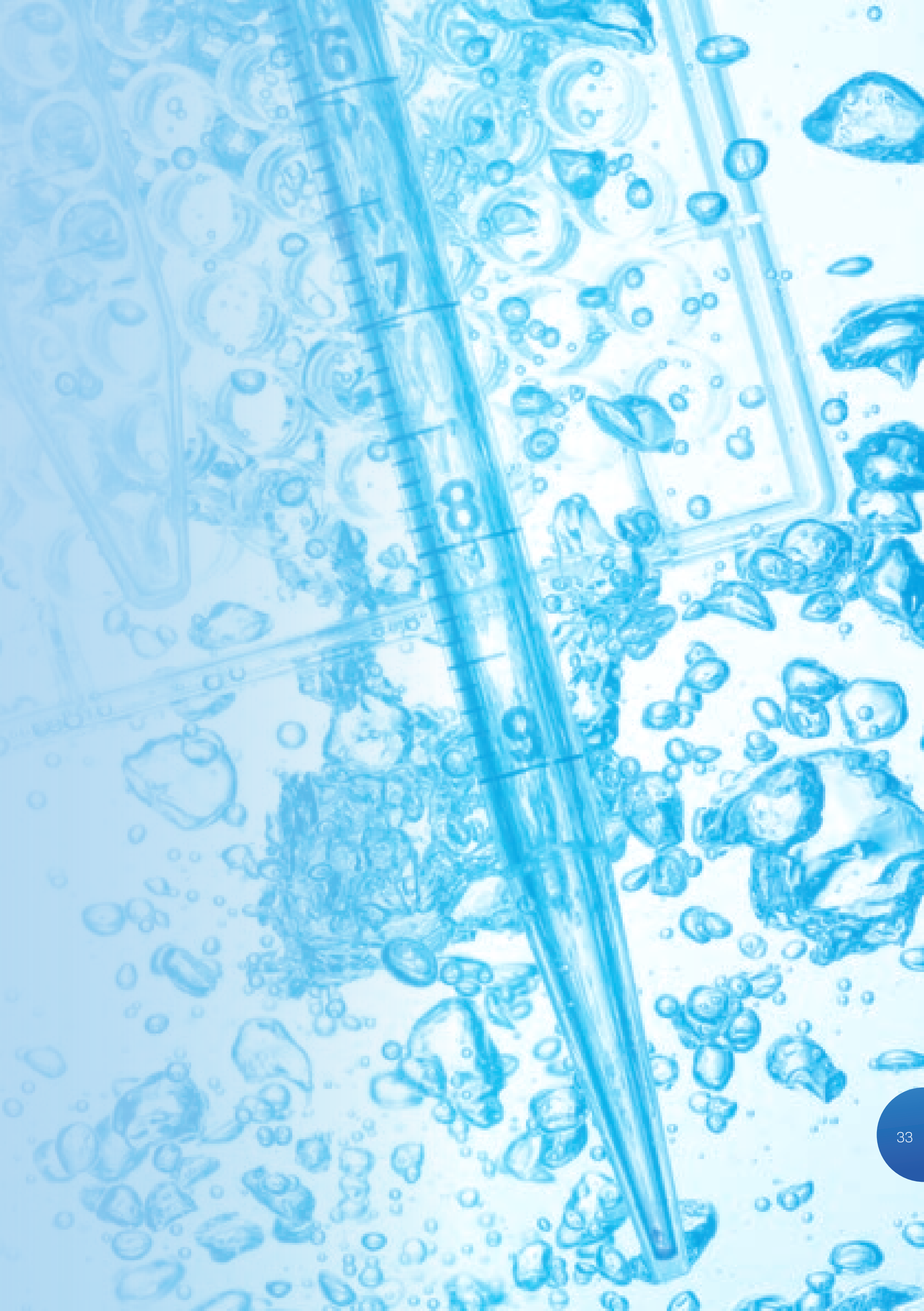
The 'real-world' relevance of the research topics is assured by the participation of large and small industrial enterprises in the project consortia and the strong involvement of municipal authorities in trials and demonstrations. In addition, it is reinforced by the creation of collaborative 'umbrella' initiatives such as the Water Supply and Sanitation Technology Platform (WssTP), in which industry, water professionals and research institutions join forces to agree on the most productive avenues to achieve short, medium and long-term strategic objectives.

WssTP maintains a permanent watch on the evolution of the various challenges faced by both the private and public sectors in relation to water, which provides input to its periodically updated SRA. A recently created task force on 'Membrane technologies for water applications' identifies gaps, opportunities and R&D needs in this specific area.

Extending the collaboration

The Water Platform continues to encourage research and technology development based on cooperation with other ETPs and pan-European initiatives addressing water management and environmental matters. A further move is its launch of an industry/business-led EUREKA cluster for water known as ACQUEAU (http://acqueau.eu/), which also aims to develop R&D projects to strengthen the technology base of Europe's water industry. One of the first actions under this programme was to publish a Call for Proposals on membrane technologies.

All of these collaborations support the main initiatives presented in the Europe 2020 strategy. The ultimate goal is to ensure that the European water sector will be at the forefront of expertise for providing safe, clean and affordable water services, while protecting the environment.



Useful links

ACQUEAU	http://acqueau.eu/
EU Environmental Technologies Research	http://ec.europa.eu/research/environment/index_en.cfm
European Desalination Society	http://www.edsoc.com/
European Membrane House	http://www.euromemhouse.com
European Membrane Society	http://www.emsoc.eu/
MBR Network	http://www.mbr-network.eu/
NANOMEMPRO	http://www.nanomempro.euromemhouse.com/
Nano4water cluster	http://nano4water.eu/
Water Supply and Sanitation Technology Platform (WssTP)	http://www.wsstp.eu/

List of acronyms

AOP	Advanced oxidation processes
BPMED	Bipolar membrane electrodialysis
CEN	Centre Européen de Normalisation
ETAP	Environmental Technologies Action Plan
EU	European Union
FP	Framework Programme
GWI	Global Water Intelligence
MBR	Membrane bioreactor
MD	Membrane distillation
MF	Microfiltration
NAM	Nano-activated membranes
NF	Nanofiltration
RO	Reverse osmosis
RTD	Research and technological development
S&T	Scientific and technical
SGP	Salinity gradient power
SRA	Strategic Research Agenda
UF	Ultrafiltration
VMD	Vacuum membrane distillation
WssTP	Water Supply and Sanitation Technology Platform

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Tackling the growing gap between water demand and water supply, while achieving good status of all water bodies, is a growing challenge worldwide. As part of the solution, membranes for water applications are arousing great interest as potentially cost-effective answers to a large range of purification and separation needs. A series of Community research projects administered by the European Commission under the Environment Theme of the RTD Framework Programmes, has investigated and tested new membrane technologies from lab-scale to full-scale for municipal and industrial wastewater treatment, as well as for drinking water production by routes including the desalination of seawater and brackish water. This brochure outlines some of the notable successes to date.

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