NanoMemPro - Expanding membrane macroscale applications by exploring nanoscale material properties

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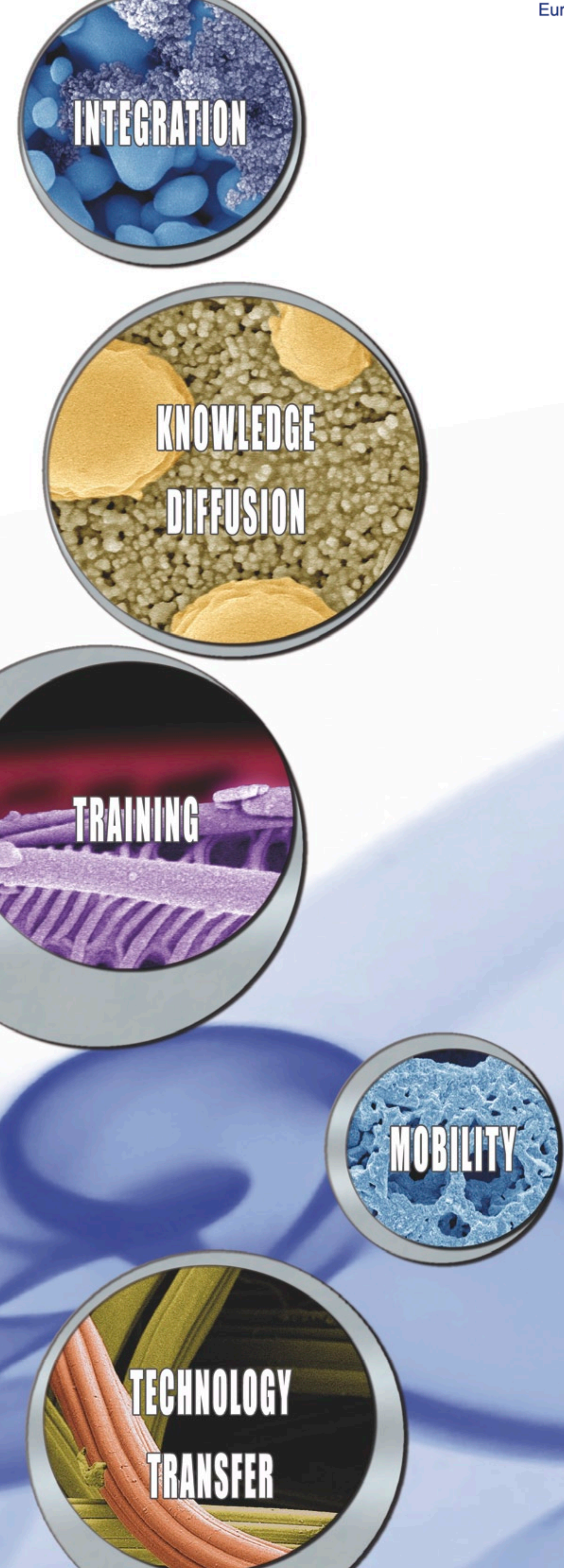
NanoMemPro

European Network of Excellence

Federating Membrane Activities in Europe

Final Dissemination Report

April 2009



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Preface

Prof. Dr. Ing. Jean-Claude Charpentier

Did you say the NanoMemPro NoE?
(September 2005–February 2009)
The NoE that has created the European "Reference" Instrument
to get sustainability in membrane science, design and engineering.

THE GOAL of NanoMemPro project, which was prepared by Research Teams recognized as Centre of Excellence of 13 different European Countries was to support a strong action aiming to increase the coordination of research activities in membrane science and technology in Europe, i. e. to raise the level of education and training (at Master and PhD levels) in membrane science and engineering, to enlarge the collaboration of European membrane specialists with colleagues worldwide active in the same field and to elaborate a strategy for the membrane engineering knowledge transfer to the industrial world and particularly to SMEs.

Sharing scientific and technical information was one of the most important objectives of NanoMemPro, and is fundamental to the definition of a NoE which is characterized by the capacity to mobilize the critical mass of expertise needed to achieve ambitious objectives, and by the structuring and integrating effects that they will have on the fabric of the European membrane research.

These efforts have led to a large success in a topic which has a strategic role in various fields from water treatment to gas separation, from agrofood and beverage industry to biotechnology, from fuel cells to dialysis and artificial organs, etc.

But what has changed due to the activities of NanoMemPro? Among the great number of work packages presented in this Dissemination Report, we shall underline 5 points to emphasize on what has changed at the European level due to the activities of NanoMemPro and contacts between industry and academia.

1- For the first time all relevant activities in membrane science and technology in Europe have been made visible to the scientific community and the membrane-based industry. Due to the exchange of personnel as well as the organization of special meetings, the activities and the areas of special interest of various European research institutions have been clearly demonstrated. Meanwhile, possible cooperation between the different research groups has been identified and synergy effects pointed out.

2- The membrane-based industry as well as other possible users of membrane technology were contacted and informed about the research activities of virtually all European institutions involved in membrane science and technology. Commercial enterprises are now able to get assistance in solving their specific membrane related problem from institutions in Europe with special expertise in their field of interest.

3- The sustainability of the results based on NanoMemPro's activities is taken care of by the creation of the European Membrane House (EMH) in 2008 which will continue the work initiated by the NanoMemPro project.

4- Medical device technology incorporating membranes is in need of interdisciplinary approaches for successful innovations.

In recent years, concepts for medical products based on membrane separation and transport were exclusively handled by polymer specialists. Only in haemodialysis and aphaeresis has interdisciplinary cooperation been successfully established. With the completion of NanoMemPro's activities, this perception has changed. Once the EMH is fully established, an expected successful dissemination of knowledge about both the potential of membrane applications for medical devices and information listing the names of experts, their facilities and equipment, will help and support not only polymer chemists and engineers, but also biophysicists, physiologists and the medical profession to start a successful cooperation in this field of rising interest. Apart from an exclusive support of innovative developments by expert knowledge, the development of prototypes by the stakeholders which prove the feasibility of membrane devices in close detail will be a landmark step forward to new innovations. NanoMemPro has set the place for this development.

5. A label on Membrane engineering at Master level has been defined and the first two calls (2007 and 2008) affected. The label is conferred jointly by NanoMemPro Network and the European Membrane Society. The development of a European Doctorate School on membrane engineering is in progress abreast of what was done for the European Master.

So "After NanoMemPro", the European Membrane Research Area, supported by the joint work of EMS (as a main learning Society) and EMH (to develop and improve technological development), is now perfectly structured for Europe to be the best place for membrane technology development on planet Earth.

Thanks to its capacity to mobilize the critical mass of expertise needed to achieve ambitious objectives, the European Membrane House will offer a single reference point of expertise and know-how to Universities, Contract Research Organizations and Industry. Indeed EMH is now the facilitator which helps to start new projects, by playing the role of catalyst for research programs, fostering new spin-offs and attracting people from other European and World Organizations to engage in membrane projects.

Last but not least, EMH will also promote the public understanding of membranes and their various uses (e. g. Environment, Energy, Health, Food and Chemistry).

Bravo for the successes obtained by the various academy, contract research organizations and industry researchers involved in the NanoMemPro Network of Excellence coordinated by Professor Gilbert Rios.

"NanoMemPro" is over! Long live the "European Membrane House", the European "Reference" Instrument chosen to get sustainability in membrane science, design and engineering.

Prof. Dr. Ing. Jean-Claude Charpentier
Past President of the European Federation
of Chemical Engineering
President of the Scientific Council of NanoMemPro

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Glossary

A

APDCA	Analysis-Plan-Do-Check-re-Act
AISBL	Association Internationale Sans But Lucratif de droit Belge (International Belgian non-profit making association)

B

BAT	Best Available Techniques
BMG	Belgium Membrane Group
BP	Business Plan

C

CA	Consortium Agreement
CFM	Club Français des Membranes
CNRS	Centre national de la recherche scientifique
CoI	Club of Interest
CP	Communication Plan
CSA	Coordination and Support Action

D

D	Deliverable
DGMT	German Membrane Technology Group
DIS	Durable Integrated Structure

E

EBN	European Business Network
EC	European Commission
ECVAM	European Centre for the Validation of Alternative Methods
ECS	European Cooperative Society
EEIG	European Economic Interest Grouping
EFCE	European Federation of Chemical Engineering
EFQM	European Foundation of Quality Management
EMH	European Membrane House
ESAO	European Society for Artificial Organs
EMS	European Membrane Society
ExC	Executive Committee

I

IPPC	Integrated Pollution Prevention and Control
IPR	Intellectual Property Rights
IR	Internal Regulations

J

JPA	Joint Program of Activities
JPI	Joint Program of Integration
JPR	Joint Program of Research
JPS	Joint Program for Spreading of Excellence

M

M	Milestone

N

NoE	Network of Excellence
NIS	Newly Independent States
NMG	Netherlands Membrane Group

P

PDCA	Plan-Do-Check-Act

R

R&D	Research and Development

S

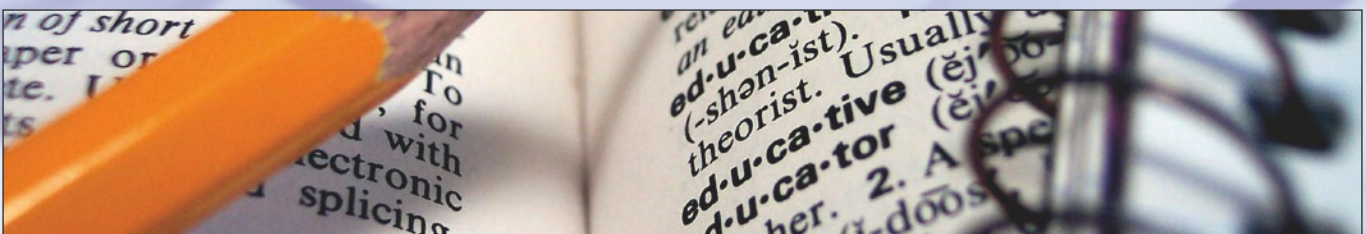
SME	Small-Medium Enterprise
SBRA	Strategic Business & Research Agenda

T

Termis	Tissue Engineering International & Regenerative Medicine Society
TT	Technology Transfer

W

WP	Work package



What's Network of Excellence (NoE)?

FP6 – A defining moment for European research

The 6th Framework Program (FP6)'s primary mission was to help strengthen the European Research Area (ERA), the perspective being to turn Europe into the world's most dynamic and competitive knowledge-based economy (strategic goal for 2010 set for Europe at the Lisbon European Council – March 2000).

New instruments were introduced for FP6, among which the Networks of excellence (NoE). These instruments are characterized by their capacity to mobilize the critical mass of expertise needed to achieve ambitious objectives. They are also characterized by the structuring and integrating effects that they will have on the fabric of European research.

What are NoE's objectives?

The aim is to strengthen excellence on a particular research topic by integrating the critical mass of resources and expertise needed to provide European leadership and be a world force on that topic. This expertise will be networked around a joint program of activities (JPA) aimed primarily at creating a durable integration of the research capacities of the network participants while, at the same time, advancing knowledge on the topic.

A network of excellence is, therefore, an instrument for strengthening excellence by tackling the fragmentation of European research, where the main deliverable should be a durable structuring and shaping of the way that research is carried out and disseminated in the topic of the network.

What is a Joint Program of Activities (JPA)?

The JPA contains a range of activities subdivided as follows:

► Integrating activities

Integrating activities aim at structuring and shaping the way participants carry out research in the topic:

- Coordinated programming and 'mutual adaptation' of the partners' activities;
- Sharing research facilities, tools and platforms;
- Joint management of the knowledge portfolio;
- Schemes for increasing staff mobility and exchanges;
- Using reinforced and shared information and communication systems.

► Activities for spreading excellence

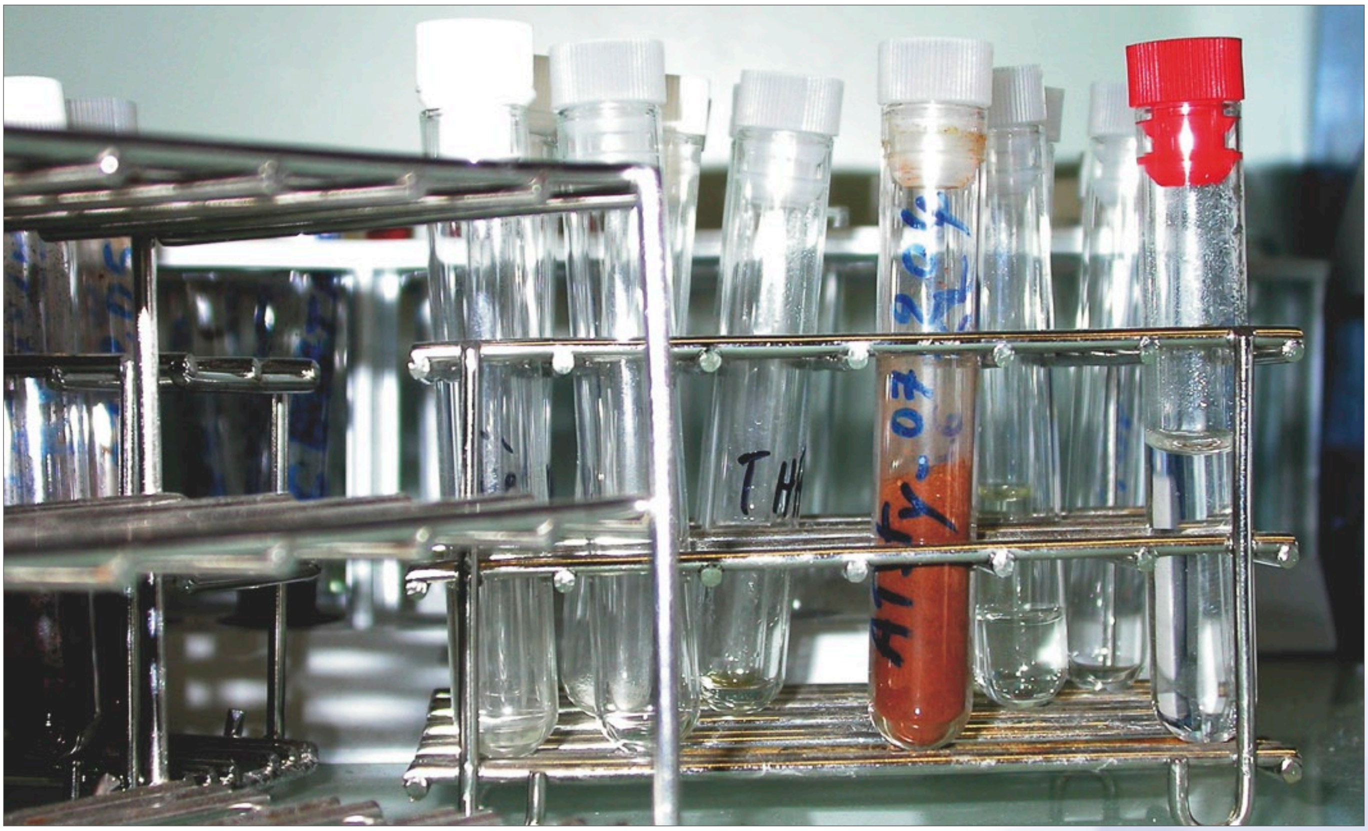
An essential mission of each NoE is to spread excellence beyond its boundaries through activities such as:

- Joint programs for training researchers and other key staff to ensure the sustainability of Europe's excellence in the topic;
- Communication campaigns for disseminating results and raising public awareness of science;
- Networking activities to encourage knowledge transfer and innovation.

► Jointly executed research activities

They aim at supporting the network's goals, for example by:

- Developing new research tools and platforms for common use;
- Generating 'new knowledge' to fill gaps in and/or extend the collective knowledge portfolio.



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Introduction

Prof. Enrico Drioli

MEMBRANE Science and Membrane Technologies have been present in Europe from their very early stages. Some of the first industrial membranes utilised in molecular separations have been studied and produced in Germany already in the middle of the 20^{th} century. Scientific interest in membrane science is well documented by the researches carried out both on biological membranes and in artificial ones by pioneers such as Teorell, Stavermann, Sollner, Katzir Katchasky etc.

Probably the first conference devoted to artificial membranes was organized as a Nato Advanced Study Institute by H. Gregor and A. Liguori in 1966 at Ravello (Italy). At that time the mechanism controlling the selectivity of the RO membranes invented by Loeb and Sourirajan in the USA was still part of the discussions.

The growing interest for membrane science and for its potentialities in facing some of the crucial problems of the industrialized world and of the medicine, have been at the origin of the creation of the European Membrane Society (EMS) in the late 1970s (1979-1980), at that time which was called European Society on Membrane Science and Technology (ESMST). It was the only existing scientific organization in the field, together with the Japanese Membrane Society.
The organization of Summer Schools on various aspects of Membrane Science and of International Conferences totally devoted to Membrane Science and Membrane Technology characterized the activities of the EMS in those years. A strategic event was the European-Japan Conference on Membrane Science and Technology sponsored by these 2 existing organization in 1984 from which the International Conferences on Membranes (ICOMs) were generated.

The visibility and the understanding of the strategic role of membrane technology in various fields from water desalination to gas separations, from artificial organs production to fuel cells etc., started also to become more significant. The fast growth of the membrane operation applications in a large variety of industrial sectors and the difficulties to transfer all the scientific achievements in the industrial world became evident in the late 1990s.

Representatives from 4 of the major Research Organizations at that time and active members of the EMS, i.e. Enrico Drioli from the Institute on Membrane Technology-CNR, Italy; Louis Cot from the European Membrane Institute-CNRS, France; Dieter Paul from GKSS, Germany, Matthias Wessling from Twente University, The Netherlands, started to discuss on the opportunity of promoting a strong action to increase the coordination of the research activities in membrane science and technology in Europe, with the support of the European Union. The aim was to create a strategy for the membrane engineering knowledge transfer to the Industrial World and particularly to the SMEs, to increase the level of education and training in membrane science and engineering in the Universities and High Schools, to enlarge the collaboration of European membranologists with colleagues active worldwide in the same field. The proposal for a Network of Excellence (NoE) on membrane and membrane operations was considered an excellent structure and tool to try and reach these objectives.

The proposal for the NanoMemPro NoE was prepared by Research Teams from 13 different European Countries, each one representing a Center of Excellence in its own area. Prof. G. Rios from the European Membrane Institute-CNRS in Montpellier was asked to serve as Coordinator. The project submitted to Brussels was approved and started its operation in September 2004. The NanoMemPro's ambitious objectives have been in large part reached thanks to the efforts of all the various academic and industrial researchers taking part in the NoE. They will be described in details in this report.

The creation of a legal entity, able to give a continuation to the NanoMemPro strategies, has been realized: the European Membrane House exists today.

Thanks to this dissemination report, we are spreading the overall results of the various activities carried out during the lifetime of the project to the industrial world at large and to a broad network of academic institutions.

Prof. Enrico Drioli
Institute on Membrane Technology – ITM-CNR
Partner of NanoMemPro Network of Excellence

NanoMemPro

European Network of Excellence

Membrane Technology Guide

MEMBRANE TECHNOLOGY GUIDE

Aim

The field of membrane science and technology is a dynamic and ever growing field of research. Today, membrane processes are utilized in a diverse range of applications and each year more and more effective uses for membrane technologies are developed and commercialised. Separation technologies are critical to reducing waste, improving energy efficiency, and increasing the efficiency of raw material use, for instance by separating from waste streams valuable materials that can be reused or sold as by-products. However, despite the growing importance of membrane processes as an engineering tool, it is not always obvious for newcomers in the field to grasp the various aspects of membrane technology.

This *Technology Guide* forms a quick reference that provides a comprehensive overview of the principles of operation, discusses appropriate applications and assesses the relative advantages and disadvantages of the various membrane techniques in use today.

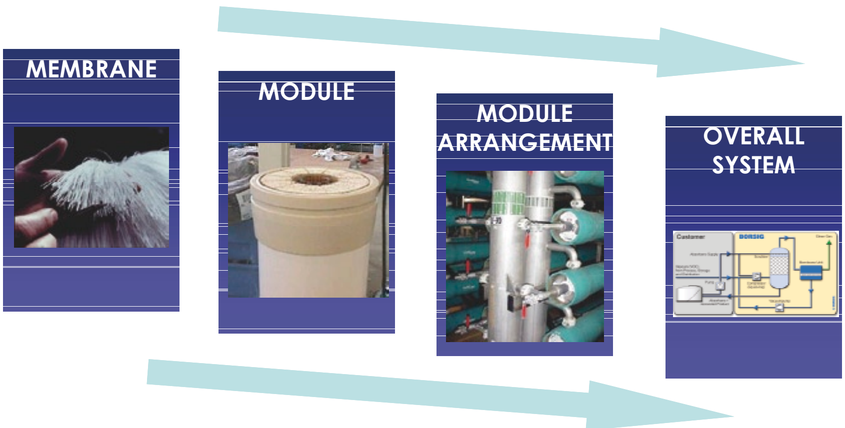
Content:

Part I. From membrane to application
Part II. Practical introduction to most common membrane technologies
Part III. Applications of successful and emerging application areas

PART I : FROM MEMBRANE TO APPLICATION

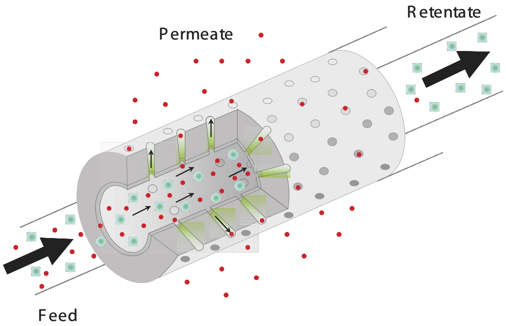
1. Introduction

Membranes can be used to satisfy many separation requirements. For a large number of applications, membrane separation is a mature technology that is commercially available throughout the world from a relatively large number of equipment suppliers. Units are generally compact, and their modular construction makes them highly suitable for scaling up or scaling down the separation process. The benefits of using membrane separation, however, are only fully achieved by selecting suitable membrane technology that is compatible with the application. This involves consultation with technology suppliers, clear identification of the substances present in the process streams of interest, an understanding of the strengths and weaknesses of the membrane systems available and completion of a structured feasibility assessment.



Based on the material science concepts, the membrane developer shapes material into a particular membrane geometry such as hollow fibres or flat sheets. The membranes need to be incorporated into membrane housing and equipment, ensuring optimal hydrodynamic conditions. Then the membrane modules must be arranged to operate stable and efficiently. Then to realise the overall system, the process needs to be interfaced with existing and complementary processes and unit operations.
The term *Membrane engineering* is used to describe all aspects that are required to enhance implementation and to identify competitive operational windows.

2. What is a membrane?



A membrane is a permeable or semi-permeable barrier between two phases that restricts the motion of certain components. Phases at both sides of the membrane can be in either liquid or gas form. The membrane has the ability to transport one component from the upstream side phase to the downstream side more readily than any other component or components, and as such induces separation.

The total amount of product transported from the upstream (feed) side phase through a membrane is called the *permeate*. The retained components are concentrated in the *retentate* or *concentrate* stream.

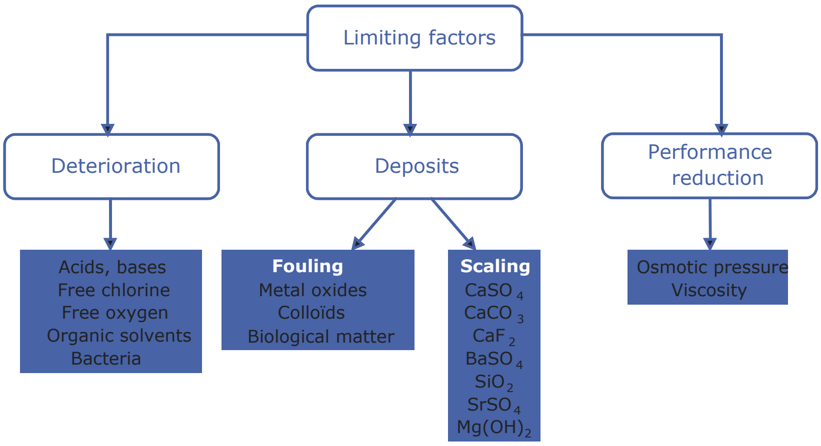
The performance of a membrane is generally defined in terms of two factors:

- **Flux:** The flux of a component (J) is the amount passing through the membrane per unit of time and per unit of membrane surface area. The flux divided by *transmembrane pressure* (TMP) yields the *permeability* ($l\ h^{-1}\ m^{-2}\ bar^{-1}$) or MTC (*mass transfer coefficient*) value. The flux and has a strong impact on the capital costs of the process (~ membrane surface area needed) and hence influences the *economic feasibility.*
- **Selectivity or retention:** Selectivity is the partition of a component into permeate and feed. For example, a retention of 80% for a component means that the concentration in the permeate is a factor of 5 lower compared to the feed concentration. In fact, selectivity will strongly determine the *technical feasibility* of a membrane separation process.

The membrane itself can have different shapes (flat or tubular) and different structures (symmetric or asymmetric). In applications, they are mounted in modules and linked together, thus connecting incoming and outgoing streams. Most flat membranes are implemented in a spiral wound module, a design with a low cost and high surface to volume ratio. The specific configuration also determines the ease of cleaning. Configurations with tubular membranes are the easiest to clean and spiral wound the most difficult. Consequently, tubular membranes are applied in process streams with a high load or a high viscosity.

3. Membrane operation

During the course of a membrane separation process, membrane performance can decrease considerably over time. Such behaviour is mainly due to concentration polarisation and fouling. *Concentration polarisation* is a phenomenon related to the concentration increase near the membrane surface. *Membrane fouling* relates to a wide array of complex phenomena linked to the deposition of components at the surface and inside the membrane. Major fouling phenomena are particulate and colloidal fouling, scaling (precipitation of inorganic salts), bio-fouling and adsorption.



Several approaches to reduce fouling can be distinguished, such as pretreatment of the feed solution, proper choice of membrane material/ properties, appropriate setting of the operational parameters and the use of turbulence promoters. Although these approaches reduce fouling to some extent, almost all filtration applications require a chemical cleaning step after a given length of time.

Membrane separation processes can be operated in cross-flow (i.e., feed flow along the membrane surface) or dead-end (i.e., feed flow perpendicular to the membrane surface) mode. Cross-flow mode induces turbulence at the membrane surface to inhibit the build up of the fouling layer on the membrane surface. In dead-end filtration, retained particles accumulate to form a cake layer and fouling tendencies are therefore high.

PART II : PRACTICAL INTRODUCTION TO THE MOST COMMON MEMBRANE TECHNOLOGIES

1. Microfiltration and Ultrafiltration technology

MF/UF specifications

Microfiltration (MF) closely resembles conventional coarse filtration and concerns the separation of particles between 0.1 and 10 µm, such as suspended solids (colloids), bacteria and large proteins. It is applied for clarification and sterilization purposes, for cell harvesting, separation of oil-water emulsions, etc. MF employs membranes with a porous structure corresponding to low operating pressures in the 0.1 to 2-bar range.

Ultrafiltration (UF) retains relatively large molecules such as proteins, polymers and colloidal substances. Small molecules such as salts pass through the membrane intact. UF is ideally suited for fractionation, concentration and purification purposes. Operating pressures are typically in the range of 1 to 5 bar for cross-flow application. With a semi-dead end operation mode, the pressures are much lower, around 0.2-0.3 bar (see section on water treatment).

MF and UF membranes can be made of hydrophobic polymers (polyfluoroethylene, PTFE or Teflon; polyvinylidene difluoride, PVDF or polypropylene, PP), hydrophilic polymers (cellulose esters; polysulfone, PS; polyethersulfone, PES) or inorganic ceramics.

The selection of the membrane material often occurs on the basis of the potential interaction of the membrane material with the feed stream. In any case, periodical chemical cleaning of the membranes will be needed. In this respect, membrane stability over a wide pH range and stability in the presence of active chlorine are important requirements. In addition, particularly in biotechnological applications, stability in the presence of steam sterilisation is also important. For the latter applications, polyethersulfone (PES) is often preferred for its higher temperature resistance.

Do's and don'ts

Do characterise your feed: For MF/UF water treatment application, the suspended solids content of the feed water should be lower than 50 mg l^{-1}. A filter (approximately 200 µm) is usually placed in front of the membrane installation. For capillary membranes, as a rule of thumb, minimal pre-treatment is set at $1/3^{th}$ of the internal diameter of the capillary.

Do use normalised flux values: An important item in the comparative analysis of permeate flux data is the need to normalise the permeate flux to a reference temperature. Since water viscosity has a significant effect on flux, resulting in an approximately 3% flux decline with 1°C at a given TMP, such normalisation is needed to rule out the impact of temperature.

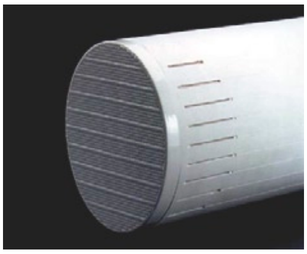
Don't dimension/build installations without pilot testing: Water quality demand prior to MF and UF is linked to the complex fouling propensity characteristics of the feed and this can only be determined experimentally. Some components are known to cause irreversible membrane fouling such as specific surfactants or cationic polymers. Consequently, their presence needs to be avoided as often indicated by the membrane manufacturer.

Do look at treatment/disposal options for your concentrate streams: For purification applications, only the permeate stream is useful. This means that the concentrate is a waste stream. For semi dead-end MF/UF operation, the volume of the concentrate stream is 5 to 10% of the feed stream. When adding chemicals/filter aids to your feed, check the technological options and legal framework for dealing with the concentrate streams. While the addition of chemicals may enhance your filtration performance, it can limit the discharge options of the concentrate stream.

New developments

The main developments in MF/UF aim at obtaining higher selectivity, the removal of finer particle sizes, lower energy consumption and/or operation for longer periods of time before cleaning or disposal. The continuous reduction in membrane cost per m² allows more membrane surface area to be used, making a corresponding shift to lower permeate fluxes possible, thus increasing membrane life and long-term membrane performance.

Other developments are related to advances in polymer chemistry, to membranes with improved chemical and fouling resistance and a longer lifetime, and to the introduction of ceramic membranes in the water-treatment market. Increasing attention is being paid to immersed membranes for large plants due to their smaller footprint and hence lower capital costs (see also the section on MBR).



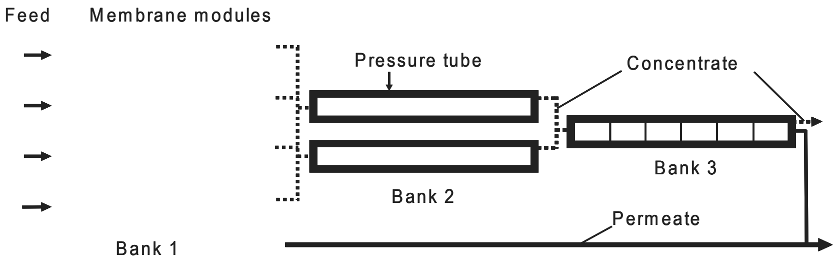
In the longer term, major developments are expected in the area of membrane functionalisation, e.g. by modification with ligands, by a combination with enzymes and/or nanoparticles.

2. Reverse Osmosis / Nanofiltration

RO/NF specifications

Reverse osmosis (RO) is typically used to concentrate, purify and recover valuable components, either alone or in combination with other separation processes such as MF and UF or evaporation.

For RO, water molecules are forced through a dense membrane by applying a pressure higher than the osmotic pressure of the feed stream, allow the removal of nearly all ions and organic compounds. Operating pressures can range from 10 bars up to 100 bars. A typical RO application is seawater desalination.



RO “Christmas tree”-configuration

RO membranes typically are integrally skinned, asymmetric membranes or thin-film composite membranes with a layered structure. Nearly all RO installations include horizontally located, spiral-wound membrane modules. The modules are standardized and fit in pressure tubes. RO installation design involves the use of multiple membrane modules in series, placed in parallel in so-called banks.

Nanofiltration (NF) typically retains multivalent ions, such as phosphate or sulphate, and molecules with molecular weights above 200 Dalton. Monovalent ions are only partially retained (typically 50 %). Consequently, NF membranes are useful in retaining Chemical Oxygen Demand (COD, a measure of the organic load of wastewater), for softening, and for partial demineralization or removal of salts, particularly when monovalent ions such as chlorides do not have to be removed. Operating pressures are between 5 and 20 bar. Most of the NF membranes are composite membranes, and suitable module configurations are capillary and spiral wound. Operation is in cross-flow mode.

Do's and don'ts

RO feed requirements

- SDI < 5 (ideally < 3 or better)
- TSS < 1 mg/l
- Turbidity < 1 NTU
- TOC < 5 mg/L
- LSI < 2.0 (with sequestrant)
- Fe < 0.05 mg/l, Mn < 0.05 mg/l

To be fulfilled at 100% of the time !

Do measure the fouling propensity of your feed water: Feed solutions can contain silt (particulates) and colloids, with variable size, shape and chemical composition. A well-known method to measure the fouling propensity of a feed is the SDI (Silt Density Index) method, standardized by ASTM D4189. The SDI of an RO feed should be < 5, some membrane producers even prefer < 3.

Do use RO installation design software: All RO membrane producers provide freeware models that enable the simulation of a complete RO installation (Table 1[1]). The software, however, is not "push-button" software that automatically calculates the optimal RO design. A disadvantage of the producer's membrane data files is that the freeware is a black box, forcing the user to use the individual versions of the different membrane producers.

Table 1. RO membrane producers and their freeware

Company	RO freeware	Internet
Dow (Filmtec)	Rosa	http://www.dow.com/liquidseps/design/software.htm
Hydranautics	Rodesign, Rodata	http://www.membranes.com/index.php?pagename=imsdesign
Koch (Fluid Systems)	Ropro 6.1, Costpro	http://www.kochmembrane.com/sep_ro.html
Osmonics	WinFlows	http://www.gewater.com/index.jsp
Toray	TorayDS	http://www.toray-membrane.com/application/page.aspx

Do calculate/prevent scaling: When sparingly soluble salts occur in the feed, there is a risk of precipitation or scaling. High salt retention by the membranes causes the salt content in the concentrate to increase in function of the recovery capacity of the installation. The chemical equilibrium calculations for sparingly soluble salts in RO concentrate can be made using equations that are available from suppliers or by using freeware, obtainable from antiscalant producers. When the scalant concentration is too high, the dosing of antiscalants can be insufficient and (partial) removal of the specific scalant from the feed is required, e.g. by precipitation/flocculation or by ion exchange softening. The situation for NF differs considerably from RO, since the retention of ions in NF is clearly not as pronounced.

New developments

The two major (emerging) trends for RO for the past 15 years are improved performance and a significant reduction in price. Ongoing developments are mainly linked to ultra-low pressure composite membranes and optimized module hydrodynamics. From an energy point of view, special attention is paid to combining with thermal technologies to obtain hybrid desalination systems.

A very recent line of research focuses on salinity gradient power (SGP) production. This technology is able to convert the osmotic energy of salt solutions into mechanical or electrical energy. Two main SGP techniques are currently available: reverse electrodialysis (RED) and pressure retarded osmosis (PRO).

For NF, recent developments have greatly extended the capabilities of the membranes to withstand aggressive environments. For water-based applications, these can be very high or very low pH environments. For most organic solvents, traditional membranes lose their stability or underperform with respect to flux or rejection. Consequently, organic solvent resistant membranes – both ceramic and polymeric – have been developed which find application in solvent exchange, solvent recovery, catalyst recovery, product purification, etc. This is further explained in section III-2 on solvent filtration.
Further progress was also made on improved performance with regard to both permeability and selectivity. Because multivalent ions are retained and monovalent ions are not, NF membrane retention can be tailored to specific applications. The use of ion-selective NF membranes as a pretreatment for RO feed water for example can be an option in reducing the scaling potential. This would allow higher system recoveries and lower chemical demand in the RO stage.

3. Electrodialysis technology

E.D. specifications

Electrodialysis (ED) is used for desalination, demineralisation (e.g. milk and whey) and the removal of metals. In these applications, ED often competes with ion exchange (IEX), but the continuous process operation of ED makes it more economical.

An ED installation consists of a stack of alternating anion-conductive (AC) and cation-conductive membrane (CM).When an electrical field is applied the anions will move to the anode through the AM while the cations move through the CM towards the cathode. This generates a concentrated stream and a diluted stream. Opposite to RO, ED involves desalination that transports only the solute (ions) through the membrane. ED thus needs less material transport. The amount of ions transported is directly proportional to the electrical current or current density.

With respect to fouling, a very important method to counteract the deterioration of membrane performance by foulants is ED reversal (EDR). During ED reversal, the anode switches to cathode and *vice versa*, while the diluate and concentrate streams are also interchanged. Such reversal is typically performed every 30 to 60 min. The production "loss" involved is only a small percentage. ED reversal should not be confused with reverse ED (RED), which is a new technique to generate power from a salinity gradient *(see also RO – New developments)*.

Do's and don'ts

Do avoid attaining the limiting current density: Increasing the current density in an ED stack will decrease the concentration at the membrane surface in the diluate compartment to very low levels. At the limiting current density, the supply of salt ions from the bulk diluate towards the membrane becomes critical. At this point, the further supply of cations and anions will result in water dissociation causing energy losses. The limiting current needs to be determined experimentally by measuring a feed's current versus voltage behaviour at different flow rates and concentrations.

Do remove suspended matter as much as possible to prevent clogging: As is the case with RO, the risk of precipitation of sparingly soluble salts at the membrane surfaces in the concentrate compartment can be estimated using design calculation software. In addition to the risk of scaling, other fouling risks exist comparable to RO use: suspended and colloidal matters, polyelectrolytes, organic anions (e.g., humates), silicates …). In this respect, it is advised to remove suspended matter as much as possible to prevent the ED stacks from clogging. This can be done by sand filtration or b y using filtration cartridges.

New developments

The inherent potential of the ED process strongly increased with the development of bipolar membranes. A bipolar membrane is in fact a combination of a CM and an AM. When all ions are removed from the boundary layer between the two polymer layers, additional transport of electrical charges can only be achieved through protons and hydroxyl ions. These are created through the dissociation of water in the surrounding solution.
Goals for new membrane developments include (1) decreasing membrane cost, especially for bipolar membranes, (2) improving the anti-fouling properties of membranes, and (3) developing ion-exchange membranes with increased and more specific selectivity.

4. Membrane Bioreactors (MBR) technology[2]

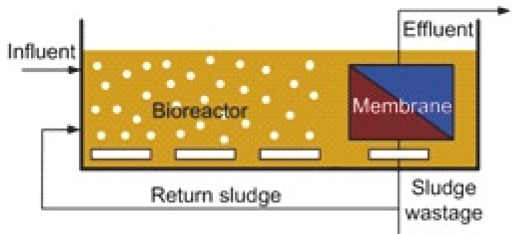
MBR specifications

In a membrane bioreactor (MBR), a biological reactor (activated sludge) is coupled with membrane separation to retain the biomass. This not only produces a clarified effluent, but also allows operation at higher biomass concentrations. In doing so, the biotreatment process becomes more efficient, thereby reducing the required tank size. MBRs thus tend to generate treated water of a higher quality with respect to dissolved constituents. By removing the requirement for biomass sedimentation, biomass concentrations can be increased to 15 or 20 g l^{-1} compared to 5 to 8 g.l^{-1} for conventional systems.

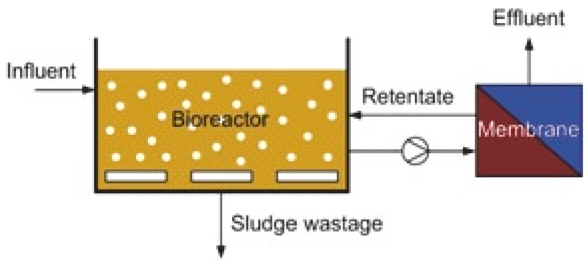
The two main MBR process configurations are submerged (or immersed) and sidestream. In the first, membranes are immersed directly in the aeration tank. Permeate is typically extracted by applying reduced pressure to the permeate side. In the latter case, membranes are installed outside the activated sludge tank. A crossflow pump is used to create the pressure and to prevent the build-up of solids on the membrane surface.

In MBRs, MF and UF membranes are used. In general, UF membranes are able to achieve higher levels of separation, in particular for bacteria and viruses. In sidestream MBRs, the external membrane module typically consists of tubular membranes with a fairly large diameter, and filtration occurs in-to-out. Submerged MBR membranes are largely configured as hollow fibres or flat sheets, and are operated out-to-in.
As is the case for all membrane filtration processes, fouling can manifest itself as flux reduction over

time when operating at a constant pressure or reversed. MBRs are usually operated under constant flux conditions, maintaining the convection of foulants to the membrane surface at a constant rate. MBR fouling is mostly affected by the interactions between the membrane and biological suspension rather than the feed.



Submerged MBR



Sidestream MBR

Fouling related to concentration polarisation can be reduced by increasing the cross-flow velocity (for a sidestream MBR) or by increasing membrane aeration (for a submerged system). Further control of fouling relies on the following strategies:

- Appropriate physical cleaning: by relaxation under continued aeration or backwashing. This removes only reversible or temporary fouling.
- Chemical cleaning: with sodium hypochlorite, acid and/or base. A so-called *maintenance cleaning* (low concentrations of chemicals, short contact times) is done every 1 or 2 weeks using, an *intensive cleaning* is applied once or twice per year.
- Reducing the flux: sustainable operation implies that MBRs should be operated at moderate flux levels, preferably below the critical flux[1] or sustainable flux[2].
- Modifying the mixed liquor or biological suspension: this can be achieved by adjusting the biological operating conditions such as sludge age, but is usually accomplished by adding chemicals such as coagulants/flocculants.

1. Critical flux is defined as the flux below which a decline in flux over time does not occur.

2. Sustainable flux is the flux at which a moderate degree of fouling occurs. It represents a compromise between reduced capital costs at high flux levels and reduced operating costs for low fouling rates.

Do's and don'ts

Do prevent clogging: To avoid membrane clogging, an appropriate pre-treatment must be applied to the feed. For example, hairs may become intertwined with hollow fibre filaments, or flat sheet membranes may clog when debris accumulates at the channel entrance. Since hollow fibre modules are more susceptible to clogging, pre-filtering down to 0.8 – 1.5 mm is advised. For flat sheet membrane modules, 2 to 3 mm screens are normally adequate.

Don't operate MBRs at a too high biomass concentration: Since MBRs operate at higher biomass concentrations than conventional systems, they constitute a very compact technology. When biomass concentrations become too high, however, oxygen transfer efficiency decreases and it may become difficult to meet the oxygen demand for the biological treatment.

Do upgrade to MBR: MBRs can generate a superior effluent quality and can effectively take the place of biotreatment, secondary sedimentation and a tertiary effluent polishing step. This offers perspectives for the discharge of MBR effluent in sensitive areas and for creating reuse options, either direct or via post-treatment by RO. When the capacity of existing wastewater treatment plants needs to be increased, or improved effluent qualities achieved without increasing the footprint, upgrade or retrofit to MBR may be an attractive option.

New developments

Capital costs for MBRs will presumably always remain higher than those of conventional treatment plants. MBRs, however, have the advantage of a smaller footprint and superior effluent quality. In addition, investment costs have decreased dramatically in the past 15 years thanks to continued technical improvements, the increased maturity of the technology, a more competitive market and growing demand. Although ongoing developments will lower membrane purchase costs, standardisation is probably needed to achieve a real breakthrough in price[3]. Operating costs also have decreased dramatically. mainly due to a reduction in energy requirements for membrane scouring.

Ongoing developments to reduce capital or operating costs focus on four major domains:

- Filtration material/fouling control: e.g. cheaper membrane materials;
- Module-filtration system: e.g. optimisation of the packing density of hollow fibres;
- System engineering: e.g. dual concepts including an MBR and a conventional system;
- MBR operation: e.g. evaluation of various chemical cleaning methods

Nearly all commercial MBRs are aerobic units. Anaerobic MBRs exist, but they suffer from substantial fouling and are therefore operated at extremely low fluxes. An excellent website

6. Pervaporation/Gas separation /Vapor permeation

PV/GS/VP specifications

Pervaporation (PV) is a fractionation process in which a liquid mixture is maintained at atmospheric pressure on the feed side of the membrane, while the permeate is removed as a vapor. Transport is induced by using a vacuum pump at the permeate side or by cooling the permeate vapor to create a partial vacuum.

Most PV membranes consist of a dense top layer and an open porous support. The transport of the feed through the top layer follows the solution-diffusion model, involving three steps:

- Selective sorption of the liquid mixture on the feed side (most dominant);
- Selective diffusion through the membrane;
- Desorption into the vapor phase on the permeate side.

The separation capacity of a PV membrane is primarily a function of the membrane material and the feed species (interaction of each feed component with the polymer). Feed temperature, feed composition (interaction between different feed components) and permeate pressure have a secondary influence.

Three different types of PV membranes can be distinguished: (1)Hydrophilic membranes, (2) Organophilic or hydrophobic membranes and (3) Organoselective membranes.

The choice of membrane type depends strongly on the type of application. Hydrophilic membranes are mostly used for organic solvent dehydrations, organophilic membranes to eliminate organic species from aqueous or gaseous effluents, and organoselective membranes for the separation of purely organic mixtures (see also section III-2).

PV can be a good alternative to more traditional techniques such as vacuum distillation and solvent extraction. The process has advantages over these techniques with respect to energy saving, process simplicity and lower capital costs. Overall, PV can offer a solution in cases where conventional separation processes fail or result in high energy consumption, such as the separation of azeotropic mixtures.

Despite its high potential, the industrial development of PV units is still very limited. The main application of PV in industry is the dehydration of organic liquids with hydrophilic membranes, usually made of polyvinyl alcohol (PVA). Organophilic membranes (mostly PDMS membranes) are used for the recovery of hydrocarbons from air or gases (petrochemical industry, natural gas industry).

In gas separation (GS), both the feed and the permeate consist of a gas; in vapor permeation (VP), these consist of a vapor. The rate of gas/vapor permeation depends on the partial pressure difference across the membrane.

Most membranes used for GS can be categorised into two types:

- *porous ceramic* membranes: highly voided structure with randomly distributed interconnected pores. Separation is a function of the permeate character and membrane properties. Different transport mechanisms can be involved
- *non-porous polymeric* membranes: Gas transport is described by the solution-diffusion mechanism, determined by molecular interactions between the gas molecules and the membrane.

Within polymer membranes, a distinction can be made between polymers in a rubbery state and those in a glassy state. With glassy polymers, diffusivity is dominant due to the rigid nature of the polymer chains. Therefore, small molecules permeate more easily. In rubbery polymers, solubility is dominant. In this case, permeability increases with increasing permeate size. In general, rubbery polymers exhibit high permeabilities and low selectivities. Glassy polymers show higher selectivities but much lower permeabilities.

The most important ceramic GS membranes are based on microporous silica, zeolite or microporous carbon.

Gas separation membranes can be an alternative to more conventional separations such as cryogenic distillation, absorption processes and pressure swing adsorption. Because no phase change is needed, energy costs are lower. Operating simplicity, intrinsic modularity and the absence of additional chemicals are additional advantages. At the moment, GS membranes are applied at an industrial scale in the following areas:

- Air separation (production of nitrogen- or oxygen-enriched air)
- Hydrogen separation and recovery;
- Natural gas separations;
- Air dehydration;
- Organic vapor recovery.

Do's and don'ts

Do study membrane performance using mixed gas conditions: The efficiency of a polymeric GS membrane is often expressed as the pure gas permeability coefficient and the ideal permselectivity. These parameters are determined by measuring the permeate flow through a membrane exposed to one gas. However, the performance of a polymeric membrane exposed to a mixture of gases is usually different. On one hand, reduced gas transport can occur due to the competition between two gases for sorption sites available in the polymer matrix. On the other hand, weakening of the matrix can cause increased permeability.

Do select the right membrane and system: The choice of the right membrane for the right application is very important. Attention should also be given to the following:

- The permeability and selectivity of the membrane: to reduce energy consumption, a PV membrane must be selective for the minor component of the feed mixture;
- The stability of the membrane: swelling can occur in polymeric PV membranes.

There are also several systems available for PV: continuous, batch or vapor permeation. They all have advantages and disadvantages, and the choice depends on the application and the feed mixture.

New developments

Although membrane GS is already used on an industrial scale, many challenges must be overcome before this technology becomes more widely adapted. New generations of polymeric, ceramic and mixed matrix membranes need to be developed with higher thermal and chemical stability, higher selectivity and improved resistance to fouling and corrosion.
Research is being conducted on many different applications. One of these applications is the reduction or elimination of CO_2 emissions from electricity power plants fuelled by coal or gas. Special membranes are needed due to the large volume flow rates, low CO_2 concentrations and process parameters such as temperatures and pressures. Three different CO_2 capture techniques have been identified:

- Post-combustion capture (separation of CO_2 from exhaust gas
- Pre-combustion capture (H_2/CO_2 separation)
- Oxyfuel combustion (supply of pure oxygen for combustion: O_2/N_2 separation).

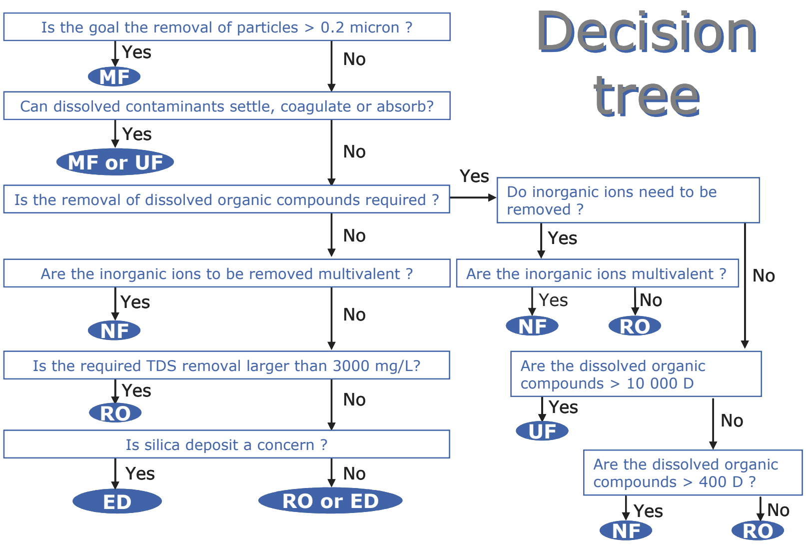
For PV, much research is conducted on the use of organophilic membranes which can be used for the removal of dilute organic compounds from aqueous streams. .

PART III : EXAMPLES OF SUCCESSFUL AND EMERGING APPLICATION AREAS

1. Water purification and reuse

Implementation of membranes in the water cycle includes drinking and process water production, industrial process and wastewater treatment, municipal sewage treatment, product recovery from aqueous streams, water loop closure, and treatment of groundwater, agricultural waste streams or percolation waters.

Contaminants are usually present in low concentrations and in mixtures. Moreover, waste streams are usually low value products. The choice for a treatment technique depends on its economic and technical feasibility. When membrane processes are concerned, they should thus be capable to accomplish the desired separation, either as stand alone technique or in combination with other treatment processes.



Low-pressure membrane technologies (MF/UF) are recognized as very attractive processes for producing drinking water from groundwater or surface water. Particularly UF can be applied for water disinfection as it achieves excellent removal of bacteria, pathogens such as *Giardia,* and even viruses. In addition, it is perfectly suited to eliminate particles (suspended solids or micro-organisms). Table 2 shows the parameter setting for a typical run for an UF in semi dead-end operation, composed of alternating filtration and backwashing cycli.

When combined with powder activated carbon addition, it can be used to treat groundwater contaminated by micropollutants such as pesticides. As an alternative, NF has been considered for the production of high-quality drinking water, as it leads to very efficient removal of natural organic matter (NOM), a precursor of disinfection byproducts.

Table 2. Typical run for semi dead-end MF/UF operation

	duration	flux ($l\ h^{-1}m^{-2}$)	volume
Filtration cycles	20 to 60 min	50 to 125	10 to 100 l permeate per m^2 of membrane surface
Rinsing cycles (Backflush)	20 to 60 sec	200 to 300 (reverse flux)	at least 3 times dead volume of concentrate side
if TMP remains high after the rinsing cycle (typically after 1 week/1 month of operation)			
Chemical cleaning (and disinfection)	static soaking (15 to 60 min) with chemical cleaning solution (e.g., NaOCl, acids, alkalines and detergents) followed by rinsing with MF/UF permeate		

Drinking water can also be produced by brackish or seawater desalination. In this area, RO and also ED are applied at large scale. Depending on the feedwater quality, various pre-treatment schemes are implemented, in which UF may play a role.

Market drivers for the implementation of membranes in wastewater treatment, are the need to meet regulations for discharge standards and the implementation of water reuse. MBRs are mostly considered when stringent discharge standards have to be met, when space is limited and when plant capacity has to be increased. When water reuse is a driver as in many industrial environments, an additional advantage comes from the fact that the permeate can be subjected to sensitive post-treatment technologies such as RO, without additional pre-treatment. MBRs therefore often form the core of water reuse schemes.

As membranes can achieve a higher treatment standard than conventional processes, they are often implemented to upgrade wastewater quality by removing particulates (MF/UF) and dissolved substances such as salts and dissolved organics (NF/RO). When applied on process streams, the aim may either be to purify the water stream, to concentrate and recover the pollutant or occasionally to achieve both. Examples are the removal of heavy metals from electroplating rinse waters by ED and the removal of volatile organic pollutants from water by pervaporation.

As industry is faced with increasing problems of water supply and increasing costs of wastewater discharge, alternative sources of process water are searched for. Wastewater is a potential source but requires regeneration before it can be recycled as e.g. industrial process water or cooling tower make-up water. Membrane technology is often implicated in such water loop closure schemes. Numerous examples exist in many industrial sectors and have been documented in literature. One arbitrarily chosen case study is the Pasfrost vegetable processing plant in Belgium. The company implemented water saving measures such as partial reuse of wash water for low-grade applications and extended wastewater treatment to produce a more stable effluent suitable for reuse. After a two step anaerobic-aerobic biological purification step, the effluent is subjected to coagulation/sand filtration. Then, the flow is directly reused for second–grade operations after a disinfection step or pumped to a two-stage RO with UF pre-treatment. After an additional UV disinfection, a sterile process water is obtained for reuse[4]. The introduction of this reuse scheme allowed the company to limit its groundwater consumption. Investment and energy consumption costs were lower than for the alternative of evaporation.

Water reuse is evidently not only considered in industry, but is also implemented for potable water production. The multibarrier approach for safe drinking water production usually involves a combination of membrane filtration and disinfection. Well-known examples are the production of NeWater in Singapore, direct potable reclamation in Windhoek, Namibia for over 40 years, and the Torreele plant in Belgium where MBR + RO permeate generated from municipal effluent is infiltrated in a dune water catchment area.
It is important to note though that discharge of concentrate streams from membrane separation processes may prohibit the implementation of advanced reuse schemes.

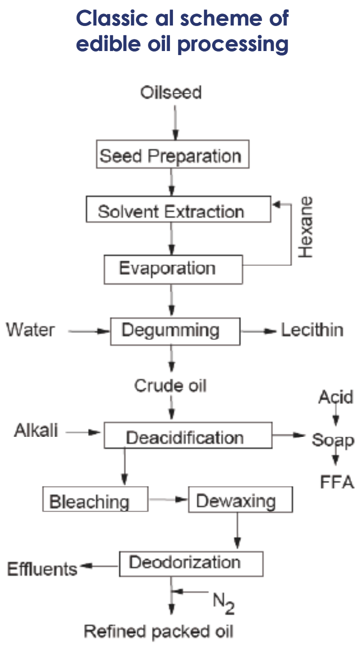
2. Organic solvent filtration[5]

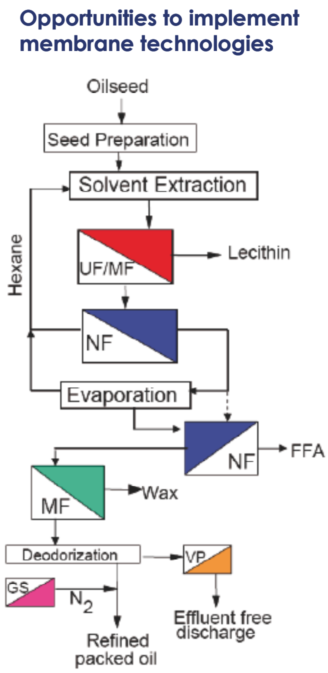
After decades of successful application in water, membrane separation processes have recently received substantial attention in attempts to integrate them in processes occurring in organic solvents. Nanofiltration and pervaporation which are widely accepted as separation technologies for the treatment of aqueous streams, are now on the threshold of being industrially applied in organic solvents as well.
Particularly *solvent resistant nanofiltration (SRNF)* and *organophilic pervaporation (OPV)*, hold an enormous application potential since they allow to separate organic mixtures down to a molecular level by simply applying a pressure gradient over a membrane or a low vacuum at the permeate side, respectively.

Both techniques have most potential as a complement in a hybrid process to complement or upgrade existing production facilities based on more traditional separation processes (distillations, evaporations, chromatographic separations, crystallizations, adsorptions or extractions). For applications allowing only low thermal stress or using non-volatile solvents, on the other hand, membrane technology can be <u>the only</u> technical solution. Most applications are found in food processing, pharmaceutical and fine chemical synthesis, catalysis and petrochemical refineries.

- *Food processing*

Most processes in the food industry are evidently aqueous, but in some cases, organic solvents are extensively used. Solvents are in first instance applied in the vegetable oil industry, (for fractionation and extraction) and in the synthesis of some food additives. Compared to the classical processes applied in oil processing, membrane technology avoids the use of additional chemicals or high-temperature treatments, thus minimizing waste streams, energy consumption and thermal damage to the products. Membrane-based solvent filtration allows solvent recycling and separation of molecules in a customized manner.



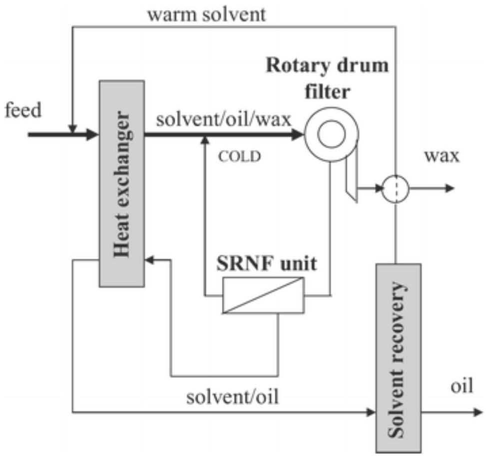


There are several steps in edible oil processing where integration of membrane-based solvent filtrations offers opportunities by replacing or supplementing conventional approaches, UF membranes have been used for degumming, while SRNF can be applied for the removal of oxidation-sensitive free fatty acids and for the recovery of extraction solvents.

As a mild, non-thermal and thus non-destructive separation technique able to separate water/organic solvent mixtures, OPV is more and more used for the isolation and purification of natural aromas which are often used as high value food ingredients. The challenge of maintaining ingredient functionality (flavor, color, texture, etc.) during processing is driven by consumer preferences relating to health and food safety, and for 'original' or natural characteristics. OPV provides and alternative to thermally driven methods for isolating highly concentrated natural aroma extracts from highly diluted aqueous solutions

- *Petrochemical refineries*

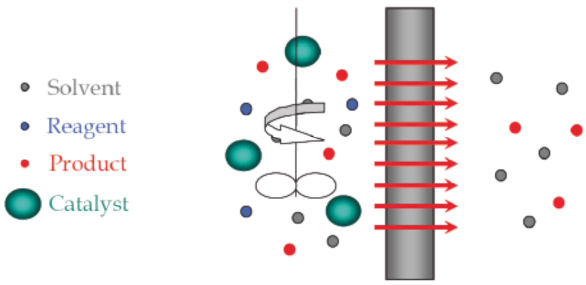
The largest scale on which membrane technology has been introduced so far in liquid-phase organic processes is in petrochemistry, more specifically in the refining of lubricants. The refining industry is both energy- and separations-intensive, and is often accompanied by a large exhaust of organic solvents, suggesting that large-scale membrane systems can provide significant benefits.



The best-known and most successful application of SRNF to date has been in ExxonMobil's MAX-DEWAX process, installed in 1998, which is employed for crude oil dewaxing at a 72000 barrels per day scale. The lube oil filtrate is treated in a SRNF installation using spiral-wound polyimide membranes achieving lube oil rejections of more than 95%. By replacing the evaporation step with a SRNF-membrane, a 99% pure solvent mixture could be obtained at refrigeration temperature, which could be directly recycled to the chilled feed stream, without the need for additional cooling. The capital investment for the SRNF was only 1/3 compared to the costs for the same capacity increase using conventional technologies. The SRNF-assisted process only needs 25% of the heat consumption, 20% of the size and 10% of the refrigeration capacity, resulting in a pay-back time of less than 1 year. The anticipated membrane lifetime of 1.5 years has meanwhile been largely passed, demonstrating the robustness of the polymeric membrane. This highly successful application at large scale clearly shows the potential for SRNF to impact the energy and chemical sectors.

Other SRNF/OPV-based refining applications that are currently investigated include desulphurization of gasoline, deacidification of crude oil, aromatics enrichments of various refinery streams, benzene reduction in naphta, and polar/non-polar separations.

- *Homogeneous catalysis*

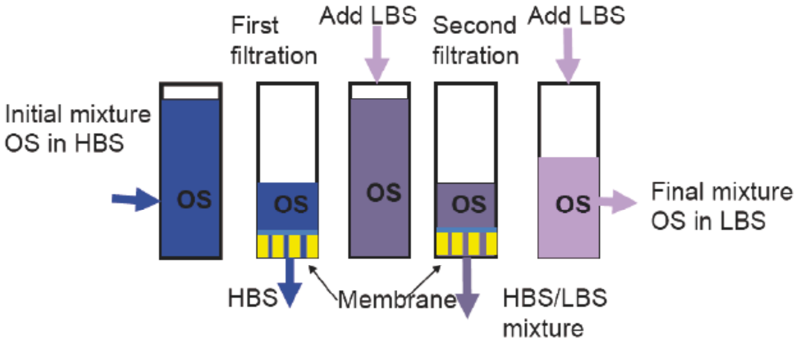


The separation of reaction products from catalysts is a major problem in many types of homogeneous catalysis. Usually, homogeneous catalysts are relatively large, and the reaction products substantially smaller, so that separation is feasible with SRNF. In parallel with the advent of several commercial SRNF membranes, important efforts have been devoted over the past years to the separation of homogeneous catalysts from their reaction mixtures in order to recycle the catalyst and/or facilitate product purification. Coupling with SRNF now allows to efficiently use and re-use highly active and selective homogeneous catalyst with all the advantages of heterogeneous catalysis, such as easy catalyst separation, straightforward product isolation and continuous operation. Removal of homogeneous catalysts is currently most commonly achieved via distillation, chromatography or extraction. Whenever SRNF is chosen to recover homogeneous catalysts, very high catalyst rejections and a long-term catalyst stability are absolutely necessary in order to be economically viable. If a membrane is not sufficiently resistant to the pressure and temperature conditions needed for reaction, continuous membrane reactors are excluded and only batchwise filtration-reaction cycles can be applied then. Evonik (the former Degussa) successfully integrated a SRNF membrane installation in its hydroformylation unit to separate and recycle the homogeneous rhodium (Rh) catalyst. Given the price of Rh (approximately €50/g) SRNF-coupled catalyst recovery clearly means an enormous cost reduction.

- *Pharmaceutical and fine chemical synthesis*

Work-up and post reaction processing and separation accounts for as much as 40-70% of the total production costs of fine chemicals. SRNF has many potential applications in organic synthesis, i.e. solvent operations, product purification and natural product fractionation. Most complex organic molecules used as active pharmaceutical ingredients (APIs) are synthesized through multi-step routes involving a sequence of organic reactions.

Solvent exchanges are used when a first stage (e.g. a reaction or crystallization) requires a particular solvent, and is followed by a second stage that requires a different solvent. When the first solvent has a much lower boiling point than the second solvent this is typically done by a sequence of distillations. However, since most pharmaceutical intermediates are heat sensitive, conventional distillation can only be carried out under vacuum. SRNF can be used to effect solvent exchanges at ambient temperature and regardless of azeotropic behaviour or the boiling point order of the two solvents to be exchanged. This means that an organic solute (OS) can be swapped from a high-boiling solvent (HBS) to a low-boiling solvent (LBS).



A similar approach can be adopted for the purification of APIs, i.e. for the removal (washing out) of impurities such as trace metals, unwanted reactants or polymeric impurities.

3. Food and beverage processing[6]

Membrane filtration is a good example of a simple and efficient technology used to enhance food quality with excellent future prospects. The use of membrane filtration offers a wide range of advantages for the consumer as well as for the producer. On the one hand, filtration technology offers an efficient way to gain *superior quality and safety* without destroying the fundamental sensory qualities of the product. It removes unwanted ingredients like microorganisms, dregs or sediments that have a negative impact on product quality, making the final product more attractive in texture and increasing its shelf life. On the other hand, it may *reduce some production steps* and increase yield, has a high degree of selectivity, improves control over the production process and has low energy costs.

In the food and beverage industries, membrane filtration is *state-of-the-art technology* for clarification, concentration, fractionation (separation of components), desalting and purification of a variety of beverages. It is also applied to improving the food safety of products while avoiding heat treatment. Some examples of final products using this technique are fruit and vegetable juices, like apple or carrot; cheeses, like ricotta, ice cream, butter or some fermented milks; skimmed or low-lactose dairy products; microfiltered milk; non-alcoholic beers, wines and ciders, etc. Membrane equipment for the dairy industry has become integral to manufacturing milk, cheese and whey proteins.

- Cheese making: Ultrafiltration of milk represents the first real innovation in the history of cheese making. During the cheese making process UF is an effective means of recovering the by-products that are otherwise lost in the whey. At the same time cheese products of higher nutritional value are obtained at a better price.
- Microfiltered milk: Classical techniques used to improve milk's shelf-life and safety are based on heat treatments, like pasteurisation and sterilisation. Microfiltration constitutes an alternative by improving the microbiological safety of dairy products whilst preserving the taste.

Despite the market's age, there are still emerging, and potentially large growth applications in protein isolation and other uses of separation. Manufacturers are placing increased emphasis on using membrane methods to replace functions formerly performed by chemical processing. One area of focus is removing or minimizing problems associated with *diatomaceous earth (DE)* in beverage processing. Substituting membranes for DE in these applications is more environment-friendly, it protects the health and safety of the workforce, and more efficiently and economically resolves maintenance and disposal issues.

In numerous industry processes, competitive technologies (such as centrifugation, adsorption, evaporation, distillation, pasteurization, and ion exchange) are used as a complement to methods based on membrane technology. In many instances, this *hybrid approach* helps manufacturers ensure the quality and safety of products as required by consumers and government agencies.

The development of filtration techniques and their distribution is not yet complete. There is continuing development of new applications based on the technique. New methods, in particular development of better and longer lasting membranes, offer new perspectives. Nanofiltration (for selective recovery of high value compounds), membrane reactors (with enzymes for biotransformation or viscosity reduction) and membrane contactors (e.g. membrane evaporation for the concentration of fruit juices) have emerged as technologies with a strong growth potential.

4. Membranes in (petro)chemical related industries[7]

Nowadays, membrane technologies are becoming more frequently used for separation of wide varying mixtures in the (petro)chemical-related industries and can compete successfully with traditional schemes. Especially the development of novel materials for gas membrane manufacturing such as organic polymeric, hybrid organic-inorganic and inorganic will expand the use of membrane technology into new fields of applications

In the petrochemical industry, olefins such as ethylene and propylene are the most important chemicals used for the production of polyolefins such as polyethylene, polypropylene, styrene, ethyl benzene, ethylene dichloride, acrylonitrile, and isopropanol. An important step in the manufacture of olefins is large-scale separation of the olefin from the corresponding paraffin. Furthermore, dehydrogenation, oxidative coupling of methane, steam reforming of methane and water gas shift reaction are some important reactions in petrochemical industry.

Membrane gas separation is attractive because of its simplicity and low energy cost, but it has one major drawback and that is a reverse relationship between selectivity and permeability. Nano composite membranes, in which selectivity and permeability can simultaneously be improved, solve this problem. Petrochemical waste streams may contain phenolic compounds or aromatic amines. They are highly toxic and at high concentrations are inhibitory to biological treatment. Membrane aromatic recovery system (MARS) is a relatively new process for recovery of aromatic acids and bases.
Wastewater in petrochemical industry is currently treated by activated sludge process with pretreatment of oil/water separation. Tightening effluent regulations and increasing need for reuse of treated water have generated interest in the treatment of petrochemical wastewater with the advanced membrane bio-reactor (MBR) process.

Traditional chemical engineering separation methods rely mostly on differences in physical properties (e.g., boiling point, size, solubility) between the components of a mixture. If physical properties are similar or if a high specificity is required, separation methods that rely on chemical differences, rather than physical differences, may be useful. Already in the early nineties, possibilities of combining membrane separation and distillation gained interest. Although most membrane processes cannot produce high-purity products, it may be possible to take advantage of the energy efficiency associated with them to perform part of the separation.

Chemical synthesis could also be combined with a closely coupled membrane separation device. This would be most useful for equilibrium processes and would require a membrane selective for the particular product. An example is the selective production of *para*-xylene by an equilibrium redistribution of mixed isomeric xylenes coupled with selective transport of the product through a membrane.
The most intimate combination of a separation process with chemical synthesis occurs in a membrane reactor, in which the membrane and catalyst are one and the same. Membrane reactors can potentially increase the efficiency of chemical synthesis because the reaction and separation steps are combined into a single process.

Synergistic processes that combine chemical synthesis with distillation, sorption, and membranes can, in principle, lead to more energy-efficient and materialsefficient chemical processing, especially for equilibrium-controlled reactions.

5. Membranes in the production of alternative fuels[8]

Membranes are helping to produce environmentally friendly systems to generate energy. Especially gas separation membranes, both polymeric and inorganic, are playing an important role in the search towards alternatives for fossil fuels.
On one hand, membranes are involved in the production of alternative fuels. On the other hand, they are used for the purification of those fuels to make them suitable for certain applications. Commercial membranes are already available for:

- hydrogen production;
- hydrogen separation and purification;
- natural gas conditioning;
- fuell cells.

Hydrogen production

Hydrogen is not available in its free molecular form on earth. To obtain molecular hydrogen as fuel, separating hydrogen from carbon, oxygen, nitrogen and other elements to which it is chemically bound is necessary. The most widely used method of hydrogen production is steam reforming of light hydrocarbons (mainly methane). The process consists of:

- the initial reforming step (methane and steam react to form CO and hydrogen);
- the water-gas shift reaction (CO reacts with steam to form CO_2 and hydrogen).

After the overall steam methane reforming process, CO_2 has to be removed from the process stream. Traditionally this separation is performed with an amine-based acid gas scrubber or with pressure swing adsorption, but membranes can offer a better solution. Because methane is a stable hydrocarbon, high temperatures and pressures are required. To make the production of hydrogen energy efficiently, the purification of hydrogen should be run at or close to the reforming temperatures. Therefore, inorganic membranes are the most suitable.
Instead of purification of hydrogen afterwards, also a membrane reactor can be used. In that case, reaction and separation can happen simultaneously. As soon as hydrogen is formed, it is transported through the membrane. By removing hydrogen selectively from the reaction system, the initial reforming reaction and the water-gas shift reaction are shifted to the product sides. That way, highly efficient conversion of methane to CO_2 and hydrogen can be attained. Membrane reactors with palladium alloy membranes are already commercial available.

Another way of producing hydrogen is electrolysis. Electrolysis takes place when an electric current flows through an electrolyte (water) from an anode to a cathode. Water molecules split into hydrogen and oxygen. Two types of water electrolysers are available: alkaline electrolysers and proton exchange membrane (PEM) electrolysers. Dupont's fluorocarbon-based membrane, Nafion, is the most used membrane.

The third method to produce hydrogen is coal gasification. Coal gasification breaks down the coal into smaller molecular weight molecules, usually by subjecting it to high temperature and pressure. This leads to the production of syngas, a mixture mainly consisting of carbon monoxide and hydrogen. Membranes can be used to separate hydrogen from the mixture.

Hydrogen recovery from refinery, petrochemical and chemical process streams

The first large-scale application of membrane gas separation was the separation of hydrogen from nitrogen, methane and argon in ammonia purge-gas streams. This application is ideal for membrane separation because

- hydrogen is highly permeable;
- the ammonia purge gas is already at high pressure;
- the gas is clean and free of higher hydrocarbons (no plasticization or fouling).

Nowadays, hydrogen can also be recovered from refinery, petrochemical and chemical process streams and a range of polymeric membranes are commercially available.

Natural gas conditioning

In many locations, natural gas contains CO_2, H_2S, heavy carbons and tom much N_2. These components have to be removed to produce pipeline-acceptable gas. Membranes can offer therefore a simple and low-cost solution. In the natural gas industry, the principal application for membranes is the separation of CO_2 from natural gas. Polymeric hollow fibre and spiral wound cellulose acetate membranes are commercially available for this application.

Fuel cells

One of the cleanest way of producing power is the use of fuel cells. Fuel cells use non-depleting fuels and can produce energy without the formation of polluting compounds. They offer a unique method to convert chemical energy into electrical energy. A fuel cell is composed of two electrodes (anode and cathode) and an electrolyte. The fuel is oxidized at the anode (with the help of a catalyst), the oxidant moves through the electrolyte and is reduced at the cathode. The electrons released in these reactions can be used to produce the desired electrical energy.

There are several types of fuel cells. They can be distinguished by type of electrolyte material used as a medium for the internal transfer of ions (protons). The electrolyte can be for example an alkaline solution, but also a membrane.

In a proton exchange membrane fuel cell (PEMFC), a proton-conducting polymer membrane is used as electrolyte. The fuel can be pure hydrogen (PEMFC), reformed hydrogen or direct methanol (direct methanol fuel cell or DMFC). Currently, perfluorinated polymer electrolyte membranes are used in PEMFCs. Nafion-type materials, also used for electrolyses, have very favourable characteristics but they are not suitable for large-scale DMFC applications due to their high methanol crossover and high costs. Therefore, research is know focused on the development of alternative materials.

The electrolyte in a solid oxide fuel cell (SOFC) can be an oxygen ion conducting electrolyte membrane (OSOFC) or a proton conducting electrolyte membrane (HSOFC). The membrane is a solid, nonporous metal oxide. In OSOFC, the main used electrolyte is made from zirconia doped with yttria. In HSOFC, perovskite materials are used.

In microbiological fuel cells, organic substrates are used as fuel. Microorganisms or enzymes are used as catalyst. They are attached to the anode and break down the organic substrate producing electrons and protons. A polymeric membrane is used as electrolyte, especially sulfonated poly (ether ether ketone) membranes are suitable.

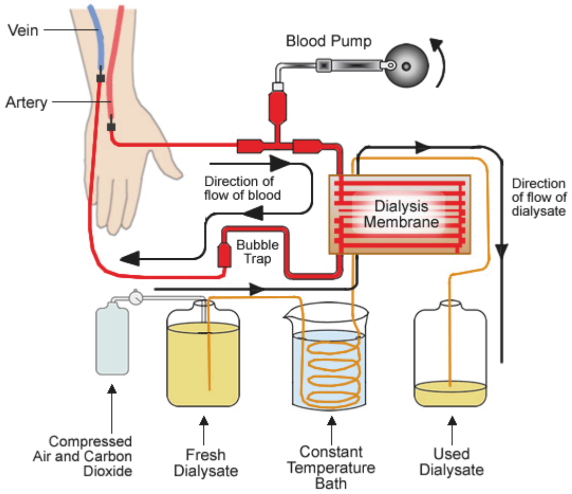
6. Medical and health applications[9]

Membrane technology is of major importance in medical applications, particularly in a number of life-saving treatments. Membranes are amongst others used in drug delivery, artificial organs, tissue regeneration, diagnostic devices, bioseparations, and as coatings for medical devices. The total membrane area produced for medical applications almost equals the membrane area of all industrial membrane applications together. In all cases, biocompatible, and in some applications biodegradable materials are required for membrane fabrication.

Drug delivery

The goal of an ideal drug delivery system is to deliver a drug to a specific site at a specific moment and with a predefined release pattern. A constant drug level in blood or sustained drug release to avoid multiple doses and bypassing of the hepatic ‘first-pass’ metabolism forms an important challenge. In most membrane-based drug delivery systems, a drug reservoir is contained in a membrane device.
In transdermal drug delivery, the drug is incorporated in a patch and delivered through the skin due to a concentration gradient or another driving force such as an electrical current. This allows continuous administration of drugs with short half-lives, rather similar to intravenous infusion, with the clear advantage that transdermal drug delivery is non-invasive and does not require hospitalization.

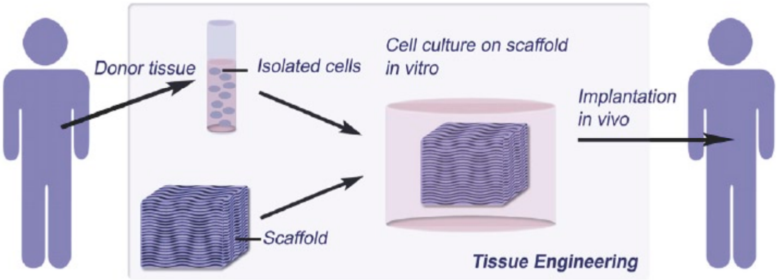
Dialysis - Artificial kidney



Healthy kidneys form an essential part of the metabolic processes of the human body. Kidney failure, due to infections, high blood pressure, diabetes or extensive use of medication, results in building up of harmful wastes and excess fluids in the body. Chronic kidney failure therefore requires a dialysis treatment using an artificial kidney. Blood is taken out of the body and passes through a special membrane that removes waste and excess fluids. The purified blood is then returned to the body. The dialysis machine can also administer drugs, for instance heparin to avoid blood clotting during the treatment. Today, more than 1.8 million people worldwide require regular kidney therapy, and among them 1.5 million undergo dialysis. A typical treatment involves 3 sessions a week which take 3-5 hours each. The yearly growth of dialysis patients amounts to 7-8%.

A dialysis membrane contains pores that allow small molecules such as water, urea, creatinine and glucose to readily pass through, while retaining the red cells, platelets and most plasma proteins. Three treatment modes are commonly used, i.e. hemodialysis, hemofiltration and hemodiafiltration, in which solute removal is basically performed by diffusion, convection, and diffusion/convection, respectively. Most of the dialysers up to the late 1960s were manufactured from regenerated cellulose, often chemically modified to enhance blood compatibility. Later on, synthetic membranes were prepared from hydrophilic or hydrophilized copolymers (e.g. polymethylmethacrylate) or hydrophilic blends (e.g. polysulfone or polyethersulfone mixed with polyvinylpyrrolidone). The first dialysis membranes were flat plate-and-frame modules. Today, hollow fiber modules are mostly used. The technology of dialysis module preparation has advanced much and is nowadays fully automated. The membrane-based therapy is still not complete and manufacturers, often in collaboration with academia, work on the improvement of membranes, modules and devices.

Membranes in tissue engineering



The replacement of organs has since long been subject of debate, however, the field of engineering tissue *in vitro* to repair damaged tissue *in vivo* arose only two decades ago. An autogenic tissue engineering transplant, using the patient's own cells, would address most limitations of direct transplantation. Therefore, *in vitro* construction of engineered tissue replacements can offer an excellent alternative. One of the major research themes is scaffold fabrication. A scaffold is a 3-D construct that serves as temporary support for isolated cells to grow into a new tissue prior to implantation in the host tissue of the patient. The scaffold design determines to a large extent the functionality of the construct. The scaffold should be highly porous with good pore interconnectivity to ensure sufficient nutrient transport towards the cells and removal of waste products. In 'soft' tissue applications, e.g. skeletal muscle or cardiovascular substitutes, mainly polymers are used (e.g. collagen, fibrin, polyhydroxybutyrate, chitosan, polylactic acid) whereas ceramics and metals are especially applied in 'hard' tissue replacements, e.g. bone substitutes. A great variety of well-known membrane fabrication techniques are used in tissue engineering, in particular for scaffold fabrication.

Since the field of tissue engineering is quite young, the broad clinical application of tissue engineering constructs is still premature. Nevertheless, a wide variety of materials have been tested as skin grafts and series of clinical products are available on the market.

References

1. Brauns, E. 2003. Computer aided design for reverse osmosis plant, in Membranes for Industrial Wastewater Recovery and Re-use, Judd, S. & Jefferson, B. (eds.), 2003, Chapter 4 Section 1, Elsevier, Oxford

2. Judd, S. (2006). The MBR book. Principles and applications of membrane bioreactors in water and wastewater treatment. Elsevier, Oxford, UK. Meng, F., Chae, S.-R., Drews, A., Kraume, M., Shin, H.-S., Yang, F. 2009. Recent advances in membrane bioreactors (MBRs): membrane fouling and membrane material. Water Research doi:10.1016/j.watres.2008.12.044 (in press). Stephenson, T., Judd, S., Jefferson, B., Brindle, K. (2000). Membrane bioreactors for wastewater treatment. IWA Publishing, London, UK

3. A white paper on MBR standardisation has been written (available at www.mbr-network.eu) and a standardisation process on submerged MBR technology was initiated via a CEN (Comité Européen de Normalisation) Workshop Agreement.

4. Jefferson, B. 2003. Case studies. In Judd, S. & Jefferson, B. (eds.) Membranes for industrial wastewater recovery and re-use. Elsevier, Oxford, UK

5. P. Vandezande, L.E.M. Gevers, I.F.J. Vankelecom, Solvent resistant nanofiltration: separating on a molecular level, Chem. Soc. Rev. 37, 2008, 365. J.H.A. Willemsen, B.H. Dijkink, A. Togtema, Organophilic pervaporation for aroma isolation – industrial and commercial prospects, Membr. Technol. 2, 2004, 5. E. Boam, Industrial applications of MET organic solvent nanofiltration membranes, presentation at EMS Summer School on Solvent Resistant Membranes, September 8-12, 2008, Leuven, Belgium. A. Livingston, Solvent nanofiltration in organic processes, presentation at EMS Summer School on Solvent Resistant Membranes, September 8-12, 2008, Leuven, Belgium. G. Baumgarten, Solvent filtration developments at EVONIK: recycling of homogeneous catalysts, presentation at EMS Summer School on Solvent Resistant Membranes, September 8-12, 2008, Leuven, Belgium.M. Cheryan, Membrane Technology for vegetable oils and nutraceuticals, presentation at EMS Summer School on Solvent Resistant Membranes, September 8-12, 2008, Leuven, Belgium.

6. Ionics Inc. 2004. Membrane technology benefits the food processing industry. Filtration & Separation 41(8):32-33. FOOD TODAY, 09/2005. http://www.eufic.org/article/en/food-technology/food-processing/artid/membrane-filtration-food-quality/

7. Maryam Takht Ravanchia, Tahereh Kaghazchia*, Ali Kargarib. 2009. Application of membrane separation processes in petrochemical industry: a review. Desalination 235:199–244.

8. Baker R., Future directions of membrane gas-separation technology, Membrane Technology 138: 5-10, 2001)

9. D. Stamatialis, et al, Medical applications of membranes:drug delivery, artificial organs and tissue engineering, J. Membr. Sci., 308 (2008), 1-34.

Advised reading

Series Introduction to membranes in Filtration and Separation by Pearce, G.

2007a. Introduction to membranes: filtration for water and wastewater treatment. March 2007: 24-27
2007b. Introduction to membranes: membrane selection. April 2007: 35-37
2007c. Water and wastewater filtration: membrane module format. May 2007: 31-33
2007d. Water and wastewater filtration: process design. June 2007: 36-38
2007e. Introduction to membranes: fouling control. July/August 2007: 30-32
2007f. Introduction to membranes: water and wastewater – RO pre-treatment. September 2007: 28-31
2007g. Introduction to membranes: manufacturers' comparison: part 1 -3. October 2007: 36-38, November 2007: 28-31 December 2007: 30-33
2008a. Introduction to membranes: an introduction to membrane bioreactors. January/February 2008: 32-35
2008b. Introduction to membranes – MBRs: manufacturers' comparison: part 1 to 3. March 2008: 28-31; April 2008: 30-32 and May

NanoMemPro

European Network of Excellence

NanoMemPro Activities

Chapter 1
Integrating Activities

1.1. Integrate Knowledge Management

WP01.1 - Coordinator: SINTEF

Aim

Efficient knowledge management is of key importance to bring research and industrial development forward. The overall objective of WP01.1 was to support training and education actions, and establish a common e-storage place where all relevant information could easily be accessed and used, through the implementation of standard procedures to collect and disseminate information.

Highlights

NANOMEMPRO installed an extranet-based e-database with a management tool providing secure and effective project monitoring and document. This database was both secure and easily accessible for all partners; all relevant information was placed in folders corresponding to each work package.

Standard procedures were set up to collect and disseminate information exchanged during meetings (e.g. seminars, workshops, and annual meetings) and to extend the dissemination of knowledge, ongoing project initiatives, scientific information exchanged during meetings held among NoE members, members of Club of Interest (CoI) and other Partners. A procedure for following up project initiatives from the NoE partners and members of the Club of Interest was discussed, with a simple chart/form suggested for such procedure. This procedure allows gathering information on joint proposals and is available on the extranet.

Many workshops and training courses for scientists/students were organized: dissemination workshops during ICIM9 – Norway, June 2006, European Membrane Society Summer Schools (Spain, September 2005 and Italy, September 2007), or the series of NanoMemCourse training courses. In collaboration with the WP03 and WP12 members working on the establishment of European Education programs on Membrane Science and Technology, efforts focused on the management of training programs for undergraduate and graduate students. SINTEF distributed a questionnaire on the NoE partners' capabilities for receiving training students. A consolidated report integrating feedback of partners was delivered. This document screens numerous possibilities for exchange of training students within the network, on the basis of short or long term training period, with or without full coverage from the originating institution. SINTEF distributed a questionnaire regarding courses on management training available within the NanoMemPro NoE. The answers show a high interest among the scientists to establish shared management training courses facilitating the integrative work of Activity 01 (WP01.1 and WP01.2).

1.2. Share and Reinforce Tools and Facilities

WP01.2 - Coordinator: CNRS

Aim

Build an inventory of the partner tools and facilities relevant to the preparation, characterization and application of nanostructured membranes; define poles of excellences and eventually suggest strategies to specialize or upgrade some of these scientific or technological facilities; set up rules to share equipment among NoE partners.

Highlights

• Create an equipment database

Our first task was to interview all partners concerning the equipment they had that could be accessed by other Network partners. Collecting this information was a joint effort carried out with WP07. A database was set up listing equipment, performances, persons in charge and access conditions. The database was posted on the internet thanks to a software developed within the framework of WP06.2. It features 200 different analytical tools or pilot facilities with their main characteristics.

• Organize topical workshops

Our response to the question of enhancing synergy between partners of the Network, and more generally centers of excellence within Europe, was to organize high level topical workshops, in order to evaluate the strengths and weaknesses of the equipment available, to share protocols, methodology and data analysis, as well as technical know-how. This kind of workshop was also meant to gather scientists and equipments operators (technicians and engineers), which is another strong argument in favor of integration. Only one workshop on scattering techniques was organized, by Dr. Arie van der Lee, but we believe that the template exists and could be well applied to many other techniques.

• Identify poles of excellence

Poles of excellence in terms of technical and scientific capacity related to the preparation, characterization and application of membranes were identified. They are listed in the Table 1. Upon consideration of the type of equipment and their distribution amongst the partners, their up-grading or specialization was not considered as one of the Network's priorities.

Table 1

Poles of excellence identified by NanoMemPro

Category	Pole
Production/modification of organic membranes	UTwente
Production/ modification of inorganic membranes	CNRS
Equipment for membrane testing	VITO
Chemical analysis of fluids	IBET
Physical and physico-chemical analysis of fluids	ICTP
Physical and physico-chemical analysis of solids	FORTH
Techniques for the characterization of zeolite membranes	UNIZAR
Membranes for high temperature gas separation and fuel cells	SINTEF
Nanofiltration in organic solvents	IMPERIAL

1.3. Adaptation of Organization Activities

WP02.1 - Coordinator: CNRS

We will hereafter lay emphasis on the work carried out during the 3rd and 4th year of the project, which aimed at ensuring the durability of the Network: indeed, what is important is the way partners can go on working together now that NanoMemPro is over!

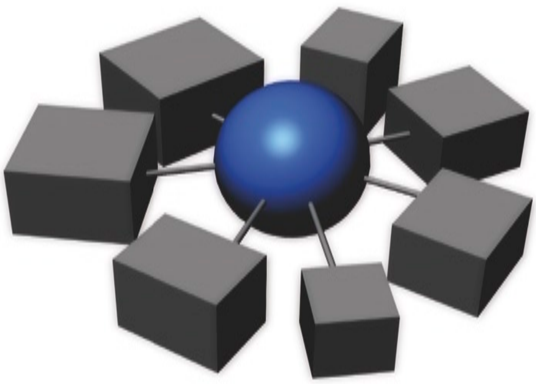
Aim

Strengthen the links between the institutions that are the European Membrane House[1]'s founding members through their active participation in the EMH's activities and tasks; adjust research projects to match the framework of the Strategic Business & Research Agenda[2]; identify new industry-driven operations; investigate the different nationally-funded programs on membranes and encourage national organizations to direct funding towards the SBRA priorities.

Highlights

Strengthen links between the different founding members

It was possible for 9 out of the 13 NanoMemPro institutions to become the Founding Members of the European Membrane House (EMH), given each partner's specific constraints. The University of Montpellier and the European Membrane Society also joined in. EMH is the Durable Integrated Structure (DIS) created to insure the long-term durability of the Network. The 4 remaining partners (Imperial, United Kingdom; ITM-CNR, Italy; DTU, Denmark; and CNRS, France) will join EMH as Associate Members: the dynamic partnership created by NanoMemPro will thus be perpetuated. The Associate Members whose contribution to EMH will have proved both reliable and sustainable will have the possibility to become "Full Members" of the association.



New joint projects in keeping with the SBRA priorities

MemBridge - CSA project

Membridge was presented in the FP7-NMP-2008-CSA-2 call in April 2008. The project's coordinating structure is the European Membrane House. The project involves 7 industrial partners (mainly SMEs). Its main objective is to create a "bridge based on membrane technologies" between EMH and a network of Russian and NIS laboratories, and to address important problems related to environment and energy through new collaborations.

Nationally-funded programs on membranes partly redirected towards the SBRA priorities

The newly accepted MEM'P project -starting time was December 2008- is supported by the French Ministry of Economy (General Directorate for Industry) for two years. It is a "Collective Action on Membranes" aiming at developing membrane projects for SMEs in France and having French SMEs participate more in European projects. If successful, the model developed by MEM'P could be transferred to other European countries, within the framework of bilateral or multilateral partnerships.

1. Refer to part 1.7 to get the gist of what the EMH is.
2. Refer to part 1.8 for more information on the SBRA.

1.4. Reinforce Electronic Communication and Networking

WP02.2 - Coordinator: UTwente

Aim

Sharing scientific and technical information is one of the most important objectives of NanoMemPro, and is fundamental to the definition of a Network of Excellence. Our aim was thus to ensure that each participant had access to such information.

Highlights

• **AN EXTRANET BASED E-MANAGEMENT TOOL** providing secure and effective project monitoring and document management was installed, in relation with WP01.1.

• **A 3D WEB CONFERENCING AND REAL TIME COLLABORATIVE WORK TOOL** was installed. This tool provides access to audio conferencing, video conferencing, collaborative work, E-learning and discussion forums on membrane related topics. This collaborative tool was accessible to the consortium members under secured access control, and proposed to the EU officer following the NoE.

• **A BI-ANNUAL NANOMEMPRO NEWSLETTER** was distributed among the partners of NanoMemPro. Its aim was to inform the NanoMemPro partners about the progress of their joint activities and to reinforce networking. In total 7 news letters were issued.

1.5. Plan for Staff Mobility and Work Positions

WP03 - Coordinator: CNRS

Aim

Make the Network more attractive for researchers; improve the mobility of researchers across Europe and between academia and industry; foster the exchange of researchers among consortium organizations; convince national bodies to take mobility into account in researchers' career.

Highlights

• Advertise the Network internationally to attract excellent researchers

The advertisement of the network actions has not been the privilege of this work package. However, we have set up NanoMemCourse, a Marie Curie Training course on topics in close relation to the expertise of the NanoMemPro Network. The objective is to attract and train promising researchers from all over the world in 5 fields identified as major fields for the future developments of membrane technologies. Two courses have been organized so far - with young researchers from 35 nationalities- and 3 more are being prepared. Three hundred grants will be offered, corresponding to more than 3000 training days at the highest level.

> **NanoMemCourse:**
> **a Marie Curie Training course**
>
> It consists in organizing 5 ten-day seminaries on Nanostructured Materials for Advanced Membrane Processes.
> For each seminary, 60 students and invited lecturers receive scholarships to cover their travel and accommodation expenses.
> Start date: February 2007.

• Improve the transparency concerning job opportunities, funding possibilities and legal requirements

One of our first actions was to collect, gather and analyze the various procedures in use in the various partner institutions for recruiting not only permanent but also non-permanent staff. A comparative analysis was prepared, showing large differences between the manpower strategies; official national web sites dedicated to job opportunities were listed.

From the interview of all Personal Officers of the partner institutions, we concluded that the mobility of the staff members is not restricted by the host institution but by the teaching or research projects commitments.

A job hunting portal (mobility portal) posted on NanoMemPro's website has been set up to advertise open job positions[1]. We have decided on financial incentives for the individuals and the concerned laboratories. In this way, all potential resistances to mobility that we could identify have been lowered. Personal and family issues remain however a question on which the network has a low impact.

• Assist researchers in mobility

Mobility within NanoMemPro's 13 partners was organized. A grid for the preparation of mobility listing the duties of the host institution as well as those of the guest researcher was discussed and published. A "mobility plan" was prepared: it regulates mobility at Master, PhD and Postdoctoral levels, and also applies to staff members.

• Prepare in liaison with WP12 the creation of a European Master and a PhD in Membrane Technology

We proposed to set up an accreditation in "Membrane Engineering" for the Master of Sciences, contributing to the creation of a European Master and PhD degree by WP12.

1. NanoMemPro Mobility Portal : http://nanomempro.com/Front/offer_b.php?id=11

1.6. Integrate the Club of Interest within the NoE Framework

WP04 - Coordinator: Imperial

The Club of Interest (CoI) is a dynamic element related to NanoMemPro.
It is the image of the market and of citizens's needs and has a great potential of resources and means to support the continuation of the Network. It consists of small and medium-sized enterprises and large industrial companies covering large fields of activities: membrane/membrane equipment producers, membrane technology industrial specialists, end-users. It also incorporates a number of public organizations/networks with activities related to membranes.
The CoI will go on beyond NanoMemPro's lifetime: it will still be open to new industrial members, public services and international organizations and will play a significant role in the activities of the European Membrane House (EMH), as a main source of industrial/technological consultants for the EMH technological clusters.

CLUB OF INTEREST

49 members of which:

18 membrane/membrane equipment producers
7 membrane processes specialized companies
17 end users
7 networks

The Club represents the main industrial fields of interest and needs for membranes in Europe.

Aim

Establish permanent interactions between membrane researchers, industries and end-users; accelerate discoveries and industrial applications of membrane technology; share costs for generic research work; finance innovation projects; stimulate fast technology transfer; set-up durable training facilities; and make people mobility easier.

Highlights

- **CoI members participating in dedicated workshops/seminars** and co-organization of workshops on membranes.

- **Participating in new research projects:** more than 20 collaborative research proposals involving CoI members were submitted for international and national funding schemes.

- **Developing a Strategic Business & Research Agenda** for Membrane Technology Development in Europe. Beyond the lifetime of the NanoMemPro project, it will be used for developing EMH future business plans.

- **Providing CoI with a privileged access to scientific expertise** of partners and to advanced technical information: a periodic newsletter was published in the European Membranes News, thus disseminating NoE information/results both to CoI members and to the European Membrane Society as well. The CoI members were also given a privileged access to the different databases developed by the NoE and various specialized equipment available within the Network.

- **Facilitating CoI interaction** with highly educated PhD, engineers and scientists specialized in membrane science and engineering. Short and long term staff exchange visits between CoI members and NoE were organized. A postdoctoral scheme with a joint funding from NanoMemPro and industry has been developed.

- **Facilitating CoI members in obtaining technical support/expertise** from the NoE consortium. Long-term cooperation on the basis of bilateral agreements were established between several CoI and NoE members.

- **Participation of the NoE** in major industrial events such as ACHEMA.

1.7. Create a Legal Entity: the European Membrane House

WP05 - Coordinator: CNRS

Aim

Make the right choice among the different possible legal entities to set up a Durable Integrated Structure (DIS); prepare the statutes in accordance, with the technical support of an external firm of lawyers; prepare the different documents which will constitute the skeleton of the activity: Strategic Business & Research Agenda (SBRA), Business Plan (BP), Internal Regulations (IR) and Communication Plan (CP); and start running the DIS by setting up its different internal structures (e.g. general meetings, directors and scientific council).

Choice of type of legal entity

After investigation of the different possibilities compatible with the specific constraints and requirements of the partner institutions, we decided to create an international Belgian non-profit making association (AISBL). In the future we may turn the structure into a European Cooperative Society (ECS), a new statute created on the request of the European Commission. The Statutes of the European Membrane House (EMH) were signed on February 27th 2008 by the EMH Founding Members, and published in mid-April 2008 in the "Moniteur Belge" (Belgian official journal)'s annexes.

Vision and objectives

The EMH will offer a single reference point of expertise and know-how to industry. It will promote Membrane Technologies and serve as interface and platform to communicate industrial and society needs in this field. In doing so it will also promote the public understanding of membranes and their various uses (e.g. Energy, Environment, Health, Chemistry and Food, etc.). The EMH will act at 4 different levels:

- As the leading provider for all kinds of contact settings, strategic advices and services to membrane-related industries;
- As a project agent inside and outside the House;
- As a strategic advisor (particularly for SMEs) for orientation or reorientation of projects towards the best available programs, for the creation of start-ups and spin-offs;
- As a one-stop place for lobbying around membrane technologies at different levels: regional, national, European or international.

Highlights

Preparation of the different documents supporting the activity

Please refer to Part 1.8, page 57.

Starting running the DIS

A Board of Directors composed of 5 members representing the founding members according to the By-Laws was set up and met in January 2008. Different proposals were made. The 1st General assembly was organized on the 27th February 2009.

1.8. Increase Financial Autonomy and Durability

WP06.1 - Coordinator: CNRS

Aim

Produce and disseminate a Strategic Business & Research Agenda (SBRA) to the entire European community (e.g. laboratories, industrialists and institutions), as the skeleton on which the European Membrane Research Area should be based; prepare Internal Regulations to inform EMH members and future members, e.g. laboratories, industrialists, research centers and institutions, of the priority missions and services of the Association; and implement a Communication Plan to establish the EMH in its role of a reference organization in Europe for all the questions related to membrane technological development.

Highlights

Strategic business and research agenda

After a huge work of 1.5 years conducted in collaboration with ALCIMED (a French consulting firm), and with the participation of many laboratories and professional associations (e.g. the CFM in France, and the DGMT in Germany), one hundred phone contacts and interviews of industrialists, 2 seminaries with 230 industrialists invited and about 60 companies participating, a Strategic Business & Research Agenda was produced and disseminated in December 2007. Six industrial sectors are covered in this document: chemicals, energy, food, health, environment and membrane materials. Scientific and technical approaches are mixed with market and industrial considerations including environmental, regulatory and competitive issues. This document should provide the orientation of new actions to launch, as well as serve as a basis for future calls at national or European level. It will be regularly updated by the EMH.

Business Plan of appropriate Internal Regulations

With the help of a subcontractor -the Efficient Technology company specialized in marketing and accounting services- a Business Plan for the EMH was completed at the end of December 2008. The sustainability of the EMH should be insured until mid 2010 thanks to the initial investment of its Founding Members. Complementary external financial resources will then have to be found. This job has already started with the agreement on 2 new 2-year contracts: MemBridge, a CSA project from the EC which aims to establish a “bridge” between Europe and Russia/NIS countries, and to provide the ground for future actions through tight contacts between 2 “networks”; MEM’P, a contract from the General Directorate of Industry at the French Ministry of Finances which aims at creating a new model to develop the activities of SMEs in the field of membrane technologies. First experimented in France, this model could be expanded to other EC countries.
The Internal Regulations document specifies the different missions and services of the EMH, as well as the way to work in order to guarantee good practices and to come to agreement among future members, particularly industrialists.

Communication and Work Plan

The EMH Communication Plan details what audiences (internal and external) are the targets of the communication actions, as well as why and how they will be reached. It features the partners’ precise roles to carry them out. It flows directly from the Work Plan pre-established by taking into account the different missions and services presented in the Internal Regulations as well as the guideline provided by the SBRA document.

1.9. Develop High Added Value Technological Services

WP06.2 - Coordinator: IBET

Aim

Structure research facilities, equipment, and software tools for common use by NanoMemPro partners and CoI members, and provide access to high added value technological services; set up common rules for accessing equipment and databases, as well as define mechanisms for technicians and researchers training with specific equipment available for sharing; and develop new software tools for modeling and simulation supported by extensive databases gathering experimental information acquired for different membrane materials and processes.

Highlights

NanoMemPro Equipment Database

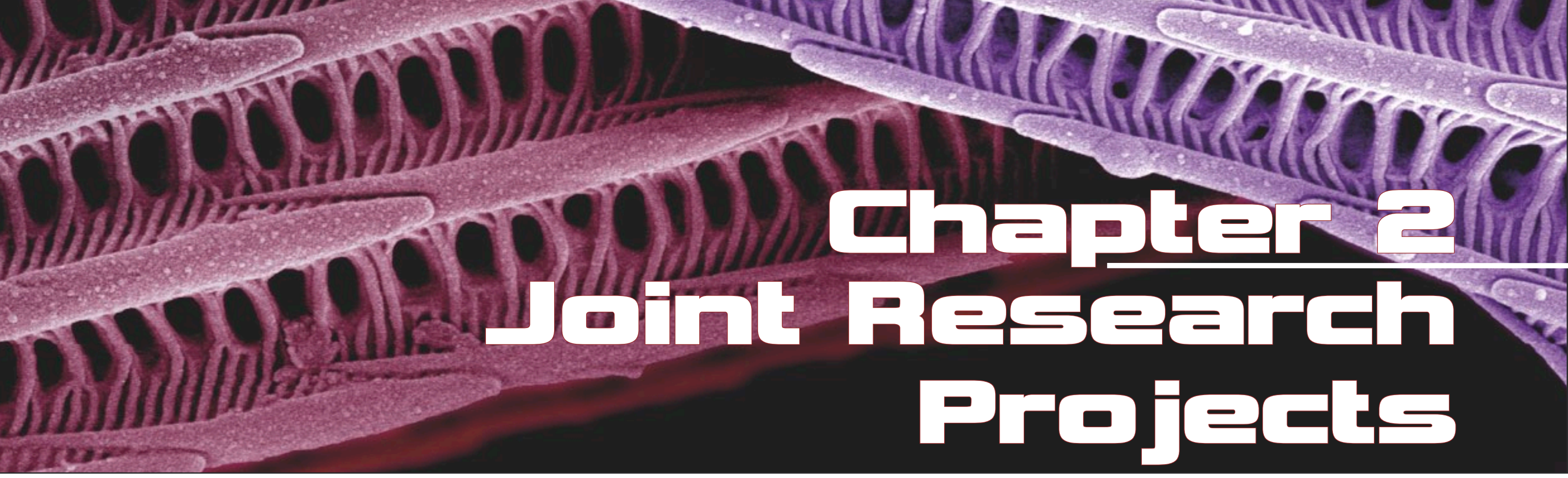
This database lists all the equipments and facilities available within NanoMemPro partners, relevant to the design, characterization, preparation and use of nanostructured materials and membranes. Its development and update throughout NanoMemPro's lifetime was ensured by WP06.2 and WP07.

The functionalities of the Equipment Database were optimized in order to allow an efficient transfer of samples between the different laboratories of NoE partners and CoI members, and to define the utilization procedures specific to each equipment. The database presents information provided by the NoE partners concerning the conditions which samples should meet when delivered, and states what additional information has to be specified by the sampler owner in order to guarantee correct measurements.

Database on solvent-resistant nanofiltration processes

The structure of a web relational database on solvent-resistant nanofiltration processes was predefined and discussed with the NoE partners. The aim is to allow comparison between different membrane materials (fabrication variables/conditions and corresponding properties/characterization) and their performance descriptors (permeability, selectivity, resistance to solvents and to temperature).
It is currently developed and will be ready by April 2009.

> **Want to know what equipment is available in the NanoMemPro labs? Then go to:**
>
> **http://www.nanomempro.com**
>
> **and click on "databases"!**



Chapter 2
Joint Research Projects

2.1. Characterization of Membrane Function

WP07 - Coordinator: UNIZAR

Aim

Optimize share use of characterization facilities; create a common reliable set of tools.

Highlights

THE CHARACTERIZATION of membranes, i.e. the measurement of the properties that determine their performance under operation conditions, is a critical step in the development of new materials or processes. From the beginning of the project, NanoMemPro has considered this task as an important field of action and has invested significant efforts to develop collaboration links in this field.

NanoMemPro Equipment Database

A first step, aiming at a better collaboration between laboratories was the creation of a database[1] describing the existing equipments, including any details useful to a potential user, such as characteristics of the sample, availability and operation limits. It was developed with WP06.2. A large number of equipments were included in this database, from those that measure the structural properties of the material (pore size distribution and contact angle) to those that evaluate the performance of the membrane under operation.

Cross-testing

A second step was to ensure that highly reproducible results were achieved in the different laboratories. Samples of materials and membranes were exchanged between the different laboratories. Material properties studied included pore volume distribution, surface area and contact angle. Membranes were also tested for gas permeation and pervaporation in several laboratories. One significant input from the Strategic Business and Research Agenda was the need for a better technology in the cut-off characterization of nano and ultrafiltration membranes. Previous results from the Charmme Network on membrane characterization, in which several NanoMemPro partners were involved, were recalled. Taking into account the lessons from that network, a new experimental program was devised, including the exchange of samples provided by Alfa Laval, a Club of Interest member. The cross-testing showed remarkable results. From the 5 participating labs, only 2 were able to meet exactly the technical requirements that were set in the agreed test protocol. A detailed analysis of the lab procedures used showed that great care has to be taken in comparing test results. Although analysis or retention curves look similar, a closer look at data analysis methods, used markers or test cell configurations can reveal different effects occurring at the membrane surfaces.

A new membrane characterization equipment

Proposals made by partners were analyzed and some of them were selected for a proof of concept. In one case, the proof of concept was successful and showed the possibility of building a new tool for the detection of defects in membranes. Such equipment was not built using NanoMemPro budget -its cost was considered too high- but one of the partners obtained other founds and was able to build the new characterization facility, thus benefiting from the experience!

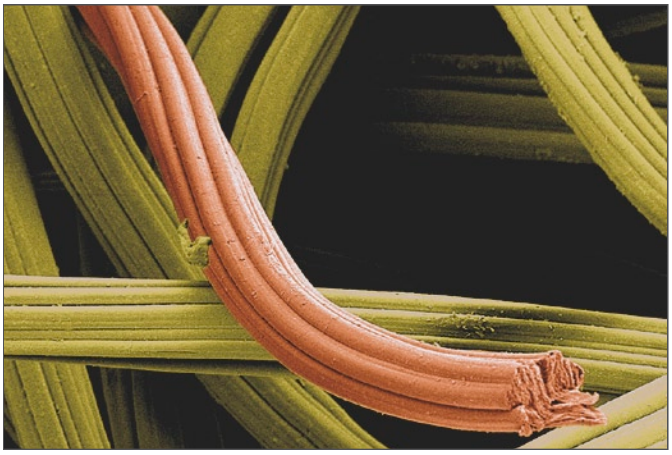
1. NanoMemPro Equipment Database: http://www.dq.fct.unl.pt/nanomemproequipmentdatabase/noev4/index.php

2.2 Modeling and Simulation of Membrane Performance

WP08 - Coordinator: FORTH/ICE-HT

Aim

Review modeling methodologies developed specifically for membranes; indicate routes and conditions for application of porous media models to certain classes of membranes (polymeric or inorganic, with emphasis on nanoscale); prepare the ground for scale-up approaches; and suggest a horizontal integration of simulation efforts focused on key membrane functions.



Approach

Structural models for different nanoporous polymer membrane materials with a special focus on high and ultra-high free volume polymers for subsequent integration into mesoscopic models and interaction with membrane synthesis, as well as optimization efforts were evaluated. A similar effort was completed using inorganic materials with emphasis on zeolites through the direct collaboration of experimentalists and modelers within the Network.

Transport models and simulators with emphasis on nanosized functional segments and calculations across scales were integrated in order to elucidate the structure-to-transport interrelation issues and concepts. Information regarding capabilities and approaches by the different partners for structure modeling were collected, along with data on modeling needs. Data was compiled and distributed among partners.

At the macroscopic scale, a systematic effort was made to identify the linking of process modeling to membrane properties. Membrane separation process models were communicated through the Network.

Six distinct exercises were launched at the beginning of the project, aiming to carry out a thorough investigation of the modeling capabilities of the Network on different thematic issues, namely:

- Membrane structure identification from SEM/TEM/SANS (CNRS-Toulouse)
- Atomic-scale material modeling/polymers (GKSS)
- Transport Calculations (FORTH/ICE-HT)
- Process-scale modeling, NF (CNRS-Montpellier)
- Membrane reactor modeling (SINTEF)
- Zeolite membranes for gas separation (ICTP)

Exercise-related questionnaires were distributed to the Partners by the exercise leaders. The data collected were subsequently tabulated in compiled form.

Highlights

Fundamental and technologically critical aspects were addressed within this work package:

- Integration of modeling methodologies specifically for membranes;
- Indication of routes and conditions for application of porous media models to certain classes of membranes (polymeric or inorganic, with emphasis on the nanoscale);
- Integration and dissemination of membrane structure and transport phenomena knowledge across the Network through partner collaboration as well as exchange of information;
- Homogenization aspects of the models within the Network;
- Simulation of membrane-based separation processes (gas, liquid and liquid-solid) and of membrane contactors;
- Exchange of ideas and information on expertise between modeling expert-members and industry in this area.

The dissemination of modeling methodologies is also performed via NanoMemCourse -"Nanostructured Materials and Membranes Training Course"- implemented by NanoMemPro partners.

Spin-off on membrane-related codes

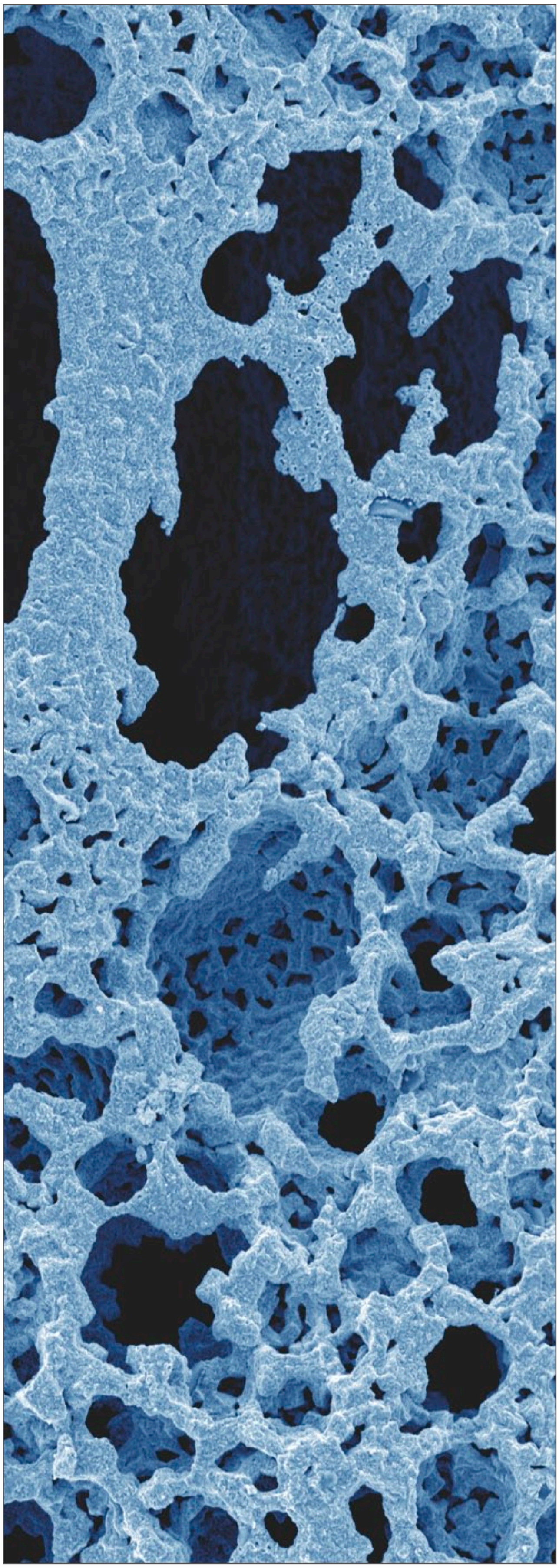
FORTH undertook a market analysis study with the objective to investigate the perspectives of a potential spin-off company that will commercialize membrane-related codes developed by members of the consortium and/or provide software-based services for industries or academic organizations.

2.3. Synthesis Optimization of Membrane Material

WP09 - Coordinator: GKSS

Aim

Evaluate and investigate new breakthrough membrane materials as well as membrane formation technologies; and share specialized membrane formation equipment of partners.



Highlights

Numerous new fabrication techniques of membranes were conducted at the laboratories of NanoMemPro's core partners. These include:

- New functionalized amphoteric polymers and copolymers (e. g. GKSS);
- Molecular self-assembly including block copolymers, surfactants and organic-inorganic templates (e. g. GKSS, CNRS-IEM, SINTEF, UTwente);
- Mixed matrix membranes with zeolites, nanotubes and carbon molecular sieves (UTwente, VITO, GKSS, ICTP);
- Zeolite membranes (e. g. FORTH/ICE-HT, SINTEF, UNIZAR, VITO, CNRS-IEM, ICTP);
- Microfabrication by microstructured mold (UTwente);
- Ceramic hollow fibers (Imperial).

Workshops

The following workshops were organized by NanoMemPro partners with or without additional support:

- Identification of breakthrough membrane materials and fabrication methods (April 28th -29th 2005 at GKSS, Geesthacht, Germany);
- Breakthrough membrane materials and fabrication methods (September 23rd 2006 in Taormina, Italy);
- New Materials for Membranes, with support of Marie Curie (June 3rd-6th 2007 at GKSS, Geesthacht, Germany);
- Emerging Membrane Materials and Manufacturing Methods (July 13th 2008 in Honolulu, USA, before ICOM 2008).

Reviews

- Review of activities on "New fabrication technologies under investigation" at different institutions partners of NanoMemPro, March 2005.
- Updated report on breakthrough technologies, October 2008.

2.4. Back-Design and Mass Production of Membrane Material

WP10 - Coordinator: ITM-CNR

Aim

Reinforce the activities on Back-Design and Mass Production of Membrane Material among the partners; increase awareness outside the consortium, involving as much as possible the membrane society as a whole.
Several priorities were defined: 1) Investigation of the current state of the art among the network partners as well as in Russia and Asian countries; 2) Involvement of technology suppliers in the actions of the network; 3) Submission of Common research proposals in the European Framework Program; 4) Work on Demo projects on Back-Design and Mass Production of Membrane Material in the partners' institutes.

Highlights

Contact with technology suppliers

The first deliverable of WP10 was the production of a (non exhaustive) list of technology suppliers, featuring the most important companies that supply either membranes, membrane modules or complete installations.

Workshop

At the start of the Network a workshop was organized by ITM-CNR in Rende, Italy, jointly with WP11.2, to evaluate the state of the art and to make plans for future actions. The workshop was attended by 28 project participants and 3 members of the Club of Interest (CoI).

Reports on membrane activities in Russia, Korea and China

An overview of the activities in Russia, Korea and China was prepared as an indicator of important membrane developments and a guide for strategic planning in Europe.
In the reports, the state of the art about the development of Membrane Science and Technology in these countries is presented. The membrane research status and the applications of the membrane science and operations are reported and analysed, with particular attention to the membrane manufacturers and suppliers, mainly in the field of water treatment and gas separation. A significant part of reported information about membrane research and applications has been obtained from companies' reports.

Demonstration Projects

Possible demonstration projects were identified in the areas of Membrane Contactors, Non-Aqueous Systems, Gas Separation and Fuel cells, corresponding to the recommendations emerging during the SBRA workshops. An introductory report on the 4 topics was mailed to all project participants and to the CoI members as an invitation to the first practical demonstration. The first demonstration on "Production and use of porous hydrophobic membranes for application as membrane contactors" was held on 23rd – 24th June 2008 in the ITM labs and was attended by members of the CoI and by Network partners, as well as by several international guests of ITM. Laboratory demonstrations, lectures and multimedia presentations alternated, covering nearly all aspects of the preparation, characterization and use of hydrophobic polymer membranes for contactor applications.

Common research proposals

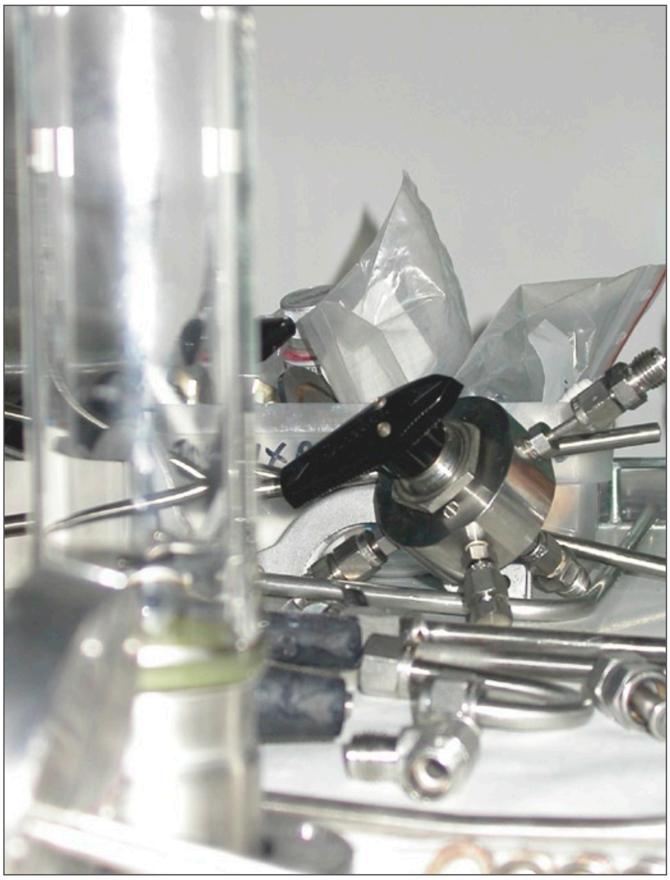
The last concrete action of WP10 was the preparation of joint collaborations, where new membrane development and/or mass production play a significant role. Several initiatives were taken by the different partners, resulting in the approval of e.g. 2 Marie Curie actions involving NanoMemPro partners (coordinated by Imperial College) and a Collaborative Project on Nanostructured Membrane Materials (DoubleNanoMem coordinated by ITM-CNR; 10 teams participating, including 2 SMEs and 2 NanoMemPro partners). The publication of a FP7 Call on "Nanostructured membrane materials" in 2008, and recently on "Membranes for water treatment", is a clear testimony of the importance of WP10 and of the NanoMemPro Network as a whole.

2.5. New Production Processes: System Approach

WP11.1 - Coordinator: Imperial

Aim

Major advances using membrane systems have been made in some areas (e.g. water and gas separation), while others remain relatively underdeveloped (e.g. organic liquid separations, membrane reactors and nanostructured materials production).
The goal of WP 11.1 was to develop more sustainable, and less hazardous production processes through development and application of membrane system engineering. Different kinds of new processes leading to intensification, environment protection and membranes mass production were investigated. The Strategic Business & Research Agenda recommendations were followed closely in the strategy and actions of this WP.



Highlights

- **A set of metrics** for measuring sustainability and hazard of membrane systems was developed.

- **A membrane system engineering approach** was applied to different production processes -e.g. syngas production, recovery and recycle of organometalic catalysts, as well as olefin recovery from the vent stream of a polyolefin production plant. A conventional process and a membrane process were compared on the basis of technical, economic, environmental and security (risk index) aspects. A set of membrane properties with the highest effect on the process sustainability and hazard was identified for each process. The findings were used as guidelines for further membrane design and development.

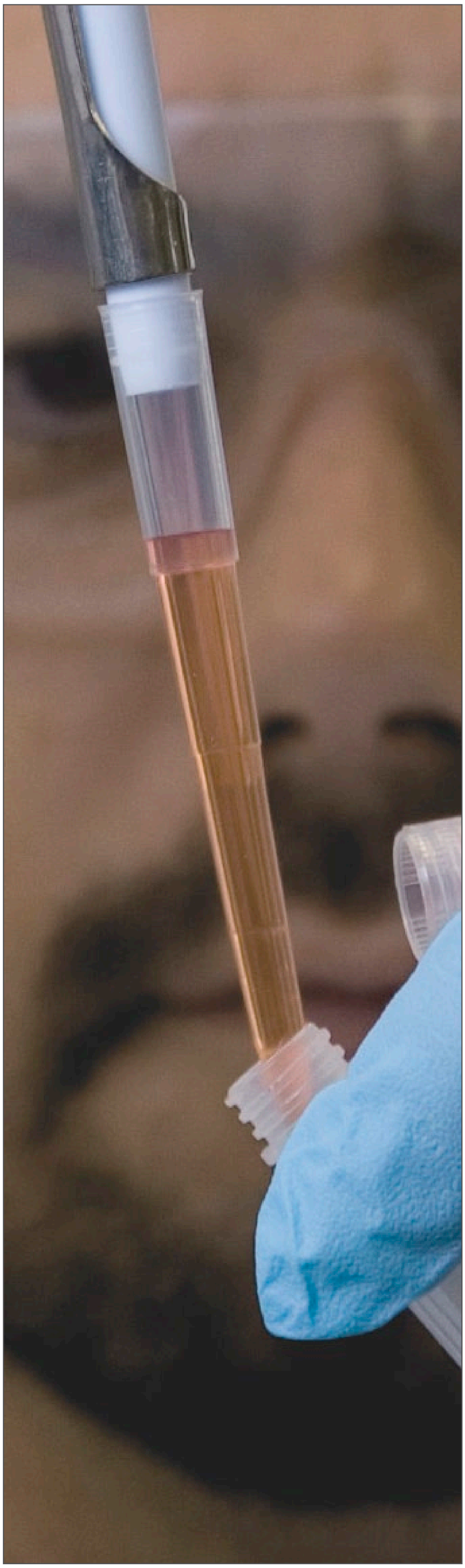
- **The way molecular architecture** of membranes impacts on macro-scale system/process performance was studied in detail – e.g. the influence of membrane formation parameters on the functional performance of organic solvent nanofiltration membranes, and on the incorporation of membrane/solvent/solute characteristics in predictive models of UF/NF performance. This approach was then used for membrane "design" for applications to different membrane processes.

- **New generations of membranes** were made, with properties "designed" to improve selected processes sustainability and reduce process hazard. Targeted membranes were highly selective, together with solvent stable membranes, acid and base resistant membranes, as well as nanostructured membranes obtained using molecular imprinting. In collaboration with CoI members, the most successful cases were scaled up from lab bench to pilot scale - small and medium scale membrane modules. The development and scaling up of membranes stable in aprotic and/or aggressive solvents follows the recommendations from industry. It is also a part of the Strategic Business & Research Agenda for Membrane Development in Europe, which thus proves the principle of better research focusing via collaboration with industry.

- **New research projects** on subjects of interest to the industry were developed. Six collaborative research proposals involving CoI members and other industrial partners were submitted for international and national funding schemes.

2.6. Food Quality: Safer Production Methods

WP11.2 - Coordinator: ITM-CNR



Aim

The work package 11.2 aimed at progressing membrane operations perspectives in food applications by evaluating needs and identifying technological strategies able to fulfill demanding challenges for high food quality, safety, stability, convenience and sustainability.

In particular, the objectives were:
1) assess state of the art, development stage of various membrane operations in various food sectors, industrial needs, consumer demand, drivers and obstacles for the exploitation of advanced membrane operations in the food industry;
2) explore the potentialities of precise and intensified membrane technologies working at molecular level, able to improve food texture, and to maximize efficiency by their synergistic integration;
3) strengthen and enlarge the critical mass;
4) structure a road map in the field of interest of the WP;
5) disseminate the work package activities and results at European and international level.

Approach

The 13 WP11.2 partners started their activities with a meeting at ITM-CNR (Rende, Italy). The objective was to map expertise, infrastructures, current and potential research areas in the food sector available within the NanoMemPro partners. A WP11.2 meeting was then performed every 6 months to update progresses in the field. Three focused meetings were organized with Club of Interest Members in order to elaborate the road map on membranes in food.
A final workshop (NanoMemFood) aiming at setting the state of the art and breakthrough advances needed in membranes and membrane processes in food industry took place in March 2008.
Three additional well recognized institutions were identified and invited to become members of the Club of Expertise. Similarly, several big enterprises were invited to become members of the Club of Interest.
An international working group was set up by inviting Institutions from Japan, China and Korea. Research plans were elaborated with expertise identified, both within NanoMemPro and beyond.
WP activities were presented at conferences and workshops at European and international level with oral and poster presentations. Scientific manuscripts were published where results of critical analyses of literature data carried out within the WP were reported.

Highlights

Food demand

Consumer demand for different food products have significantly changed in economically advanced countries due to increasing per capita incomes, demographic shifts and lifestyle changes.

These countries share a rising trend toward higher consumption of meat, cheese, fruit, vegetables, bottled drinks, functional foods for special diet. Consumers want convenient and easy-to-use products, with all the qualities of fresh products.

The changes in food consumption have important implications for food production, processing, retail sectors and environment through the choice of diet, demand for food related services, way to purchase, store and prepare food. They also impact on the amount of organic and packaging wastes generated.

Where and how food is produced, processed, packaged, preserved, distributed, prepared and disposed of also affects areas such as energy consumption (production, processing and preservation), waste generation (food losses in the farm or through the retail chain, packaging for households goods, pre-packaged foods, as well as food packaging for transport and storage), transportation (the direct-related food transport, changes in food shopping, location of hypermarkets outside large cities and small towns), and Greenhouse Gas emissions (related to direct energy consumption for food preservation, preparation and food transport).

Strategies to achieve challenges

Raw materials: abundant, non toxic, with right properties to be processed.

Technologies: clean, safe, low energy consumption, preserve properties of products and co-products, allow new product formulation.

Maximization of mass utilization: every component of the raw material entering the manufacturing process should become a valuable (saleable) product.

Maximization of energy utilization: every erg introduced should produce a derived material transformation.

Maximization of recovery and recycling: recovery in food industry mainly includes oil refining, fuel or energy generation, spreading on land, composting or use of waste.

Innovative technologies should facilitate the recycling of co-products for food applications.

Membrane Technology in Food

Benefits

Products and co-products are of high quality; concentration and separation are carried out without use of heat; membrane operations permit innovative process design and formulation strategies; equipments need small space; the membranes are flexible and easy to scale-up, they respond well to process intensification strategy for a sustainable growth; operating costs are low; and the energy used is low (e.g. it can be decreased up to 90% compared to evaporation), which is recognized among the Best Available Techniques (BAT).

General Drawbacks

The capital costs are higher compared to evaporation. The increase in concentration might be lower compared to evaporation; life of the membrane and membrane (bio)fouling is relatively short.

Innovations to overcome or minimize drawbacks

Integration of RO and MC (MD, OD); design of new membrane modules and process systems with optimized fluid dynamics and on-site cleaning procedures; membrane materials (or functionalized surfaces) to avoid microorganisms adhering.

Major drivers for Membrane Processes Implementation

More stringent legislation towards higher food quality and waste prevention, raw material scarcity, state incentives to promote technological innovation, increasing confidence in and acceptance of membrane technology, public concern, decreasing of investment costs, improvements in process design, improved operation and maintenance schedules, longer membrane life and standardization of element dimensions.

Membrane development in Food Industry

Membrane filtration is state-of-the-art technology in food processing. Major applications are treatment of whey and milk and whey protein concentration followed by beverages, wine, beer and juices. Other well developed operations, such as bipolar electrodialysis, are at an emerging stage in food applications. More recent operations, such as membrane emulsification, are at an emerging-exploratory stage.

Worldwide development of advanced membrane processes

The following figures show the worldwide patent applications on membrane emulsification and membrane bioreactors respectively. The analysis shows that EU urgently needs to increase research efforts in this field to raise competitiveness at international level.

Future research perspectives

The common opinion about challenges and needs of membranes in food applications concerns the research development of:

- **Functionalized membranes**
  - ► to immobilize of bio-molecules, e.g. for the development of membrane reactors, affinity UF and micro-structured multifunctional systems
  - ► to create surfaces repulsing cells and bio-molecules, e.g. to control bio-fouling
  - ► to prepare intelligent packaging to control the release of drugs when necessary and/or to detect the presence of harmful substances

- **Formulation** (micro-emulsion and encapsulation; need for inorganic membranes with very low pore size and pore size distribution)

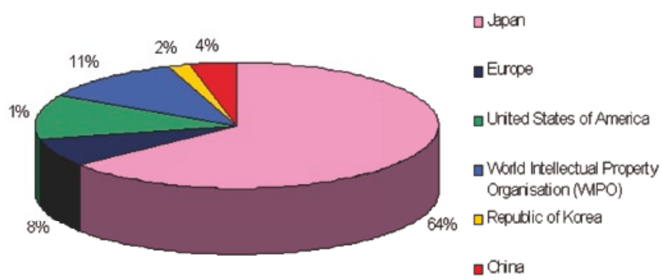
- **Design of integrated membrane processes** considering the raw material as well as the consumer demand and acceptance

- **Integration of bio-catalysis** with membrane operations

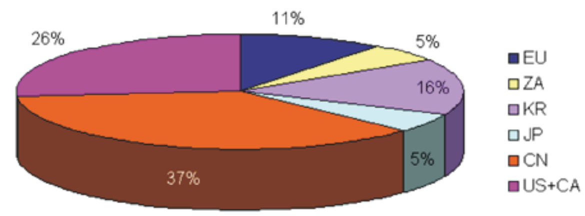
- **Integrated membrane systems** to achieve zero discharge

- **Redesign of processing/production lines** integrating and intensifying membrane operations for transformation, separation, concentration and final product formulation

Patents on Membrane Emulsification



Patents on Membrane Bioreactors



2.7. Sustainable Energy Systems

WP11.3 - Coordinator: SINTEF

Aim

Research on sustainability, security and diversification of energy supply is becoming increasingly important, particularly for combating greenhouse gases emissions and climate change, supporting regional development and cohesion. Fuel cells and CO2 capture processes such as pre-combustion decarbonisation, oxyfuel and post-combustion are technologies where membranes may play a key role. The WP11.3 tasks aimed at reaching the technological breakthroughs necessary for membrane commercialization in the field of energy, currently hindered due to the inability to prepare low-cost and stable membranes on a large scale.

Highlights

A **STATE-OF-THE-ART REPORT** was issued. It describes relevant membranes for sustainable energy technology, discusses the shortcomings and challenges of existing membranes and points at required developments. A workshop was conducted to discuss potential cooperation between partners and members of the CoI, and a document was prepared describing partners' activities and capabilities related to sustainable energy technology.

Inputs were contributed to create the SBRA's energy roadmap, its main elements being collected thanks to a workshop on energy (February 7th 2007, Brussels) chaired by Rune Bredesen (SINTEF) and Henk van Veen (ECN, CoI member); SINTEF subsequently contributed with improvements.

WP11.3 activities were intensively dedicated to generate and follow up collaborations with NoE Partners. An increasing number of joint collaborations with at least one member of the Network were initiated on the basis of bilateral and/or industrial partnership. This clearly reflects the dynamism and the willingness for collaboration between NanoMemPro partners, and is in line with further integration of partners' resources and capabilities. External partnerships with academia, industries and other European Networks of Excellence developed, strengthening the leading role of the NoE in Membrane-based Technologies in Europe.

Based on the collaborative work performed during the creation and follow-up of new joint actions, the NoE Partners worked to integrate their research facilities and identify needs for performing projects. Infrastructures that could meet challenges were foreseen, e.g. facilities for up-scaled and S-containing gas testing.

2.8. Life Support and Health

WP11.4 - Coordinator: UTwente

Aim

Integrate and synchronize R&D programs concerning life support and health in the various laboratories to ensure there is no overlapping between the works of the involved partners. Besides complementary developments and novel research in the above fields, definition of common research proposal as well as establishment of contacts with other communities were stimulated.

Highlights

- **Two major clusters:** bioartificial organs, as well as sustainable and safe water production.

- **Three important documents** concerning integration of activities of the partners: "Overview on infrastructure and competences", "Expression of interest for common project proposals" and "Common research interests".

- **On September 26th 2007**, a workshop on "Membranes for artificial organs" was organized by Dr D. Stamatialis in collaboration with Prof J. Crespo and Prof M.N de Pinho (Lisbon -Portugal), including talks from various experts:

  Dr. D. Stamatialis (UTwente): Medical membrane applications;
  Dr. P. Dejardin (CNRS-IEM): Artificial kidney: polymer membranes and hemocompatibility;
  Dr. L. de Bartolo (ITM-CNR): Membrane bioartificial systems for liver, neuronal and lymphocyte function reconstruction;
  Dr. N. Reis (BIOSURFIT, S. A - Portugal): Biosensors for Point-of- Care Diagnostics;
  Prof. C. Legallais (University of Technology of Compiègne,– France), member of the NanoMemPro Club of Expertise: Mass transfer in artificial organs.

- **On June 22nd-26th 2008**, a symposium entitled "Membranes for Bioartificial Organs and Tissue Engineering" was held during the Termis-EU 2008 (Annual meeting of European chapter of Tissue Engineering society 2008", Porto – Portugal). Several partners of WP11.4 (and others) gave oral presentations:

  Dr. D. Stamatialis (UTwente, The Netherlands - keynote lecture): "Membranes for bioartificial organs and tissue engineering";
  Dr. K. Luetzow (GKSS Research Center Germany): "Poly(ether imide) membranes as a matrix for cell-polymer interactions";
  Prof M.N. Pinho (IBET-IST – Portugal): "Hemocompatible membranes for blood oxygenators";
  Prof Legallais (University of Technology of Compiègne, France): "Different configurations of membranes for bioartificial liver application";
  Dr. L. De Bartolo (ITM-CNR – Italy): "Membrane biohybrid systems for liver tissue engineering".
  This symposium was an excellent opportunity for establishing contacts and interaction between membrane scientists and the broader "tissue engineering" community. Similar initiatives were planned for the Annual meeting of the European Society for Artificial Organs (ESAO 2009).

Chapter 3
Activities to Spread Excellence

3.1. Joint Training and Education Program

WP12 - Coordinator: DTU

Aim

Set up a joint training and education program on membrane related topics; increase the exchange and interactions of Master and PhD students between European universities and research institutions.

Highlights

A label on Membrane Engineering at Master level was defined and the first 2 calls (2007 and 2008) were affected. The criteria for the calls are:

- Validation with merit of a Master of Science performed in a European university;
- A Master curriculum including at least 60 hours (6 ECTS) of theoretical courses directly related to membrane science and membrane technology;
- A mobility of at least one semester (30 ECTS) in a research laboratory or a company recognized in membrane engineering in another country other than for the theoretical courses.

The label was conferred jointly by the NanoMemPo Network and the European Membrane Society.

A curriculum structure for a European Master of Science program in membrane engineering was discussed and organized with the following 3 specializations:

- Nanotechnologies and Biodevices;
- Energy and Environment;
- Biotechnologies, Food and Health.

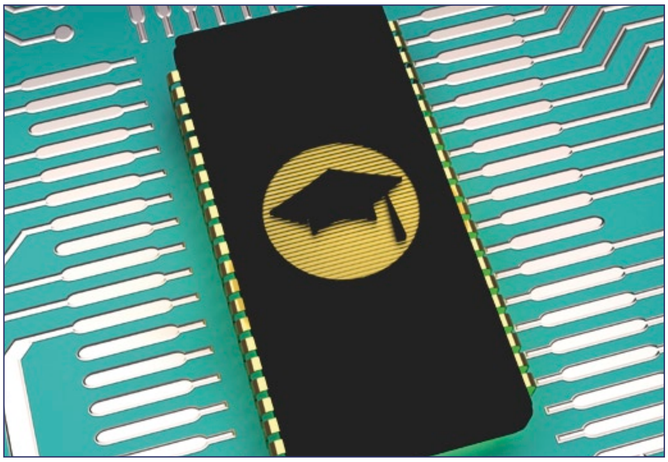
An application for the next call for the Erasmus Mundus Master program is in progress.
The development of a European Doctorate School on Membrane Engineering is in progress and will follow similar trends as for the European Master.

Several training workshops on membrane manufacturing, membrane characterization, and membrane modeling were organized by NanoMemPro partners or supported by NanoMemPro:

- NanoMemCourse: joint initiative of some of NanoMemPro partners with the support of the Marie Curie Program. Two courses have already taken place while 3 more will take place during the next 2 years (see WP03).
- EMS Summer Schools on Membranes: annual event organized by European Membrane Society on different membrane topics in collaboration with NanoMemPro partners.
- Network of Young Membrains: annual event organized by young membranologists mainly for young PhD students and supported by NanoMemPro.

3.2. Knowledge Transfer and International Cooperation

WP13.1 - Coordinator: ICTP



Aim

Reinforce the cooperation with both new EU members and non EU countries in the field of membrane materials and processes. Focus was laid on Eastern European countries, Russia, China, USA and Japan.

Highlights

Organizing workshops,

colloquia and summer schools on the Network's research and application subjects with the greatest possible international impact.
Sessions focusing on Membrane Processes and Materials were organized and chaired by NanoMemPro members, within the framework of International Congresses -Euromembrane, ECCE (European Congress on Chemical Engineering), CHISA (2004-2008). Researchers from Eastern European Countries, Russia, etc. were invited to participate in these events.
Summer schools were organized in cooperation with EMS and NanoMemcourse – a Marie Curie Conference and Training Course Action: Smart Membrane materials, Prague 2006; Nanostructured material and membrane synthesis and characterization Zaragoza 2007; Nanostructured materials and membrane modeling and simulation, Patras 2008.

Reinforcing exchange

and cooperation with new EU members from Eastern Europe.
A one-day meeting took place on April 19th 2007, Prague. The subject of this meeting was to discuss the relations of the NoE with European Central and Eastern countries.
Cooperation with the Polytechnic University in Tomsk, Kuban State University and Russian Academy of Sciences in Russia was established (MemBridge and Erasmus Mundus Study Program). Informal contacts with structures belonging to New Member States (Romania, Bulgaria, Poland and Hungary) were established, including International Centre of Biodynamics (ICB), Wroclaw University of Technology (WUT), Budapest University of Technology (BUT), University of Chemical Technology and Metallurgy (UCTM), Institute of Chemical Engineering, and Bulgarian Academy of Sciences.

Implementing subgroups

in charge of training courses, electronic communication and workshops.
EU Lifelong Learning Program Agreements were signed between NanoMemPro members.
NanoMemPro members accept training students taking both theoretical and practical courses on membrane techniques and processes (e.g. SINTEF practical courses on Environmental Health and Safety (EHS) policies, Imperial College technical course on Natural Extracts, Products and Technologies 2007).

Promoting international collaborations

with developing countries (e.g. South Africa) as well as with the US and Japan; focusing our efforts on establishing scientific and educational cooperation with our partners within the framework of new programs.
Contacts with groups in the USA, Japan and other non EU countries were intensified: e.g. with Prof. J. Falconer and Prof. R. Noble, co-director of the NSF Industry/University Cooperative Research Center for Membrane Applied Science and Technology - University of Colorado (Boulder); with Prof. E. Marand, Virginia State University (IMC); with researchers from the University of the Western Cape and Vaal University of Technology in South Africa.

Participating in educational fairs

in Asia and Central America to draw the attention of students on the scientific areas covered by the Network.
NanoMemPro and study programs involving membrane topics were presented in educational fairs in China (2006, Dalian and Beijing), India (2006, Bombay and Calcutta) and Mexico (2007, Mexico City).

3.3. Cross-linking with Other Programs or Institutions

WP13.2 - Coordinator: CNRS

Aim

Develop the communication and networking between the European Membrane Research Area (i.e. between the European Membrane House and the European Membrane Society and other EC coordinated programs); develop partnerships with third countries and other non-European scientific organizations.

Highlights

As an illustration of the first point:

the creation of N2I - Networks to Innovation.

It is a cross-fertilization process set up between NanoMemPro and 2 other NoEs working on complementary fields: InsidePores -nanoporous materials- and Idecat -catalysis. Broad and very important field are thus addressed — Porous media: preparation, characterization and related processes/systems, with the main idea being to be stronger together to address important challenges, e.g. the participation in the activities of the European Institute of Innovation and Technology (EIT), or the infrastructure programs for large equipments.

The 1st general meeting of N2I was organized on June 13th 2008 in Montpellier (France) with 21 participants. Different representatives of the 3 NoEs were present, as well as external experts (e.g. J.C. Charpentier, the former president of the EFCE; J. Weitkamp, the current vice-president of DECHEMA; R. Rodriguez-Clemente, the coordinator of Melia and MIRA EC projects) and local representatives (e.g. Languedoc-Roussillon region, Montpellier University and CNRS).

The 3 NoEs then decided to organize together a new conference on “NanoPorous materials for Energy and Environment” (NAPEN) in mid October 2008 in Crete, and to hold the 2nd N2I general meeting on this occasion. Following this meeting, it was decided to organize every year a new edition of the conference that would serve as a regular meeting point for the community after the end of the EC financial supports to the NoEs. NAPEN 2 should be held in Spain in autumn 2009.

As an illustration of the second point:

the “MemBridge” CSA project presented within the framework of the FP7-NMP-2008-CSA-2 call was approved by the EC in July 2008. The goal of this project is to gain first-hand knowledge of the state of the art in membrane science and technology, with environment protection and energy applications, and to make a step towards reaching an effective integration of research activities, training, equipment sharing, R&D and technological transfer between Europe and Russia. This project, through the establishment of a “bridge” between NanoMemPro, a Russian network of laboratories and various industrial partners, should reinforce the strategic partnership in the field of membrane science and technology in the European enlarged area, from the Atlantic to the Ural.

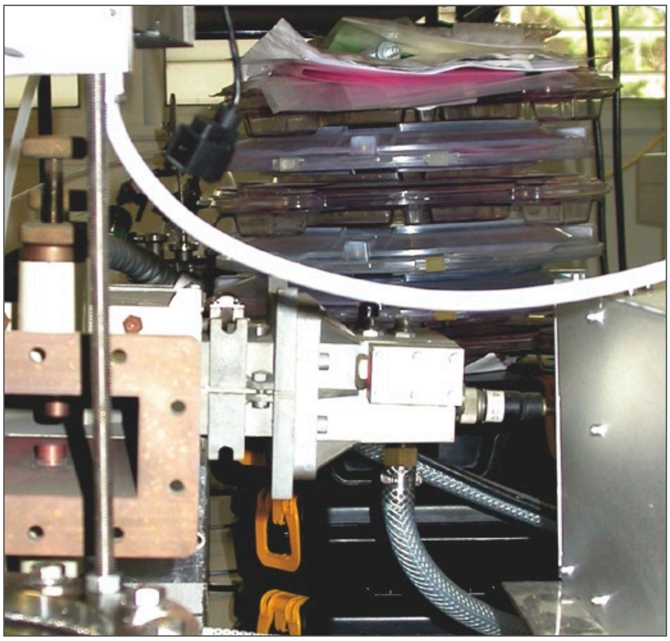
Contacts developed steadily thanks to the Coordinator’s participation to conferences and workshops:

- EU-MENA workshop organized by the NMP priority in Sharm-El-Sheik (Egypt) in January 2008;
- BioVision conference in Alexandria (Egypt- April 2008);
- ProMembrane (FP6-2002-INCO-MPC/SSA-2) meeting in Sfax (Tunisia- June 2008);
- MELIA (Inconet –FP6) conference in Marrakech (end of October 2008) where the Coordinator was invited to present NanoMemPro and “membrane technologies” in water applications.

A number of actions are now envisaged with the MENA countries via either NanoMemPro/EMH or N2I: Project proposals within the framework of the joint NMP/Environment Call on “Novel membrane for water technologies (SICA –Publication date: November 17th 2008) or other calls (e.g. Europaid and Capacities). Collaborations are also considered with UNESCO on these topics (e.g. through the SIMEV chair /Prof. L.Cot).

3.4. Technology Transfer to Industry

WP14 - Coordinator: VITO



Aim

Be sure that matches between technology offers and demands are maximized.

Highlights

A **SPECIFIC** definition of technology transfer is difficult to provide. The concept can be described as any agreement, both tangible and transparent regarding the technology transferred, resulting in a partnership that is considered as value by both parties involved. In most cases, Technology Transfer (TT) involves the transfer of know-how, technology or expertise from the Developer to the Recipient.

NanoMemPro set up a framework to stimulate technology transfer and collaboration in order to establish permanent interactions between membrane researchers, industries and end-users, and thus accelerate new discoveries and industrial applications of membrane technology.

The first step involved the creation of a webpage on Technology Transfer on the NanoMemPro website[1]. A link to the Technology Transfer database directed visitors to the Technology profiles submitted by the NanoMemPro partners and the Club of Interest. All profiles added to the NanoMemPro database were automatically entered into the Innovation Relay Centre (IRC) Network database. The co-operation with the IRC network was extended and a Brokerage-Event was co-organized at the 11th Aachener Membrane Kolloquium (AMK), taking place on March 27th-29th 2007. A booth was also arranged to display and promote the network activities by posters and leaflets. In the run-up to the conference a catalogue of technology profiles from the participants was compiled. Thirty profiles were submitted, 12 being submitted directly by NanoMemPro partners. At the Aachener Membrane Kolloquium in October 2008, the brokerage event initiated by NanoMemPro during the previous edition was repeated.

To make the European membrane technology developments and the EMH activities more visible to a broad industrial audience, membrane presentations and posters were presented at broader oriented conferences and industrial gatherings. At the I-SUP2008 conference in April 2008 (Bruges, Belgium), a special session on separation technology was held. Prof. Gilbert Rios was invited to make a general presentation of the concept of NoEs to SMEs during the Detect-it2 - EBN spring meeting on March 21st, 2007.

Several other actions were taken by NanoMemPro partners to disseminate activities to industry and the link with the SBRA activity. IBET elaborated a report on the treatment and valorization of wastewaters from cork and tanning industry for an Association of Portuguese Industrialists. VITO started a "Technology advice service" entitled "Membrane technology for sustainable chemical processing" in cooperation with the Belgian Federation of Chemical Industry (essenscia). SINTEF has contact with a large group of Norwegian and international industry partners, involving a continuous evaluation of technological challenges present in several research fields.
On November 26th, 2008, the national membrane organizations of Belgium (BMG) and The Netherlands (NMG) co-organized a Membrane symposium in Antwerp, Belgium. This was the first effective co-operation between national organizations. NanoMemPro and the EMH supported this event, setting an example on the broadening of the international dimensions and facilitating the growth towards a European membrane community.

1. NanoMemPro Technology Transfer web-page: http://nanomempro.com/Front/offers.php?id=26

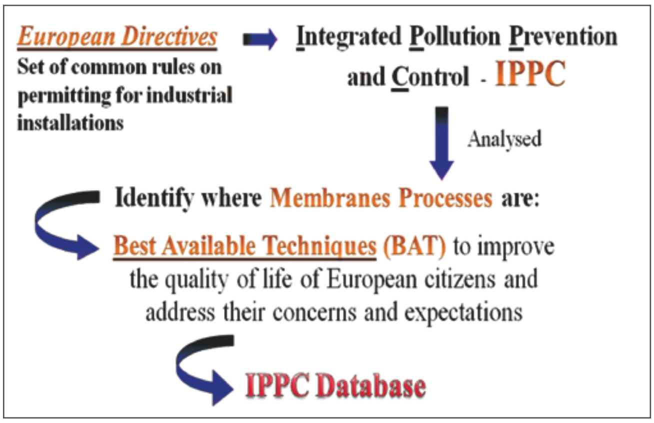
3.5. Consumers' Concerns and Regulations

WP15.1 - Coordinator: IBET

Aim

Identify the citizens' concerns and expectations that can be addressed by membrane processes, in fields such as food, health, water, environment and energy. Implementing a "consumer's policy" to improve citizens' wellbeing is a key target for the European Commission (EC). Bearing in mind that the EC work on regulations for water and air quality, on a Sustainable Energy Policy and on the Integrated Pollution Prevention and Control (IPPC) directive already reflect the main concerns and expectations of European citizens, the approach used in WP15.1 was based on the analysis of European Water Directive and on the IPPC Directive for 33 industrial sectors.

Information was collected on membrane processes as Best Available Techniques (BAT).The areas where membranes can contribute to the implementation of EC directives and to the development of new cleaner production processes were thus identified: they make up NanoMemPro's IPPC Database.



Highlights

The Database also includes data on the partners' expertise and their areas of intervention in relation to the IPPC Directive. Dissemination actions related to the NanoMemPro IPPC Database are summarized below:

Date & Place	Actions
June 11th -12th 2006, Lappeenranta, Finland. "Separations Conference"	Posters displaying Membrane Processes as IPPC BAT's in Pulp & Paper and Food, Drink & Milk Industrial sectors.
September 2006, Taormina, Italy. "Euromembrane 2006"	Posters displaying Membrane Processes as IPPC BAT's in Pulp & Paper and Food, Drink & Milk Industrial sectors.
November 2006/January 2007	Information on Membrane Processes as BAT's in the IPPC, gathered on a CD by the Portuguese Environment Institute (group working with IPPC) and IST.
January 19th 2007, IST Congress Centre, Lisbon, Portugal. "Membrane processes as Best Available Techniques (BAT) and as candidates to BAT in the Integrated Pollution Prevention and Control (IPPC) directive". Joint organization: NanoMemPro and Portuguese Environment Institute (Portuguese IPPC Committee). 400 Attendants (majority from industry)	Presentations of key European Industries: Membrane Technology Suppliers – Alfa Laval – and End Users – Arla Foods, Ford Land – and Portuguese Environment Institute members and Academic Researchers.
	Handing out CDs with NanoMemPro Database to the 400 attendants from Pulp & Paper, Dairy, Textile, Metallurgical Industries etc. and Research institutes.
March 13th 2007, Lisbon, Portugal. Visit of the President of the Portuguese Republic – IST, as part of the 2nd Presidential Campaign of the Route to Science and Technology.	Presentation of 2 posters on Membranes as Clean Technologies (based on NanoMemPro IPPC Database)
June 21th – 22th 2007, Oslo, Norway. SINTEF participation in the 2nd IEA /CSLF Workshop for the G8 on Early Opportunities for Carbon Capture and Storage	Support activity of the G8-Plan of Action from Gleneagles in 2005. The workshop's main objective was to provide inputs for the final recommendations for the G8 summit in Japan 2008.
July 6th-11th 2007, Campina Grande, Brazil. "Ibero American Congress on Membrane Science and Technology" (CITEM 2007)	Presentation of the NanoMemPro network and NanoMemPro IPPC Database.
September 27th 2007, Lisbon, Portugal. "3rd Annual NanoMemPro Meeting"	Presentation of «The role of NF as BAT in the IPPC framework and as an emergent technology in the Water Framework Directive (WFD)».

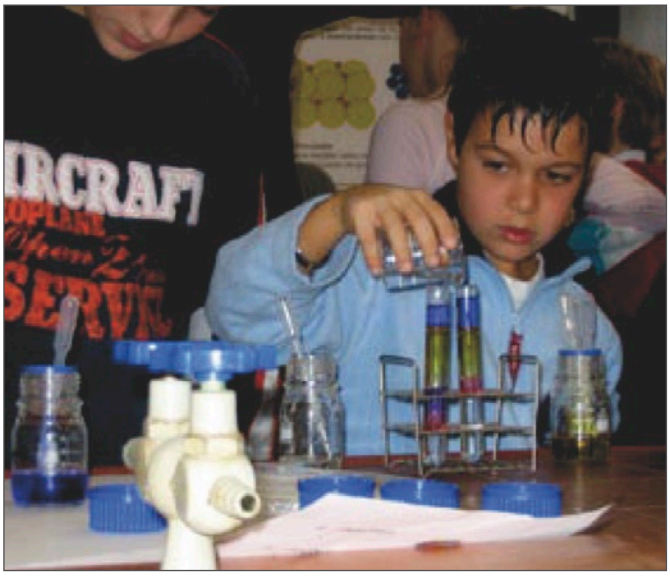
NanoMemPro IPPC Database can be accessed via 2 websites: NanoMemPro's web site and Wikipedia. The database was circulated among the members of the Club of Interest for further comments to be inserted in the database; the impact of the dissemination actions was monitored.

3.6. Strengthening Citizens' Awareness in Science

WP15.2 - Coordinator: LUT

Aim

Strengthen citizens' awareness in membrane science.



Highlights

Thousands of people were informed of membranes and their possibilities today and in the future thanks to events directed to citizens and school children. The work carried out can be divided into 4 main parts:

Preparation of educational materials

to citizens, such as posters, videos and web-pages

More than 20 posters on different membrane applications have been prepared. The posters have all been made in at least 2 languages. Some materials have also been made to illustrate membrane theories. The posters have been shown at different occasions to the public and they are available for future use at the work package web pages. Many of them are also permanently on view in universities. Some videos on membrane manufacturing were also made.

Events for children and adults to increase their awareness of science

Children were gathered at different occasions in some countries to learn about how to measure acidity of solutions by pH. They were very interested to see the differences between lemon juice and apple juice. They learnt how to make bubbles from powder in water (sodium carbonate). The idea about how to fit objects through specially formed "pores" depending on them being slits or tubular was researched. Demonstrations on membrane filtration (e.g. removal of color by self-made membranes) interested both adults and children.

Citizens from town, industries or schools were taught at fairs or in the laboratory some data on membranes. They were allowed to make their own membranes and try it out in a real membrane module. About 200 people have made their own membranes. They learnt how nanofiltration can fractionate color molecules from each other and how drinking water can be made from less pure surface water or salty water.

Special days were arranged all over Europe for school children to strengthen their interest in science and membranes. VITO participated in the "Flemish Science week" with the topic membrane technology. In France within the frame of the "Scientific and Technologic Workshop" about 200 attendees attended a rather similar event. At IBET-IST, about 700 students from several high schools participated throughout the 2 daily sessions of the so-called "Open Laboratories" (IBET-IST, February 5th-16th 2007). At the University of Zaragoza (UNIZAR), an Immersion Research Week oriented for high school students, was organized on 20th-24th July 2005. During the research week, students were shown the research world with significant emphasis on microporous membranes and some applications in common life. Researchers' nights arranged by LUT were great successes and several hundreds of people were informed with membrane technology. LUT also participated in membrane demonstrations on the 2006 annual Region Day arranged by South Karelia in the Senate Square in Helsinki.

Spreading of knowledge on membranes through the press

Membrane Technology and what can be achieved with them need to be known all over the world. Many articles and press releases were made during the project. NanoMemPro participants were interviewed and their message was conveyed to a larger public than what could be reached by eye-to-eye contact.

Web-pages on membranes

They feature different aspects of membranes, e.g. history, applications, existing large industries and vocabulary etc.. They also function as storage place for the communication materials produced during NanoMemPro's lifetime so that we can go on using them.

Chapter 4 Management Activities

4.1. Management Activities

WP16, 17 and 18 - Coordinator: CNRS

THE NETWORK implemented a strong and coherent excellence-oriented management system to ensure a sustainable implementation of its Joint Program of Activities. The management system was made up of 3 levels: strategic management, integrative management and daily management of activities. It was designed and set up within the first 6 months of NanoMemPro, and then steadily improved throughout the life of the Network according to the APDCA (Analysis-Plan-Do-Check-re-Act) pattern in order to reach excellence. At the beginning of the project, NanoMemPro's coordinating institution was supported by ACIES -an external consultant company- to monitor the good implementation and improvement of the whole system, and to transfer management know-how to the NoE members. After 18 months, the CNRS started to work alone in an autonomous way with 2 assistants. This enabled the Network to operate on a long-term basis as an integrated and self-sufficient high-level organization. The creation of a legal entity then reinforced the management structure of the Network. The management system also made the most of the recommendations of the scientific experts at the strategic and executive levels in order to better connect basic research, engineering and industrial developments.

The different decision-making bodies in NanoMemPro are presented in the following table according to the 3 different levels of management.

Level of Management	Decision-maker	Role
Strategic Management	Governing Board	Define political and strategic orientations Arbitration; Decide on Consortium choices / tasks proposed by ExC
	Executive Committee (NoE coordinator, and Activity/Workpackage leaders)	Implement the GB orientations and decisions; Manage and report on JPA, IPR and CA; Monitor the project
	NoE coordinator	Ensure administrative obligations and communications with EC in relation with the Governing Board and integrative management; Manage the reception and allocation of EC grant; Prepare requested documents to ExC and EC
Integrative Management		
	Integrative project manager and Integrative Management team	Implement deployment and monitoring of processes related to integration; Assist the ExC and the Coordinator
	Scientific Council	Composed of external experts recognized for their expertise in the field of the Project/ Appointed by the Governing Board. Advise the Governing Board on project orientations
	Club of Expertise	Composed of external experts recognized for their expertise in the field of the Project. Members advise or are consulted by the decision-making bodies on issues of task execution.
Activity and Work Package Management	Activity/Work Package leaders	Monitor and coordinate Work Packages; Report Work Package progress; Inform and make proposals to the ExC
	Activity/Work Package team	Implement activities, deliverables and milestones

Work Package Leaders

WP#	WP Title	Leader	
		Organization	Name
01.1	Integrate knowledge management	SINTEF	Rune BREDESEN Paul I. DAHL
01.2	Share and reinforce tools and facilities	CNRS	Pierre AIMAR
02.1	Adaptation of organization activities	CNRS	Gilbert RIOS
02.2	Reinforce electronic communication and networking	UTwente	Matthias WESSLING Kitty NIJMEIJER
03	Plan for staff mobility and work positions	CNRS	Pierre AIMAR
04	Integrate the Club of Interest within the NoE framework	Imperial	Andrew LIVINGSTON Ludmila PEEVA
05	Create a legal entity: The European Membrane House	CNRS	Gilbert RIOS
06.1	Increase financial autonomy and durability	CNRS	Gilbert RIOS
06.2	Develop high added value technological services	IBET	Joao G. CRESPO Carla BRAZINHA
07	Characterization of membrane function	UNIZAR	Miguel MENENDEZ
08	Modeling and simulation of membrane performance	FORTH/ICE-HT	Vasilis BURGANOS Eugene SKOURAS
09	Synthesis optimization of membrane material	GKSS	Klaus-Viktor PEINEMANN
10	Back-design and mass production of membrane material	ITM-CNR	Enrico DRIOLI Johannes C. JANSEN
11.1	New production processes: system approach	Imperial	Andrew LIVINGSTON Ludmila PEEVA
11.2	Food quality: safer production methods	ITM-CNR	Lidietta GIORNO
11.3	Sustainable energy systems	SINTEF	Rune BREDESEN Paul I. DAHL
11.4	Life support and health	UTwente	Dimitrios STAMATIALIS Matthias WESSLING
12	Joint training and education program	DTU	Gunnar Jonsson
13.1	Knowledge transfer and international cooperation	ICTP	Bohumil BERNAUER Vlastimil FILA
13.2	Cross-linking with other Programs or Institutions	CNRS	Gilbert RIOS
14	Technology transfer to industry	VITO	Inge GENNÉ
15.1	Consumers' concerns and regulations	IBET	Maria Norberta DA PINHO Carla FARIA
15.2	Strengthening citizens' awareness in science	LUT	Marianne NYSTRÖM Mika MÄNTTÄRI
16	Strategic Management	CNRS	Gilbert RIOS
17	Integrative Management	CNRS	Gilbert RIOS
18	Activity and Work Package management	CNRS	Gilbert RIOS

Conclusion

Prof. Gilbert M. Rios

AS COORDINATOR of the NanoMemPro Network of Excellence, I would like to thank all the core partners for the fantastic work they have done during the 4 ½ years of this project. Such work was not directed at reinforcing their own labs or institutions through classical research projects, but at preparing the future of our whole European membrane community (labs, industry and society). How? By setting up a common framework to amplify the development of membrane-based technologies. By doing this, the NanoMemPro researchers were at times faced with misunderstanding, despite a strong communication effort towards the membrane community… Indeed, with this project, the core partners did not obtain money for research activities; on the contrary, they asked some of their staff members to accept non traditional tasks, which were difficult to promote according to usual evaluation criteria: setting-up new communication tools; thinking over new mechanisms to enhance people mobility between European centers; creating a legal entity to increase the legibility and long term sustainability of the network; developing international policy; developing new degrees (master and PhD in membrane engineering); proposing tools to help original industry-driven RTD actions, such as a Strategic Business & Research Agenda. In some cases, tensions arose with core partner institutions, around issues of autonomy and subsidiarity of the new legal structure: the creation of the said legal entity had yet been scheduled since the beginning of the contract.

Thanks to our joint efforts, we found appropriate solutions and fulfilled our contractual commitment with DG RDT whose huge financial support would have been impossible to get from national or industrial partners. As testified by the annual evaluations, our work is fully appreciated and now considered a success story, well beyond initial expectations.

As first Executive Director and Chair of the European Membrane House, the international association created to insure the long term durability of the Network of Excellence and build up the European Membrane Area, I would like to confirm that our priority for the next months will be to welcome in our structure more institutions as new members, in agreement with the association's statutes and rules. By doing so, departments and clusters, which constitute the core of the organization, will be started. Departments will focus on basic fields, such as new materials or modeling, while clusters will tackle thematic issues, such as energy or water. Together they will create the tools to complete the "Membrane network", in relation with other large structures (e.g. the European Technology Platforms).

The European Membrane Area is not only a new concept: it is the melting pot from which the methods and tools answering the issues raised by our societies will emerge. Membranes are already considered as "dominant technologies" in most of the economically advanced countries. By themselves or in association with other technologies - among which catalysis- they will take an increasing place in the systems and processes on which our daily life depends. Thanks to membrane engineering, solutions will be found to the issues tackled by European Technological Platforms, Joint Technology Initiatives or Poles of competences in the field of environment, energy, health, chemistry, textiles, food and biotechnologies! It will be the role of the EMH's Governing Board and core management team to perform the overall lobbying and develop institutional contacts to inform on future challenges and show how the EMH clusters and departments can offer efficient solutions.

Let us remember that ***"there will be no future for those who do not prepare for their future"***. French people used to say "It took more than one day to build Paris". We have already done a lot in 4 ½ years. Let us go on, to build a strong framework for the future generation of membranologists!

Prof. Gilbert M. Rios

From NanoMemPro
the European Network of Excellence...

...towards the European Membrane House

EMH European Membrane House

The one-stop place for membrane expertise
and international research and industrial partnerships

Sixth Framework Programme