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Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE
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Industrial Applications of Membrane Technology in Ireland: A Review

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

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EPA STRIVE Programme 2007–2013

Industrial Applications of Membrane Technology in Ireland: A Review

(2005-ET-MS-32-M3)

STRIVE Report

Prepared for the Environmental Protection Agency

by

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Please note that this report resulted from the original EPA funded project undertaken by the authors entitled: *Integrated research programme into membrane separation process technology.* A Master's thesis also resulted from the project work.

The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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http://erc.epa.ie/safer/iso19115/displayISO19115.jsp?isoID=187#files

Executive Summary

Background

Membrane separation processes are used widely in industrial, laboratory, medical and research applications to purify, concentrate, sterilise or separate streams or samples. They can provide an efficient and reliable solution for critical separation challenges and have demonstrated superior performance across a broad range of applications, versus alternative technologies. A detailed study has been made of synthetic membrane separation technology application and research in Ireland. This report highlights existing trends and compares the current status of membrane technology in Ireland with international norms.

Three sectors are considered in detail: (i) the water sector; (ii) the pharmaceutical sector; and (iii) the food and beverages sector. Water, which includes both water supply and wastewater treatment, is the largest sector of membrane application, and is likely to have the largest growth rate. Industrial process wastewater treatment may be considered under this heading. The pharmaceutical industry is extremely significant to Ireland's economy. Applications for membranes in classic active pharmaceutical ingredient manufacturing may be niche and only emerging, but, in contrast, membranes are integral to biopharmaceutical processing. Food and beverages are again an important sector of the Irish economy and, in the context of dairy and beverage products, have used membrane technologies for many years.

Three other sectors are considered briefly: (i) large-scale applications; (ii) small-scale applications; and (iii) medical applications. Large-scale and small-scale applications are very fragmented. Niche applications may be possible, some of which are allied to pharmaceutical applications and are addressed in this report. The medical sector is again both important to Ireland and a major user of membranes, but the membrane elements are a relatively small proportion of the total sectoral value.

Analysis of the Membrane Technology Environment in Ireland

Ireland lags far behind leading membrane technology centres or clusters around the world. While there are exceptions, it may be concluded that there is:

- Little end-user expertise in membrane technology;
- Little evidence of technology transfer between different sectors using membrane technology;
- Limited research (pockets of research expertise exist, but are fragmented across at least eight institutions).

Trends do not indicate that the gap is closing. The current level of activity and focus is not sufficient to have a significant impact. In contrast with leading international competitors, there are no independent membrane centres of expertise evident in Ireland to deliver expert advice to end-users, execute extensive application research or deliver training across different industry sectors.

Supportive Factors for Membrane Technology in Ireland

This situation persists despite the low tax environment in Ireland, a focus on targeted industrial sectors, significant foreign direct investment and more recently the emphasis on research and development. The increased level of funding for research and development combined with a higher level of entrepreneurship could create a more supportive environment for new start-up enterprises. In Ireland, the cost of inputs such as energy, water and labour increases the urgency and motivation for adopting more aggressive cost-reduction measures. Factors that are more specific to membrane technology include:

- More stringent regulations for water and wastewater will require more advanced treatment technology, especially in sensitive areas – potentially allied with limited potable water availability in some regions.

- The large pharmaceutical industry presence in Ireland, the increasing importance of biotechnology, and the strong food and beverages sector, could raise end-user membrane technology competence levels and spur spin-off opportunities.

Strategic Options

The long-term consequences for a *laissez faire* approach to membrane technology are serious. This approach would have a negative impact on the long-term success of some strategically targeted industries, for example the environmental goods and services sector (water supply and wastewater treatment), biopharmaceutical, and high added value food and beverages. Long-term weaknesses in membrane technology expertise will undermine the development of these industries and significantly curtail the economic payback potential. End-users would be reliant on overseas suppliers for advice and troubleshooting. It would have a more severe impact on small-technology start-up companies who would not be able to access international expertise as easily as the multinationals.

A very important consequence of the development of membrane technology in Ireland would be the opportunity to access a growing worldwide US$10 billion (b) market for membrane technology applications; US$2b–4.5b per year is attributed to the environmental goods and services sector – an area in which Irish companies could make inroads. The preferred approach is to coordinate and develop the available expertise in Ireland. This would require the development of a measured strategic plan for nurturing and enhancing membrane technology expertise within the targeted research and business spectrum. It would involve a collaborative approach across industry and academia and between multiple organisations and institutions across the country.

Recommendations

A series of options has been evaluated. These include consideration of whether initiatives should be: (i) industry or academic led; (ii) single location centre or network; (iii) research only or a full spectrum of research through technology transfer, consultancy and training services.

The main recommendation of this report is that a formal membrane technology network-of-excellence (similar to the Enterprise Ireland [EI]/Industrial Development Authority [IDA] competence-centre model) should be established in Ireland to address the current gaps. It is possible to conservatively estimate the gains that could be made in the water sector, for example: if Ireland were to gain 0.5% of a lower estimate of US$2 billion for the global market, this would be equivalent to a national gain of US$10 million per annum. Efficiency gains equivalent to this might also be achieved by diverse technology users or niche application development in other sectors. The typical budget for these centres is €1–2 million per annum for five years.

This membrane technology network-of-excellence will need to be initiated and driven by centralised economic policy groups and structured in such a way as to deliver the required control and oversight, while still leveraging the capability and expertise of existing decentralised groups.

This network should be:

1 Industry led (similar to the EI/IDA competence centre model);

2 Composed of multiple (at least three) existing research institutions (similar again to the competence centres and Science Foundation Ireland [SFI] and Higher Education Authority [HEA] models);

3 Provide research (contract, collaborative and original), consultancy, education and training;

4 Capable of facilitating industry-driven pilot plant activity;

5 Focused on delivering technology transfer;

6 Competent to facilitate and encourage communication and the sharing of research and end-user experiences;

7 Formally linked to international membrane bodies.

The network should be funded following a competitive tendering process (again in accordance with EI/IDA, SFI and HEA models). The funding model should be initially based on grant aid, but should progress to combined grant-aid, membership fees and self-funding services. Having defined and quantified the objectives for the network, a cross-functional and cross-organisational (academic and industry) steering group should oversee implementation. These academic and industry representatives within the overall steering group would agree priorities, coordinate activities and oversee progress in relation to the range of activities in specific fields and applications across the different research institutions. Detailed areas of activity are identified within the body of this report.

1 Introduction

1.1 Report Context and Objectives

The report provides the key information on the outcomes from a project undertaken by the Irish National Centre for Membrane Technology (NCMT) at the Cork Institute of Technology (CIT) and funded by the Environmental Protection Agency (EPA) under the National Development Plan (NDP).

A detailed study has been made of synthetic membrane-separation technology application and research in Ireland. This report highlights existing trends and compares the current status of membrane technology in Ireland with international norms. It identifies and assesses future potential research and market opportunities in the field. It also reviews the strategic role of membrane technology in Ireland's economic development and concludes with recommendations on how to address the identified challenges and gaps.

The research objectives were to:

- Complete a desk-top literature review of synthetic membrane-separation processes focusing on existing commercialised applications and on new or emerging high areas of opportunity;
- Report on the dynamic forces and restraints impacting on the broader adoption of membrane separation processes in a number of key application areas;
- Identify leading international expertise in membrane-technology suppliers and membrane research;
- Survey and assess the range of applications and level of penetration of synthetic membrane-separation technologies in Ireland;
- Complete a gap analysis of research and commercial membrane activity in Ireland versus international practice;
- Consider how identified opportunities might be addressed in Ireland.

1.2 Background

Membrane separation processes are used widely in industrial, laboratory, medical and research applications for purifying, concentrating, sterilising or separating streams or samples. They can provide an efficient and reliable solution for critical separation challenges, and have demonstrated superior performance across a broad range of applications in comparison to alternative technologies, such as evaporation or heat sterilisation. The focus of this report is on synthetic membrane applications only. Naturally occurring or biological membranes are excluded from the study.

Focused and detailed reviews describing applications for the different individual membrane processes are readily available (Baker, 2004; Yacubowicz and Yacubowicz, 2005; Nunes and Peinmann, 2006). The focus of this report is to categorise and explore membrane applications from the end-user perspective rather than from the viewpoint of the membrane industry or individual membrane processes, within the context of Ireland.

Three sectors are considered in detail: the (i) water sector; (ii) pharmaceutical sector; and (iii) the food and beverages sector. Water, which includes both water supply and wastewater treatment, is the largest sector of membrane application, and is likely to have the largest growth rate. Industrial process wastewater treatment may be considered under this heading. The pharmaceutical industry is extremely significant to Ireland's economy. Applications for membranes in classic active pharmaceutical ingredient manufacturing may be niche and only emerging, but, in contrast, membranes are integral to biopharmaceutical processing. Food and beverages are again an important aspect of the Irish economy and, in the context of dairy and beverage products, have used membrane technologies for many years.

Three further sectors are also considered briefly: (i) large-scale applications; (iii) small-scale applications;

and (iii) medical applications. Large-scale and small-scale applications are very fragmented. Niche applications may be possible, some of which are allied to pharmaceutical applications and are addressed in this report. The medical sector is again both important to Ireland and a major user of membranes, but the membrane elements are a relatively small proportion of the total sectoral value.

1.3 Report Structure and Format

The report contains five sections:

- This section, 1, provides an Introduction, and outlines the subject, objectives and format of the report.
- Section 2 describes typical membrane products, processes and technologies. It outlines the leading industrial sectors where membrane technology is deployed, including the general driving forces and restraints for membrane adoption versus alternative technologies. It also presents a strategic assessment of the industry, examining both macro and micro business environmental factors. This is followed by a detailed assessment of the competitive industrial environment, which includes a description of market analysis data for the different membrane technologies and application areas. A review of the leading membrane technology suppliers and a top-level review of the primary research institutions are provided in Appendix II.
- Section 3 provides an overview of membrane technology applications in six sectors (illustrated in Fig. 1.1):
  - Water and wastewater treatment; pharmaceutical processing; and food and beverages processing, in detail. It identifies the key sectoral drivers, and specific sectoral advantages and disadvantages of membrane technology.
  - Large-scale industrial applications; small-scale industrial applications; and medical applications, in summary.

  Each of these is elaborated in an associated appendix.
- Section 4 reviews the status of membrane technology in Ireland, and explores the macro and micro factors of the industry. It maps the scope of membrane technology application in Ireland against each of the sectors previously reviewed, focusing mainly on the water, pharmaceutical and food and beverages sectors, while indicating potential niches in the other sectors. It also identifies potential research and business opportunities relating to the field.
- Section 5 incorporates a strategic assessment of membrane technology in Ireland and discusses how the potential opportunities might be exploited, whether via a single centre of excellence or a network of excellence, and some of the available models to accomplish this in Ireland.

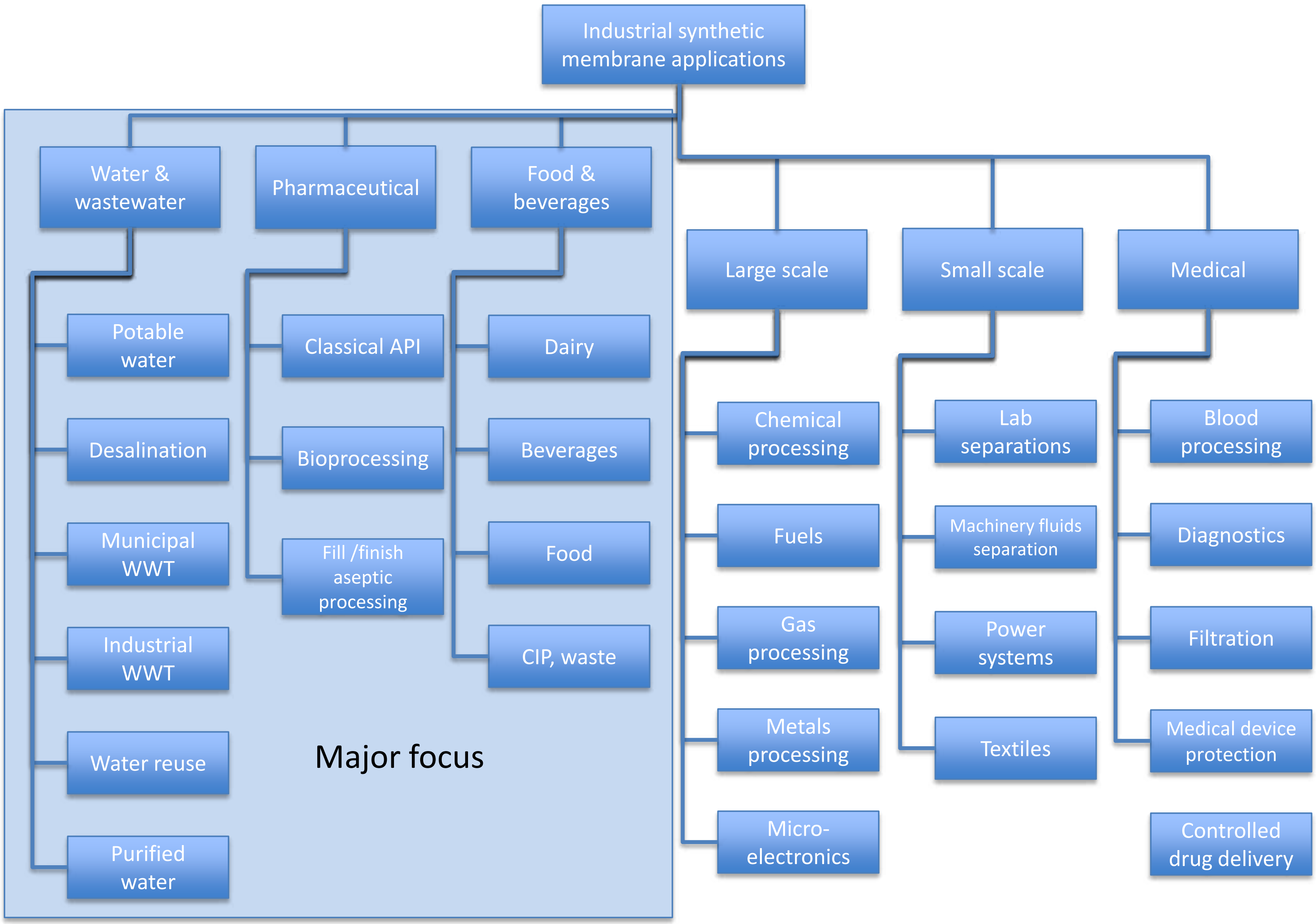

Figure 1.1. Categorisation of synthetic membrane industrial applications. WWT = wastewater treatment; API = active pharmaceutical ingredient; CIP = cleaning in place.

2 Membrane Purification and Separation Technology

2.1 Introduction

There are many detailed and comprehensive references available on the fundamentals of membrane science and technology. Some of the more recent publications combine a science and technology overview with a detailed review of current and potential applications (Baker, 2004; Nunes and Peinmann, 2006; Schafer *et al.*, 2005). The objective of this section is to provide a top-level summary of key underlying aspects that are particularly relevant when discussing the industrial applications of the technology in Section 3 and Appendices IV–IX. The membrane industry competitive environment will also be assessed.

The International Union of Pure and Applied Chemistry (IUPAC, 1996) defines a membrane 'as a structure, having lateral dimensions much greater than its thickness, through which mass transfer may occur under a variety of driving forces'. A more application-focused description is to describe a membrane as 'a thin selective barrier with the ability to separate particles and/or molecules by size, charge or solubility'. These are very broad definitions and encompass many materials which can selectively separate mixed components. The following additional criteria will be used to narrow the focus of the review:

- Synthetic (i.e. non-biological) membranes are incorporated in industrial applications and this review will focus exclusively on this grouping.
- There are multiple woven and non-woven depth media used in general filtration applications. Although such depth filter media meet the general definition of a membrane, general convention describes particulate filtration of greater than 1 μm (sometimes 10 μm) as depth filtration and not as a membrane application. This general convention will be adopted here.

2.2 Membrane Technologies and Materials

There are multiple characterisations that can be used to sub-classify membranes into specific categories and which provide a useful framework for discussion and analysis. The framework used for this review can be described as the '5M' model – membrane processes, material, mass transfer mode, module and mode of operation. Membrane manufacturing technology will not be reviewed here and multiple sources are available for more detailed investigation if required (Baker, 2004).

2.2.1 Membrane Processes

The most useful and widely adopted classification is based on the nature of membrane processes used for component separation. The main processes currently applied in industrial applications are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), dialysis (DA), electrodialysis (ED) and electro-deionisation (EDI), pervaporation (PV) and gas permeation (GP) (see Box 2.1).

Box 2.1. Membrane processes.

Microfiltration (MF)

A pressure-driven (0.5 barg to 7 barg) membrane process removing particulates, suspended materials and dissolved macromolecules greater than 0.1 μm and less than about 3 μm.

Ultrafiltration (UF)

A pressure-driven (3.5 barg to 14 barg) membrane process removing particulates, dissolved solids and macromolecules less than 0.1 μm and greater than about 2 nm. In terms of molecular weight cut-off (MWCO), the range of rejection is generally described as 1000 Daltons to about 500,000–1,000,000 Daltons.

Nanofiltration (NF)

Often described as an intermediate between UF and RO, NF is a pressure-driven membrane process (10 barg to 35 barg) removing dissolved molecules and ions greater than about 1 nm and in the range of 200 Daltons to about 1000–2000 Daltons. Ionic rejections vary depending on the valence of the salts and the specific characteristics of the membrane material.

Reverse osmosis (RO)

A pressure-driven (usually >14 barg) membrane process causing the selective movement of solvent against its osmotic pressure and the removal of dissolved molecules (organics, sugars and inorganics) greater than about 0.1 nm and a high percentage of ionic molecules.

Dialysis (DA)

A membrane process where the selective separation of components is achieved through concentration differences across the membrane.

Electro-dialysis (ED) and Electro-deionisation (EDI)

A membrane process where ions are separated by a membrane through the use of an electric potential difference across the membrane. A later variation of ED is a technology known as electro-deionisation (EDI), also known as continuous deionisation (CDI), which is a combination of ED and resin deionisation.

Pervaporation (PV)

A membrane process where the feed stream is a liquid and the permeate stream at the downstream face of the membrane is a vapour, and component separation is achieved through a vapour-pressure differential.

Gas/vapour permeation (GP/VP)

A membrane process where the feed and permeate streams are both in the gas/vapour phase and component separation is achieved through partial pressure differentials.

2.2.2 Material

2.2.2.1 Material of construction and coating: polymeric or inorganic and degree of phobicity

Early membranes were manufactured from cellulosic material such as cellulose acetate and mixed esters of cellulose. Although the vast majority of commercial membranes continue to be polymeric based (Baker, 2004), there is an increasing focus on and application of non-polymeric inorganic materials such as ceramics and sintered metals. These are typically formed from alumina or zirconia coatings on the inside surface of a ceramic support and are generally only available in MF and UF formats. In addition to the basic membrane material of construction, there is also a range of membrane additives and surface coatings applied to generate specific enhanced properties: hydrophobic or hydrophilic effects; improved specificity and fouling-resistance performance.

2.2.2.2 Membrane structure: porous or non-porous

Certain membranes such as those used in MF and UF are porous and cellular with a randomly distributed interconnected structure. The pore-size distribution determines the selectivity and separation performance of the membrane, and selectivity is generally achieved through a sieving-type mechanism. Non-porous (also called dense membranes) are thin films through which components (permeants) move by solution diffusion rather than through size exclusion and sieving action (Buschke, 1995). Non-porous membranes discriminate according to chemical affinities between components and membrane. Reverse osmosis, VP and PV processes are generally achieved through the use of such membrane types. Nanofiltration processes can be considered as using semi-porous membrane structures, an intermediate physical structure. Major performance improvements have been achieved across all membrane types by the development and manufacture of composite membranes where different pore structures are combined in membrane layers to achieve enhanced separation and throughput.

2.2.2.3 Membrane charge: neutral or charged

A positive or negative electrostatic charge can be applied permanently to a membrane matrix through fixed ions and/or resin adsorption activity, often generated through surface modification. Electrically charged membranes preferentially attract ions of opposite charge and repel those of the same charge. They may also achieve some degree of separation through the basic sieving or solution-diffusion mechanisms.

2.2.3 Mass transfer mode

The mass transfer force(s) driving and impacting separation activity within a membrane process is an important consideration for understanding performance, modelling behaviour and optimising separation efficiency. There are four main driving forces or gradients for mass transfer within membrane technology (Box 2.2).

Box 2.2. Four main driving forces for mass transfer in membrane technology.

Pressure-driven filtration is the primary force in MF, UF, NF and RO membrane processes. Increased pressures are required, in the order: from MF to UF, NF and to RO. The dynamics of separation are greatly complicated by secondary forces associated with the ionic charge of membrane and solutions, solute molecular structure, concentration polarisation behaviour, fouling mechanisms and membrane material of construction.

Concentration differential is the primary driving force for dialysis applications.

Electric potential gradient is the leading force for electro-dialysis applications, although generally they also include significant pressure-size exclusion activity.

Vapour pressure differential across the membrane is the primary driving force for gas permeation and pervaporation, through a solution-diffusion type transport mechanism.

2.2.4 Modules

Membranes are thin films manufactured in flat roll stock or hollow-fibre formats. For effective use, they need to be incorporated or encapsulated into a specific device that can be readily used in an end-user application. The large variety of end-user applications and requirements has determined that multiple module formats (also called elements or devices) have been developed to meet this need. From an end-user perspective, the overall performance of the membrane module in the specific application is what determines the level of success. As a result, the design, manufacture, test and selection of a membrane module are critical success factors for an application, in addition to the specification, selectivity and performance of the membrane film itself.

Box 2.3. Key factors impacting on the module design and selection.

- Amount of active membrane filtration surface area available in the module and the flux achieved.
- Robustness and reliability of module performance within the temperature, pressure and solution composition ranges.
- Compatibility of the materials of construction, including any adhesives or leachable additives.
- Nature, degree and rate of fouling or clogging by a typical feed solution.
- Ease and response to cleaning and resistance of the module to cleaning processes and agents.
- Ease of use.
- Degree to which the module can be tested before, during or after use to confirm integrity.

The main module designs used in industry today are flat sheet (also called ‘cassette’ or ‘plate & frame’), spiral wound, hollow fibre, tubular and cartridge. There are also a small number of unique or custom designs addressing specific issues such as vibrating modules or rotating vanes to increase flux and reliability. These are usually incorporated into specific housings, fluid systems and piping arrangements, which are designed to achieve the desired separation.

2.2.4.1 Flat sheet modules

Flat sheet modules include the traditional plate & frame design, stacked discs and the more recent and sophisticated cassettes. They are generally suited for MF and UF only as it is more difficult to achieve the required pressure ratings for the other processes. The amount of surface area available per unit volume (packing density) is relatively low, but the design is generally robust and suited for higher fouling streams.

2.2.4.2 Spiral wound

Spiral wound designs are widely used in NF and RO applications. They are robust, can accommodate high packing density and are easier to manufacture. They are constructed from layers of flat-sheet membrane, separated by support or mesh spacers, and wrapped around a central permeate collection tube. The flow channels are achieved through the material spacers and as a result are relatively narrow and can be more prone to fouling.

2.2.4.3 Shell and tube hollow fibre

Certain membranes are manufactured as long strands of unsupported hollow fibre, also called capillary fibre. These are very thin polymeric tubes with the diameters of each fibre generally between 0.1 and 2 mm. They can be manufactured from many organic thermoplastic polymers and are also available in ceramic and carbon materials. Large membrane surface area can be accommodated in a device and, depending on the fibre diameter, up to 2 million fibres are packed into a 20 cm diameter module (Nunes and Peinmann, 2006). Generally only available in MF and UF processes, the high packing density delivers a very low cost per unit area and is in general the most cost-competitive option.

2.2.4.4 Tubular

Membrane-supported materials can be formed into a singular or multiple (small number) tube format with internal diameters of 5 mm to 25 mm. They can be designed to operate at high pressures and are more readily able to process fouling streams. Inorganic metals and ceramics are generally available in tubular format. They are robust designs, easily cleaned and effective in harsh or stressful environments.

2.2.4.5 Packed or pleated cartridge

The packed or pleated cartridge is widely used for dead-end MF and UF filtration. They are installed in plastic or stainless steel housings and usually replaced on a regular basis. They are easy to install and use, have a high packing density, but limited pressure ratings and are difficult to clean. As a result, they are relatively expensive.

2.2.5 Mode of Operation

As noted above, membrane modules are generally integrated into specific housings, fluid systems and piping arrangements, designed to achieve the desired separation. They can be considered as consumable elements of the system, although the life-time of a module can vary anywhere from a few hours to multiple years depending on the application. The modes of operation also differ depending on the application. Flow regimes may be dead-end or cross flow; feed addition may be batch or continuous; and control can range from manual to fully automatic. Single or multiple stages may be required and finally the need for pre-treatment and an effective cleaning regime must be considered.

2.2.5.1 Dead-end flow or cross flow

Dead-end flow membrane operation (also called normal flow) describes a process where the feed stream flows perpendicular to the membrane surface and all the fluid flows through and is discharged downstream of the membrane. This mode of operation is typically used for purification applications where contamination levels are low – for example, in the final sterilisation of an injectable (parenteral) drug liquid just prior to final vial packaging, where the contaminants are captured on the upstream side of the module and on the membrane structure. Gas filtration or venting can also be described as dead-end applications.

Cross-flow (also called tangential flow) operations describe processes where the feed solution flows across and parallel to the upstream membrane surface. Retained particles and materials are swept away from the membrane surface and retained fluid is discharged from the upstream side as the retentate stream. Some fluid flows through the membrane and is discharged from the downstream side as the permeate stream. Normally the retentate is re-circulated through the device to achieve the desired separation performance. Most industrial applications involve cross flow separation, although dead-end filtration is used extensively in the pharmaceutical industry.

There are a small number of important membrane applications that do not utilise separation capability but instead use the membrane film and structure as 'carriers' (e.g. diagnostics test kits). In these applications, the sample moves laterally across the membrane and the applications are described as lateral flow.

2.2.5.2 Batch or continuous

Cross flow operations can be designed as batch processes where an initial feed quantity is processed until the desired separation is achieved. Continuous processes can also be designed where feed is added and product (retentate and/or permeate) is withdrawn. There are also many possibilities in between batch and continuous to achieve the desired performance (Yacubowicz and Yacubowicz, 2005).

2.2.5.3 Manual, semi-automatic or automatic

The separation dynamics and equilibrium may be very complex and difficult to model but once properly piloted and tested the actual aggregate fluid flow is standard engineering. As a result, membrane systems are very suited to high degrees of automation and control if desired. The level of automation complexity is determined largely by the end user's preferences and mode of operation rather than any specific membrane property or attribute.

2.2.5.4 Single stage or multistage

The effective and efficient design for a specific separation process can sometimes involve multiple membrane steps in series. In this design, each step delivers some increment of the separation and/or purification objective. Among other advantages, multistage systems can deliver great flexibility for the optimal design and selection of membrane and module properties (Yacubowicz and Yacubowicz, 2005).

2.2.5.5 Cleaning regime and pre-treatment

The cleaning regime involves intermittent operational cycles, regular backflushes and/or off-line chemical treatment. This is an integral part of the mode of operation for the system and membrane module. The pre-treatment of the feed stream to a membrane system should also be considered as an integral part of a membrane system, even though this is likely to be a separate process step and/or equipment. The reliability and consistent performance of a specific application and system depends largely on effective pre-treatment and the continued execution of a proven cleaning regime.

2.3 Advantages and Disadvantages of Membrane Technology

The advantages and disadvantages of membrane technology in an industrial application depend on the specific situation and the unique circumstances related to that case. However, in general, there are common advantages and disadvantages associated with the technology whose relevance or weighting will vary depending on the local circumstances. The most common and relevant factors influencing the adoption of membrane technology are detailed in Tables 2.1 and 2.2.

Table 2.1. General advantages of membrane technology adoption.

Advantages
Acts as discrete physical barrier
Consistent output even with changing feed
Low energy use
Capability of operating at room temperature
Process simplification
No (or low) requirement for chemical addition
No effect on the chemistry or form of solution
Small physical footprint required
Minimum of moving parts and low maintenance requirements
Lends itself readily to automation
Lends itself readily to continuous processing
Modular, scalable and flexible

Table 2.2. General disadvantages of membrane technology adoption.

Disadvantages
Membrane fouling
Feed requires pre-treatment
Cost – capital and operating costs
Membrane fragility and level of compatibility with chemicals, pH and temperature/pressure range
May generate a concentrated waste stream for disposal
Membrane cleaning regime
Concentration polarisation impacting performance
Hard to model and requires empirical testing
Degree of selectivity
Lack of familiarity and understanding of technology
Lack of visibility of successful similar applications
Requires specialised equipment which may not be readily applied to other processes

The specific factors impacting performance and selection will be discussed and assessed in more detail under each application sector.

2.4 Major Trends Impacting Membrane Technology

2.4.1 STEP environmental analysis

Key global macro-environmental – sociological, technological, economical and political (STEP) – factors impact directly or indirectly on membrane technology research and industrial applications. The most relevant trends have been listed in Fig. 2.1 below. The increasing demand and cost of raw material commodities and energy will require greater productivity, efficiency and selectivity in industrial processes. Greater sensitivity to local and global environmental concerns favours technologies that reduce waste and enhance general reuse. The rising economic standard of the developing world suggests the adoption of shared higher-quality standards and raises general expectations for the quality of life. 'Process intensification' describes the industrial approach needed to address these converging challenges. This incorporates design principles focused on substantially increasing efficiency, lowering fixed investment and operating costs, saving energy, minimising waste and increasing control and reliability. Membrane separation technology can address many of these goals.

In general, the advantages of membrane technology, as detailed in Table 2.1, are very much in line with this philosophy. A growing adoption of membrane technology supported by this overall trend can be therefore anticipated.

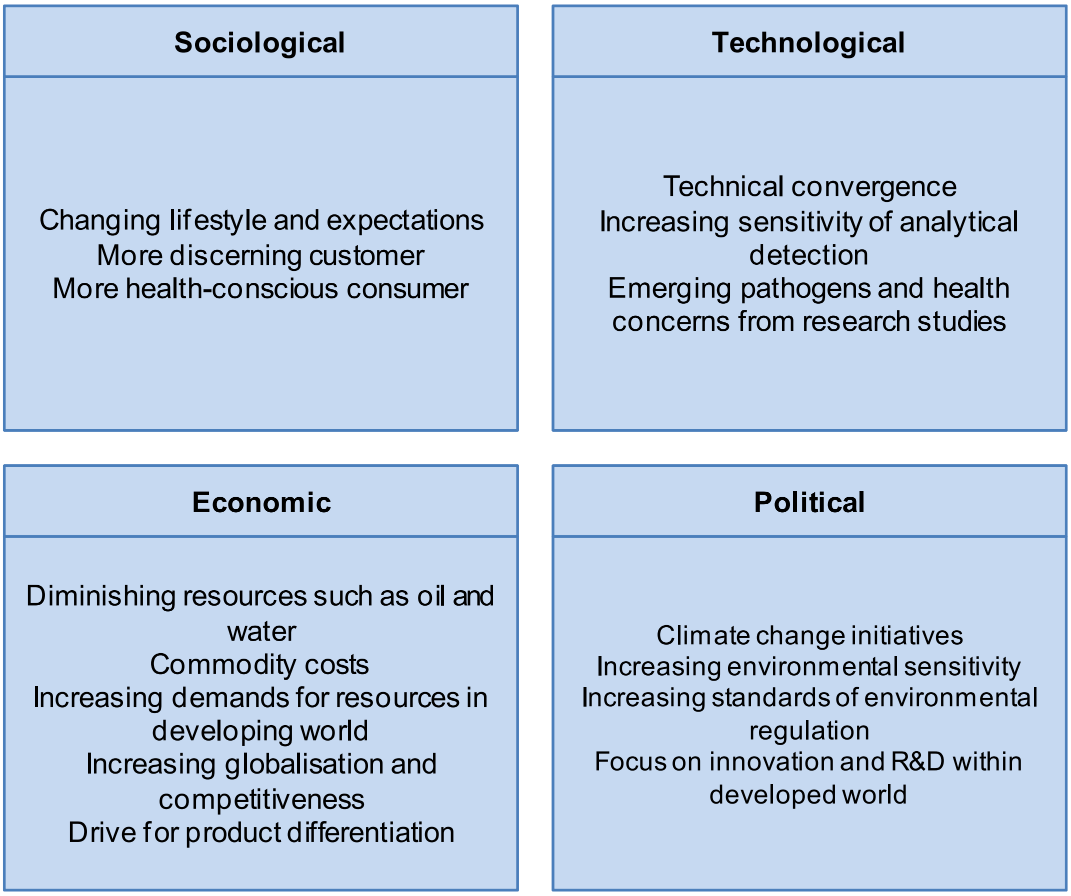

Figure 2.1. Sociological, technological, economic and political (STEP) analysis of membrane technology adoption.

2.4.2 Industry analysis

There are also specific trends evident within the competitive environment of the membrane industry, which already have or will have a direct impact on membrane applications and adoption. They have been analysed and assessed using Porter’s (1980) ‘Five Forces’ framework model – suppliers, new entrants, substitutes, customers and competitors – which is summarised in Fig. 2.2.

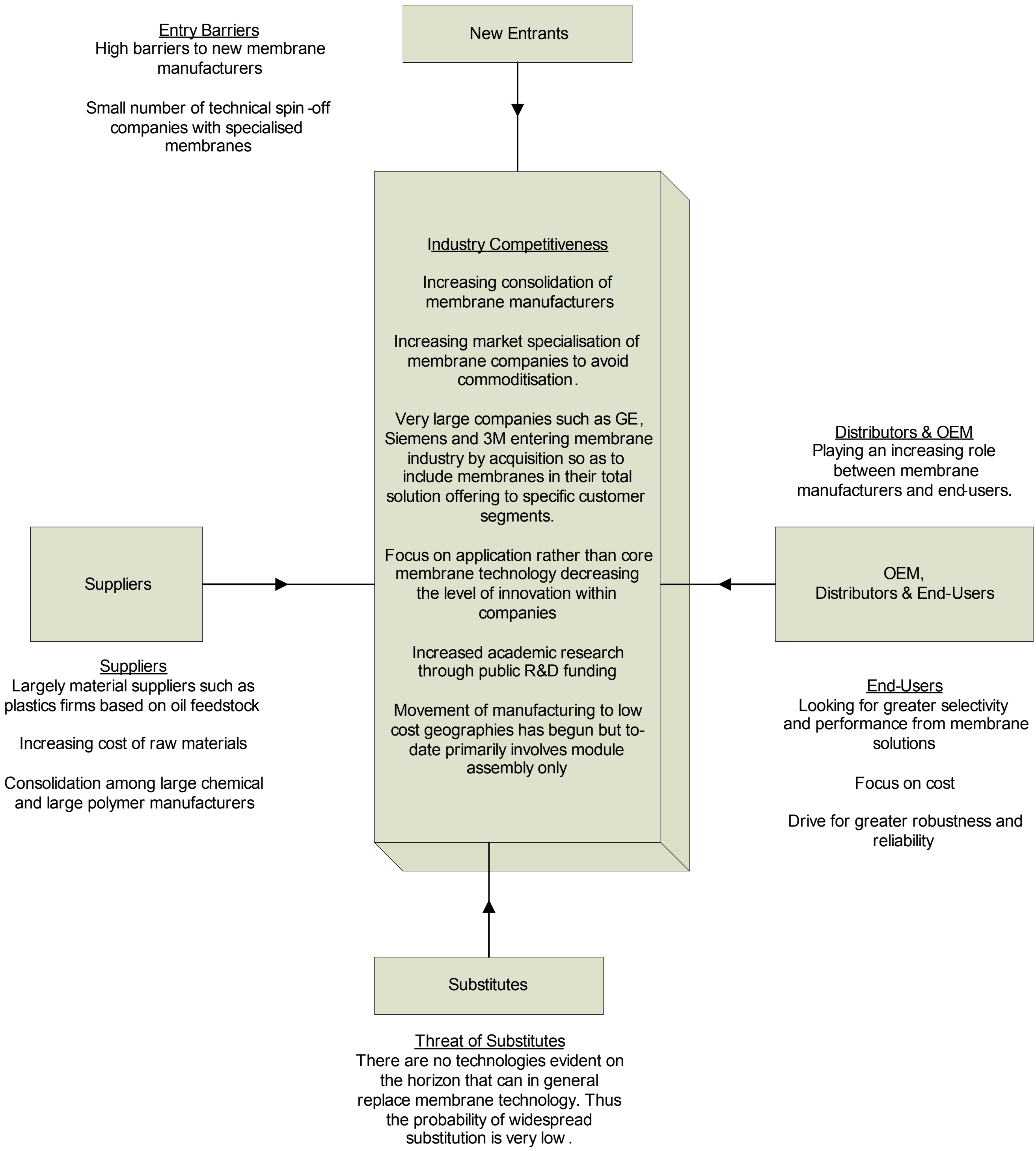

Figure 2.2. Membrane technology industry analysis using Porter’s (1980) Five Forces model.

The threat of technological substitution over the short to medium term is low and the barrier to entry for new entrants is high. Thus, it can be expected that, in general, the existing membrane technology suppliers will continue to dominate the industry except where a company enters the market through acquisition. An example of such a market entry is General Electric (GE) who have acquired a number of membrane speciality companies since 2005. A number of the main suppliers are traditionally material-science based companies such as Dow, 3M and Asahi Glass who have expanded into membrane science through internal technological development. The assessment would suggest that the most critical factors impacting future development will be in the interaction between the membrane supplier and the user or end-customer. This is supported by the general trend within membrane companies to focus on applications and application development rather then on core membrane science and technology. This raises the opportunity for independent research organisations to enter niche membrane technology areas and potentially partner with specific suppliers. Nevertheless, it is important to note that the level of impact varies across the different application sectors and will be reviewed in more detail in Section 3 and Appendices IV–IX.

2.5 Market Analysis Overview

The membrane industry is part of the broader Filtration, Purification and Separation industrial sector, which was estimated in 2007 to be worth about US$35b (Pall Corporation, 2007). Combining information from a number of sources, for 2006 global revenues of membrane-based products were estimated at about US$10b. This includes membranes, membrane modules and in general the hardware equipment required to accommodate and operate the system. Different approaches are taken by market research companies to define, quantify and track the industry sector. Some studies include membrane modules only; others include the hardware; in other cases, the definition of a membrane product is expanded to include depth filtration media and associated products. Therefore, it is difficult to fully validate and compare alternative sources of information. The split in market revenue across the main categories is summarised in Fig. 2.3.

Splitting the 2006 revenue across membrane technologies as opposed to applications leads to Fig. 2.4.

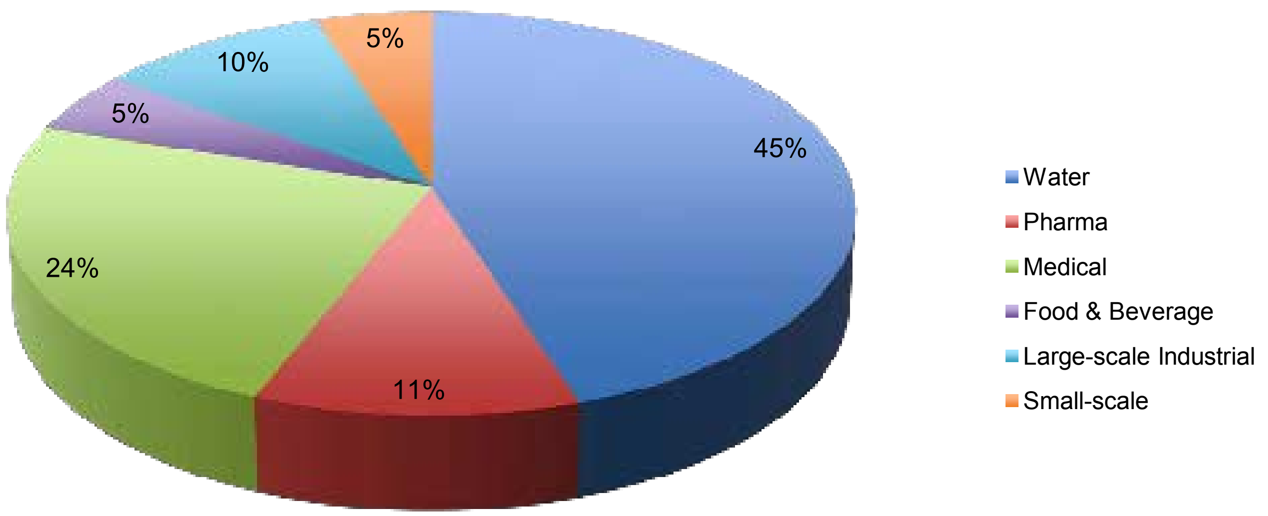

Figure 2.3. Global revenues from membrane-based products by application, 2006.

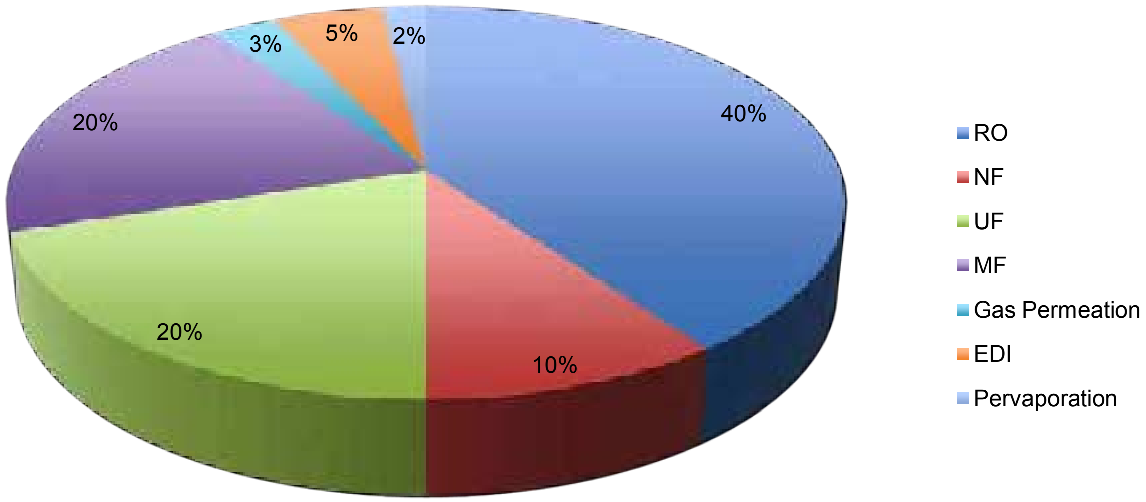

Figure 2.4. Global revenues from membrane-based products by technology, 2006.

2.6 Membrane Technology Suppliers

The range and diversity of membrane technology suppliers is very large and mirrors the fragmented variety of membrane technologies, materials and applications. Different supplier comparisons have been published over the last number of years which are usually focused or limited to a specific application or product type. For example, Pearce (2007) reviewed the leading MF and UF product suppliers for water and wastewater purification in a late 2007 article. Based on multiple personal and public information sources, a leading 50 or so global membrane technology suppliers across all technologies and product types were reviewed and referenced against their specific membrane technology expertise and targeted industrial application. More recently, there has been intense merger and acquisition activity within the sector. The leading membrane brands and/or divisions incorporated within each corporate entity have been included within the detailed summary, presented in Appendix II. The United States (US) dominates the membrane industry as the home location to a large number of global membrane suppliers.

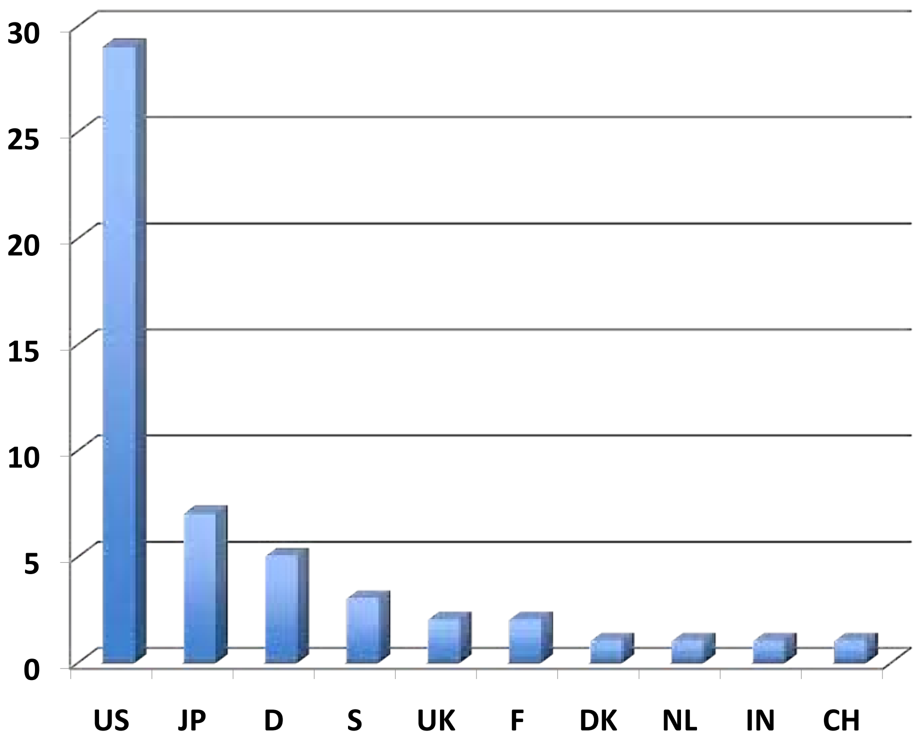

Figure 2.5. Number of supplier headquarters versus location.

It is important to note that Appendix II may not be an exhaustive and complete listing of supplier HQs. It is difficult to fully capture all leading membrane companies across the world, especially in China and Asian geographies. It is possible that a number of companies from this region have been overlooked in the compiling of this list.

The strategic role and purpose for membrane operations within a business varies from company to company. This has a significant impact on how each company views its membrane operations and invests resources in fundamental membrane research and development (R&D) and application expertise. Companies have been categorised according to their overall strategic focus to help assess and interpret the competitive landscape.

Table 2.3. Supplier segmentation by strategic focus

Description	Company
A combination of related different companies engaged in many diverse activities and sectors; one division provides products and services as a 'total' package	ESCO, GE, Siemens, Veolia, Mitsui, Honeywell
A combination of related different companies engaged in many diverse activities and sectors; providing products characterised by their performance and their composition	Air Liquide, Air Products and Chemicals, Asahi Glass, Dow, Dupont, InterTech Group, ITT, Johnson Matthey, Linde, Mitsubishi Rayon, Nitto Denko, Praxair, Toray, WL Gore, 3M, WR Grace
Single company serving several sectors or markets, with a focus on several particular cross-sectoral membrane applications	Baxter, BD, Corning Inc, Culligan, DSS Silkeborg, Entegris, Folex, Innovative Gas Systems, Millipore, Medtronics, Norit, Sartorius-Stedim, Sulzer, Tetra Pak
Single company specialising in providing products and services as a 'total' package, with a focus on separation applications, including membrane processes	Donaldson, Pall, Parker-Hannifin, Roki
Single company specialising in membrane separations in multiple sectors and for multiple applications	Koch, mdi Membrane Technologies, Polypore, Sinomem/Microdyn-Nadir, SpinTek, New Logic International
Single company specialising in membrane separations in specific sectors or applications	Applied Membranes, Kubota, Membrane Technology and Research, Membrane Extraction Technology

The current status outlined in Table 2.3 suggests that a large portion of membrane operations are now 'bolt-on' businesses supporting the broader product portfolio or total solution offered to a specific industry segment. Today there are very few companies focused exclusively on membrane technology and those that do exist are small with limited resources. This compares with 20+ years ago when there were a significant number of relatively large membrane-focused companies. Basically, the membrane industry has shifted from a technology focus to an application focus. This hypothesis is supported by the large increase in installed plant and systems since the 1990s and the steady increase in effectiveness, performance and cost efficiency of membrane applications versus alternative technologies. A further observation or potential hypothesis that can be drawn from this trend is that there will be a significant reduction in fundamental membrane research in industry over the next 10 to 20 years compared to the past, as most research effort is now focused on specific applications and product-based objectives as opposed to more fundamental membrane science. Information from private sources and discussions across a number of companies support this assessment. Because of this trend, greater potential may exist in the future for academic institutions to collaborate with companies on fundamental research as this activity is no longer a central and leading driver within a company's own R&D. A final segmentation of suppliers is outlined in Fig. 2.6 where suppliers are mapped against the scale and breadth of their membrane business activities.

The number of large broad membrane companies is relatively small and probably getting smaller as companies focus their business activities on growth-driven narrower market opportunities. This may lead to intense competition in specific market sectors. For example, the level of membrane activity currently focused on water and wastewater is very heavy and explains to some degree the level of growth and competitiveness of membrane applications in that sector. The supply of RO modules for water treatment has largely been commoditised, and it is likely that this trend will expand to NF, UF and MF membranes targeted at water.

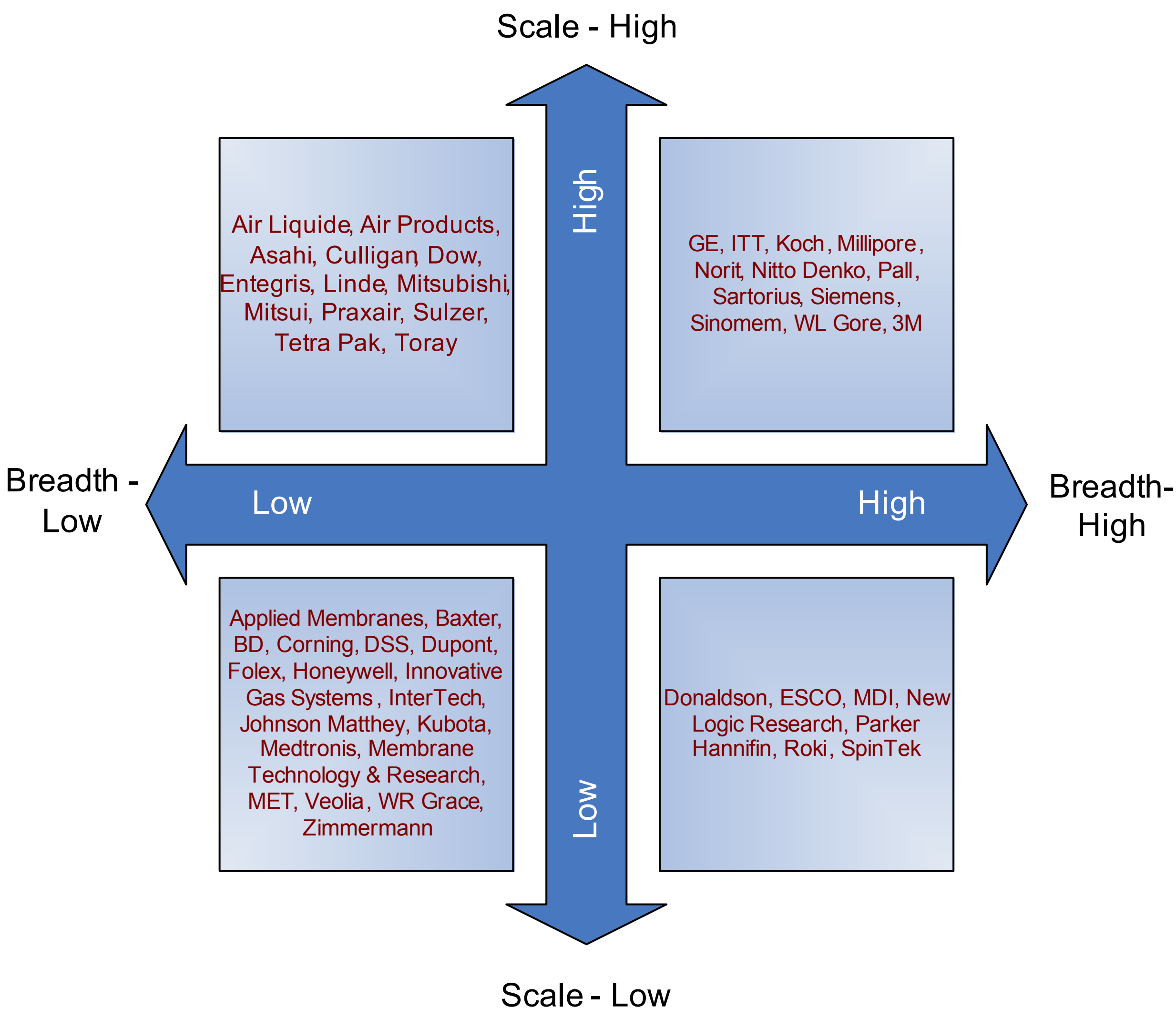

Figure 2.6. Supplier segmentation by scale and breadth of membrane business.

2.7 Professional Membrane Organisations and Research Centres

There are a number of regional professional membrane organisational networks in operation around the world. They act as an interface between suppliers, academics and end-users and in some cases facilitate or engage in specific membrane-research activities. In addition, there is a high level of academic research activity evident from some leading institutions around the world, with perhaps 15–20 in the European Union (EU), 5–10 in the US and 5 in Asia (though the latter may be an underestimate).

A detailed list of leading membrane groups and academic research centres has been prepared and is presented in Appendix III. As with membrane suppliers, it is difficult to compile a complete and exhaustive list and there may be some unintentional omissions, especially from the Asian region. However, the list provides a reasonable summary of the location and spread of such groups.

2.8 Summary

The membrane industry encompasses a broad field of science, engineering and technology. It operates at the intersection of multiple disciplines, including material science, chemistry, chemical engineering, mechanical engineering, electrical engineering, life sciences and nanotechnology. The latest membrane industrial applications deployed today originate from the convergence of these technologies. The industry has a strong and diverse base and since the late 1980s has focused on the application of products derived from technical and scientific research from the mid to late 20th century. More recent research has focused on achieving more cost-effective solutions and improved performance and efficiency from membranes, modules and systems. The trends in the development and use of membrane technology are summarised in Table 2.4.

Table 2.4. Summary observations from the review of the membrane industry.

Major global trends support the increased adoption of membrane technologies across multiple industry sectors
The overall membrane industry is growing at high single digit figures (5 to 8%) and will continue to do so over the next five years
The level of competition within the membrane industry has increased significantly since the late 1990s and for some products and applications has become a commodity market with minimal differentiation
In general, the membrane industry has shifted from a technology/product focus to an application focus (with some exceptions)
The US holds a dominant position in the supply of membrane technology
Academic membrane research is more evenly split across the US, Europe and Asia
Academic research may play an increasingly important role in developing innovative and breakthrough membrane technologies as companies focus more on application

3 Membrane Technology Applications

3.1 Membrane Technology and Water

Membranes have been associated with water purification, treatment and recovery for many years. Water (including wastewater treatment) is now the largest outlet for membrane materials: about 50% of the worldwide demand for membrane materials is used in associated applications (Frost & Sullivan, 2006). Revenues in 2006 for membrane modules and equipment in water applications were estimated at around US$4.5b (Frost & Sullivan, 2006). The cumulative annual growth rate over the next five years is forecast at 6 to 8% (Frost & Sullivan, 2004a). A more recent report (Lux Research, 2010) suggests a lower market value at US$1.5b in 2009, but a similar growth percentage rate, with the market rising to US$2.8b in 2020. Reverse osmosis is the dominant technology, but RO membrane prices have fallen, due to competition from Chinese manufacturers and a lack of differentiation among suppliers. Recycling municipal water is identified as a ‘boom’ application, particularly in India and China. Figure 3.1 outlines the underlying drivers impacting the water industry over the next five years.

Tables 3.1 and 3.2 present the advantages and disadvantages of membrane technologies in water processing.

Table 3.1. Advantages for membrane technology use in water applications.

Advantages
Delivers a higher-quality output (water or wastewater discharge)
Provides an absolute physical barrier to pathogens
Delivers a consistent performance and high level of quality assurance even with changing feed
Low-energy utilisation versus comparative new technologies such as ultraviolet (UV) sterilisation
Requires no phase change or higher temperatures, unlike evaporative water treatment processes
Generally requires less chemical use
Requires less space and a smaller facility footprint
Lends itself readily to increased automation and control
Allows easy scale-up and incremental capacity expansion through modular design
Supports small-scale decentralised treatment while also adaptable for large centralised systems
Strong competitive membrane technology industry steadily improving efficiency and reducing costs

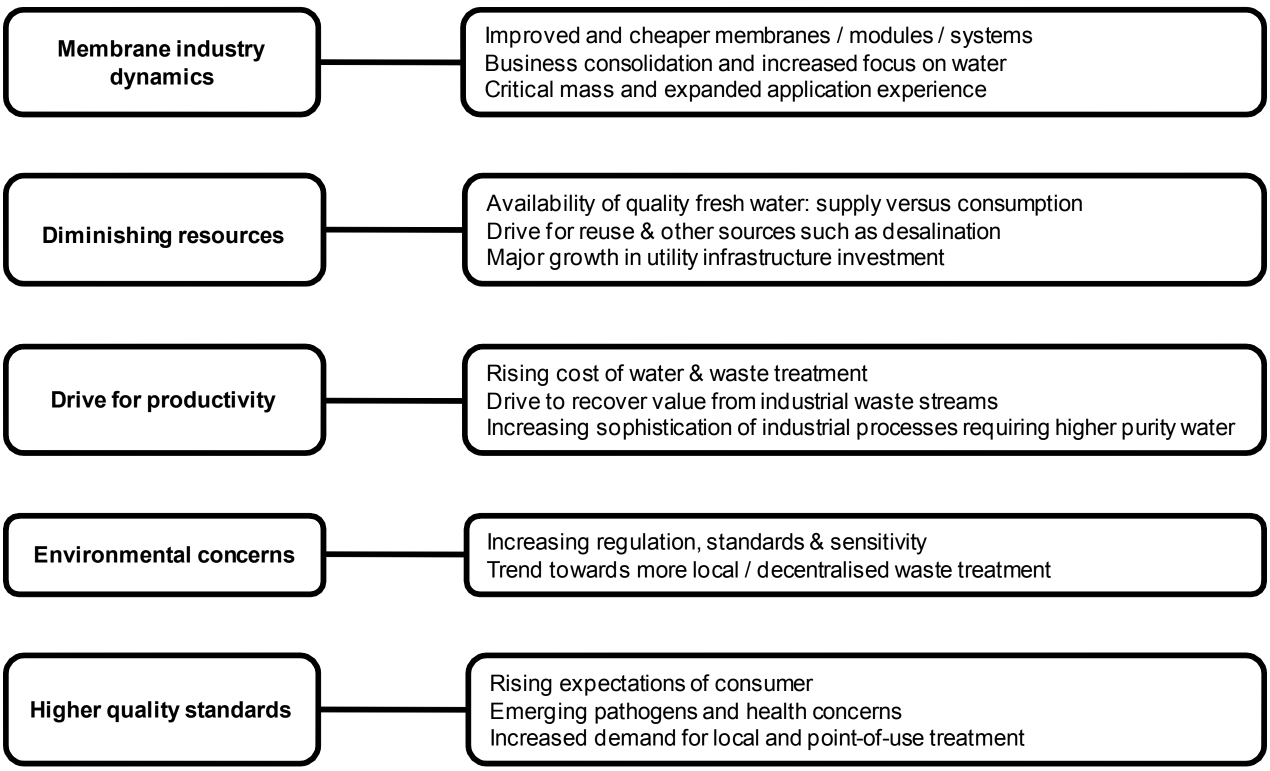

Figure 3.1. Key drivers of the water sector.

Table 3.2. Disadvantages for membrane technology use in water applications.

Disadvantages
Membranes tend to be more fragile and less robust in application
Tends to have a higher capital cost and operating cost
Flux and product flow rates can be impacted by fouling
High energy utilisation versus older more conventional processes such as sand filtration
Feed stream may require customised pre-treatment
Membranes require regular cleaning with some chemicals
May generate a concentrated waste stream for disposal
Lack of familiarity and understanding of technology within end-user groups
Hard to model and usually requires pilot plant work
Maximum short-term flow-rate limitations usually at about 1.5 x design output
Does not include residual disinfection

The major water applications are:

- ***Potable (or drinking water) treatment***: Membrane systems provide a physical barrier to particulate and microbial contaminants. Their use has been extended to small-scale local water-treatment plants and residential point-of-entry or point-of-use applications.
- ***Desalination***: Reverse osmosis and other membrane technologies are generally cheaper than thermal distillation techniques. In addition to large-scale operation, small-scale packaged systems have been developed for emergency situations and where the available space is severely restricted.
- ***Municipal wastewater treatment***: Membrane bioreactors are activated sludge processes where the clarifier is replaced by a membrane separation. They have performance advantages, but at a cost. As the cost differential with conventional systems narrows, their use increases. Membrane separations may also be used for tertiary treatment and for the treatment of landfill leachate.
- ***Industrial wastewater treatment***: Membranes are used for applications similar to municipal wastewater treatment, but the specificity of industrial waste streams will typically require more detailed evaluation and piloting.
- ***Water reuse***: Membrane processes may be used in combination with 'conventional' processes to provide water that may be reused. The subsequent use may be relatively low grade or may extend to drinking water quality, subject to the sophistication of the process. This is an area of high growth potential.
- ***Purified (including ultrapure) water***: Membrane technology has become the leading technology for purified water generation, in applications such as boiler feed water, semiconductor washing and pharmaceutical manufacture.

Additional information on each application, including a discussion of research and technology trends, may be found in Appendix IV.

3.2 Membrane Technology in Pharmaceutical Processing

The conventional active pharmaceutical ingredient (API) is a small chemical-based molecule, manufactured by multiple chemical synthesis steps. Manufacturing is generally based on large-scale organic chemistry processes, operated within chemical manufacturing facilities using a broad range of classical engineering unit operations. Following the final reactive step, the API is purified in concentrated form and formulated into the final product – a tablet, cream or ointment, aerosol, liquid vial for injection or oral solution. More recently, biotechnology has taken an increasingly larger share of the pharmaceutical market, although still only a small part of the overall market. Biopharmaceutical products are typically large molecules. The biopharmaceutical manufacturing process for the active ingredient is generally categorised as a two-part process – upstream cell-culture processing to generate the desired product followed by downstream purification to achieve the required product purity. The fill-and-finish operations are generally liquid-based formulations delivering sterile solution vials for injection or they involve lyophilisation where the biomolecule is freeze-dried for enhanced product stability and shelf-life. The underlying drivers impacting the pharmaceutical industry over the next five years are outlined in Fig. 3.2.

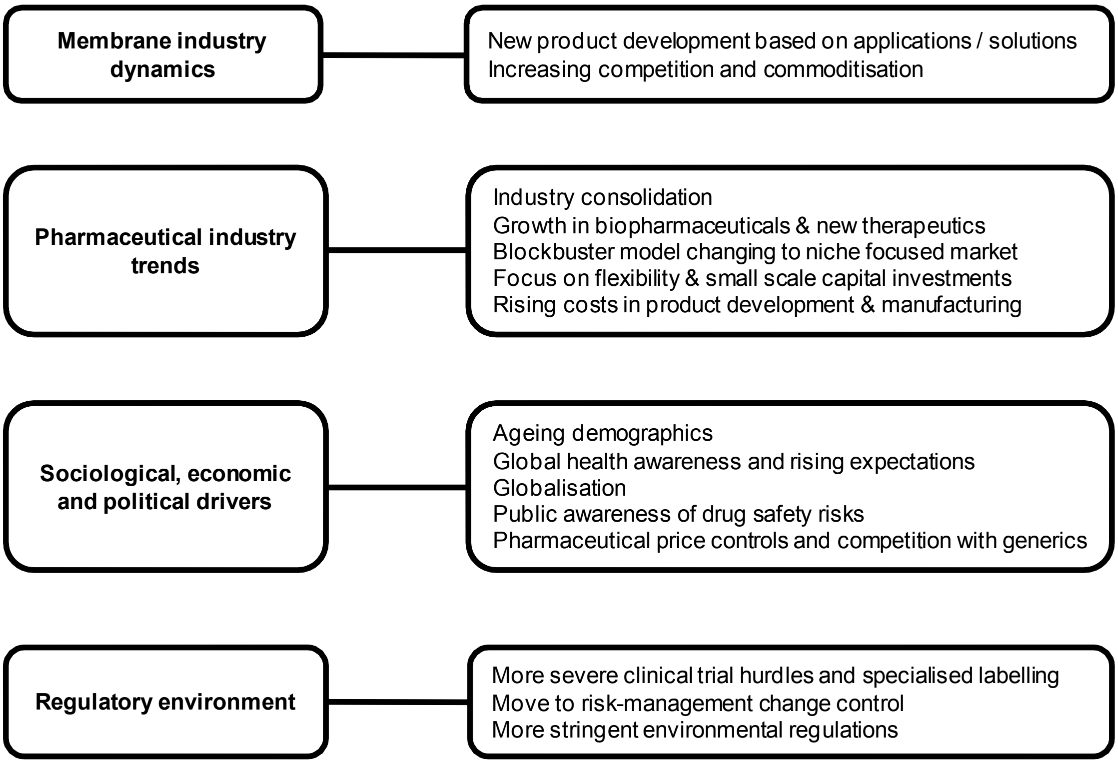

Figure 3.2. Key global drivers impacting pharmaceutical industry.

The 2005 membrane separations market for pharmaceutical applications has been estimated at about US$1.1b made up of non-sterile membrane filtration modules (US$140 million [m]), sterile filtration modules (US$540m), ultrafiltration (US$100m), virus filtration modules (US$50m), stainless steel housings, systems and hardware (excluding membrane modules) (US$200m) and other (<US$50m). The advantages and disadvantages of membrane technologies in pharmaceutical processing are presented in Tables 3.3 and 3.4.

Table 3.3. Advantages for membrane technology use in pharmaceutical applications.

Advantages
Delivers consistent selectivity and assurance for the separation of bio-molecular compounds
Provides an absolute physical barrier to pathogens and the potential to sterilise liquid and gases
Removes suspended and dissolved components to varying degrees depending on pore-size system design
Does not require higher temperatures and is gentle on heat-sensitive and bio-molecular compounds
Requires less space and a smaller facility footprint than alternatives
Lends itself readily to increased automation and control
Allows easy scale-up and incremental capacity expansion through modular design
Supports waste-treatment processes and generates cleaner discharge streams and provides potential for product recovery

Table 3.4. Disadvantages for membrane technology use in pharmaceutical applications.

Disadvantages
Fouling can be an issue, impacting throughput, performance and cost
Membrane systems are generally more expensive than depth (media) filtration alternatives which may deliver acceptable separations and purification performance in specific situations
Many membranes and modules are not compatible with concentrated solvent streams
Membrane modules are not easily cleaned to good manufacturing practice (GMP) standards and are usually replaced frequently at high cost
Membrane systems tend to be process specific and may not provide sufficient flexibility in multi-product plants
Existing unit operation capacity is in place and expensive to displace
Hard to model and usually requires pilot plant work with a significant risk factor for success
Conservative industry, slow to adopt new technology and regulatory barriers to major process changes

Membrane technology plays a relatively small but significant role in classical API pharmaceutical manufacture, a more critical role in fill/finish formulation operations and is a central and integral part of bioprocessing. The current status of membrane technology within each of three major process areas will be discussed in the following sections and in the Appendices. Purified water supply, which is also relevant to this sector, has already been addressed in the context of water in Section 3.1.

- ***Classical API manufacturing**:* Excluding water purification, membrane separations have traditionally played a limited role in organic synthesis API manufacturing processes. As an exception, membranes have played a more central role in water-soluble antibiotic production (Schäfer *et al*., 2005). These small molecules are heat sensitive and not suited to traditional chemical unit operations. Only recently have membranes been developed that can withstand organic solvents. Some success has been achieved is removing APIs from wastewater streams using nanofiltration, and PV or VP membrane technology is occasionally used in combination with distillation to break azeotropes and achieve the required purity levels for solvent recovery.
- ***Biopharmaceutical processing:*** Bioprocessing is very purification intensive, and large-scale production requires economical separation solutions at high throughput. Membrane processes are used for the purification of raw materials (liquids and gases) at inlet, the purification of the target compound, the assurance of solution sterility and the final purification step prior to fill and finish (Charcosset, 2006). Membrane applications can also be found as part of clean-in-place systems and general vent filters.
- ***Fill/finish aseptic operations:*** All incoming liquids and gases are sterile filtered using membranes to reduce contamination. Some products can only be sterilised aseptically as they are unsuitable for thermal or radiation sterilisation techniques (Jornitz, 2002; Jornitz *et al*., 2002). Membrane filtration is also used for bioburden reduction to increase assurance levels where a product is subject to an alternative terminal sterilisation step such as ethylene dioxide (ETO) or radiation treatment.

Additional information on each application, including discussion of research and technology trends, may be found in Appendix V.

3.3 Membrane Technology in Food and Beverages Processing

Membrane technology has been widely adopted in the food and beverages industry over many years, and there are very few modern processes that do not have at least one membrane technology step (Kramer, 2000; Butchermaker, 2004). By far, the most common membrane technologies applied in food and beverages processing are the pressure-driven MF, UF, NF and RO systems. Ultrafiltration is the most widely used, providing separation selectivity and fine purification. In 2001 the installed membrane capacity in food and beverages processing was estimated at 850,000m^2 – 47% UF, 35% NF, 10% RO and 6% MF (Daufin *et al*., 2001). Nanofiltration is the more recently adopted process step (Neff, 1999) but has grown rapidly and is now often used to concentrate

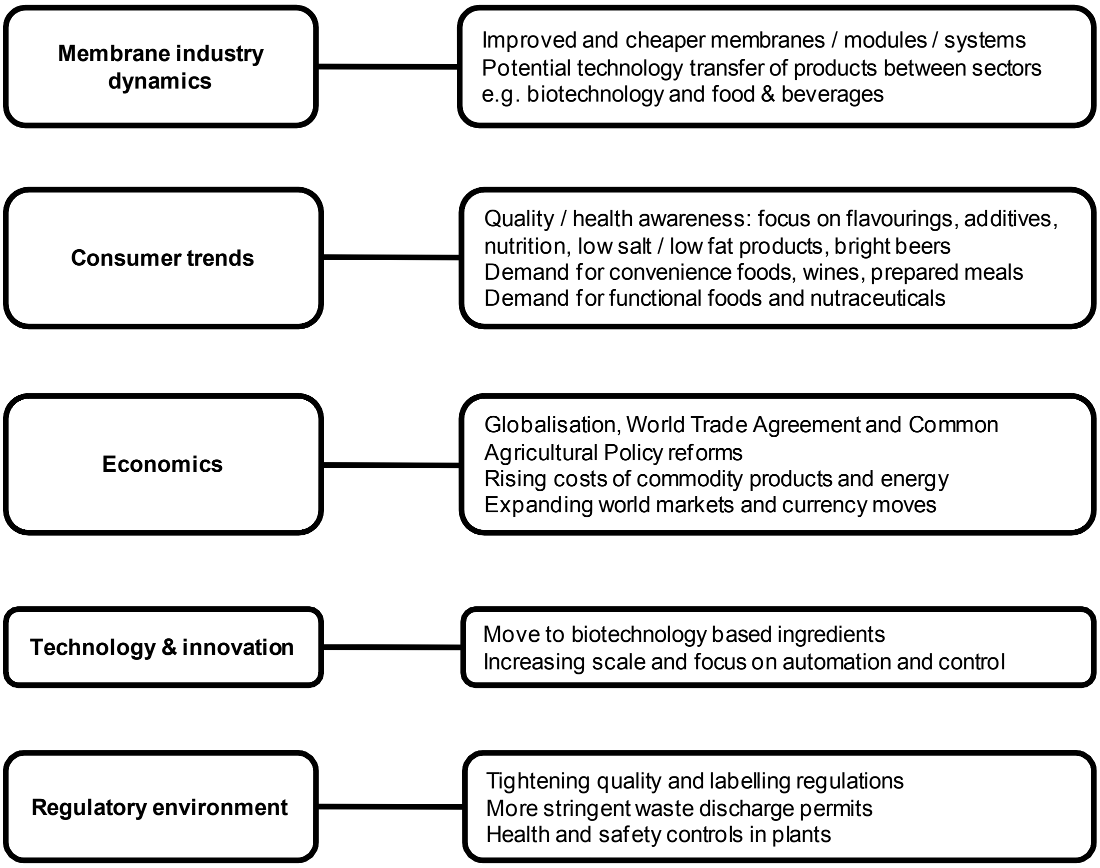

Figure 3.3. Key global drivers of the food and beverages sector.

materials at lower cost and increased production rates than comparable RO processes. Nanofiltration is also commonly used in recovering clean-in-place (CIP) solutions for reuse. Electrodialysis (ED) or electrodionisation (EDI) play a niche role generally associated with demineralisation in dairy applications. Some of the key underlying drivers impacting the food and beverages industry over the next five years are outlined in Fig. 3.3.

The global market for membranes and modules in process-related food and beverages applications was estimated at US$210m in 2006, with a forecast cumulative annual growth rate of about 5% over the following five years. The leading application by installed capacity and consumable purchases is the dairy industry, representing about 50% of the market, followed by beer and beverages at 20% and the remainder made up of a large variety of products and processes (BCC Research, 2006).

Table 3.5. Advantages for membrane technology use in food and beverages applications.

Advantages
Delivers excellent selectivity for separation of biomolecular compounds and tends to provide a higher quality product
Provides an absolute physical barrier to pathogens with a high level of assurance
Delivers a consistent performance and high level of assurance even with changing feed streams
Low-energy utilisation versus comparative thermal technologies
Does not require higher temperatures and is gentle to biomolecular compounds preserving taste and molecular functionality
Generally requires less chemical use and has been identified as a real alternative for the replacement of kieselguhr (diatomaceous earth) which has safety concerns
Requires less space and a smaller facility footprint than alternatives
Lends itself readily to increased automation and control
Allows easy scale-up and incremental capacity expansion through modular design
Facilitates waste product recovery to levels of purity suitable for use

Table 3.6. Disadvantages for membrane technology use in food and beverages applications.

Disadvantages
Tends to have a higher capital cost and operating cost to alternative processes such as pasteurisation, media filtration and evaporation
Hard to model and usually requires pilot plant work with a significant risk factor for success
Fouling from 'dirty' and variable feed-streams can be a recurring issue
High-energy utilisation versus some conventional processes such as media filtration
Feed stream may require customised pre-treatment
Membranes will require regular cleaning with some chemicals
May generate a concentrated waste stream for disposal

The major food and beverages applications are:

- ***Dairy***: The primary dairy applications can be categorised into the following groups: fractionation and purification: the separation and purification of individual components and proteins, including casein and whey proteins; pre-concentration, concentration and demineralisation: the reduction in product volume normally through the elimination of water and salts, including whey and milk concentration; bacterial removal and bioburden reduction: treatment of micro-organisms; waste reduction and by-product recovery, for example, whey protein concentrate and lactose.
- ***Beverages***: Cross-flow microfiltration has been identified as the preferred alternative to diatomaceous earth media filtration for beer final filtration and polishing post-fermentation. Emerging applications for membrane technology include rough beer clarification and the cold sterilisation of clarified beer prior to filling. Since the 1990s, cross-flow MF has been increasingly adopted in wine-making for post-fermentation clarification and the removal of micro-organisms. Reverse osmosis and/or NF filtration is now also used widely to produce low and reduced alcohol wines (Lipnizski *et al.*, 2006). Ultrafiltration has become the standard in the soft drink industry for the preparation of process water at bottling plants. Membrane technology has traditionally not played a significant role in juice processing. However, cross-flow MF and/or UF is now an established and proven technology in some processes for low-temperature clarification and sterilisation.
- ***Food processing***: There are a wide variety of miscellaneous membrane applications, e.g. lactic acid manufacture, clarification of sugar and glucose syrups, concentration, demineralisation and purification of protein gelatine in meat industry by-products, soy protein concentration, concentration and recovery of aromatic compounds from mussel cooking juices, recovery of a concentrated aqueous sugar product and water for reuse from a raisin wash wastewater stream.
- ***Clean-in-place (CIP) and waste treatment***: Membrane systems may be used if a high standard of cleanliness is required in the reused CIP solution or if particular valuable components would otherwise be lost. The food and beverages sector is a major water consumer and is increasingly adopting membrane technology for wastewater treatment and water reuse.

Additional information on each application, including a discussion of research and technology trends, may be found in Appendix VI.

3.4 Membrane Technology in Large-scale Industrial Applications

Many large-scale industrial applications use membrane technology for purification and separation processes. They are generally chemical industry based and include both liquids and gases. In some cases, the membrane is an ancillary process step to improve manufacturing performance and yield, such as in the microelectronics industry, or for facilitating the treatment of a wastewater stream; in others, it is a central part of the manufacturing process, such as in chlorine and caustic manufacturing or in nitrogen gas generation. Some of the primary drivers include improved process capability, energy efficiency, low maintenance, automation, modularity and reduced footprint. An overview of applications is presented in Table 3.7 and further discussion on each application may be found in Appendix VII.

Table 3.7. Large-scale applications of synthetic membrane technology.

Chemical Processing	
Chlor-Alkali	The manufacture of chlorine and caustic from salt solutions is largely based on traditional electrochemical technology. Although membrane-cell is currently the best available technology, the conversion costs are very high. This limits or at least slows down the full conversion of installed capacity
Organic Mixture Separation	Currently membrane technology is applied in a limited number of very specific and challenging industrial separations, e.g. some azeotrope separation and the recovery or purification of heat-sensitive compounds. In certain cases membrane processes (generally VP or PV) offer a competitive energy efficient alternative
Organic Solvent Dehydration	The main industrial application of PV is the dehydration of solvents that form azeotropes with water. PV can now be considered as state-of-the-art for the dehydration of some solvents (Sommer and Melin, 2005)
Fuels	
Petroleum Refining	Wastewater treatment and the separation of small solvent molecules from larger hydrocarbons in mixtures used to extract vacuum residual oil in refineries
Biofuel Production	Pervaporation has gained broad acceptance as a cost-effective bioethanol dehydration technology compared to alternative distillation processes (Huang *et al*., 2008). Membrane technology has the potential to be an important tool for biodiesel production via the transesterification route: feedstock pre-treatment, reaction by-product removal and final product purification (Vasudevan and Briggs, 2008)
Gas Processing	
Hydrogen Purification	Hydrogen recovery from purge gas streams in ammonia plants and refineries is common
Natural Gas Processing	Gas permeation membranes efficiently remove contaminants including carbon dioxide and hydrogen sulphide from natural gas feedstocks
Industrial Gas Generation	For lower-purity nitrogen, membrane separation has become a very competitive alternative to cryogenics or pressure-swing adsorption
Carbon Dioxide Capture	Gas membrane technology is not currently competitive for flue gas CO_2 removal, in comparison with conventional processes (White *et al*., 2003)
Metal Processing	
Electrocoating of Metal Parts	Membrane processes may be applied to control the primary bath concentration at minimum cost and minimum loss of active components, along with reduced rinse water consumption
Micro-Electronics	
Process Liquids and Gases	Membrane technology is one of the leading technologies used to achieve the required contamination control of incoming gases and liquids, including water, for clean room operations

3.5 Membrane Technology in Small-scale Industrial Applications

The primary driver for the use of synthetic membrane technology in such a diverse range of applications is the precise and consistent filtration or separation capability achieved, combined with the ease of fabrication into a specific device configuration.

Traditional fluid filtration markets such as the laboratory and machinery fluid market segments are mature sectors with limited growth potential. There is strong competition within the field and many similar product options are available for each application. Increasing commoditisation has driven suppliers to focus principally on cost reduction through innovative device redesign, relocation of manufacturing to low-cost areas and/or automation. More recent product improvements have been achieved through the adoption of more efficient membranes (faster flow rates with higher-throughput) into existing device formats. On the other hand, the more recently developed power system and textile market segments have great growth potential. An overview of applications is presented in Table 3.8.

Table 3.8. Small-scale applications of synthetic membrane technology.

Laboratory Separation Products	
Life Science Filtration	The life science laboratory filtration market in 2003 represented approximately US$375m (Frost & Sullivan, 2003). Products include basic membrane cut-discs, vacuum filtration cups and pressure filtration devices such as syringe filters. The main laboratory applications include sample preparation, sterile filtration and particle monitoring
Protein Research	Areas of application include clarification, separation, purification, concentration and detection. MF and UF membranes are used in a range of different disposable formats with pressure separation achieved using syringe or centrifugal forces. The market for membrane-based consumable products in protein research was estimated at US$84m in 2003 (Frost & Sullivan, 2003)
Drug Discovery	Membranes are attached to the end of a multiwell plate where a biomolecule of interest is immobilised on the membrane surface. The overall market for multiwell filter plates and associated membranes in 2003 was estimated at US$209m (High Tech Business, 2003)
Machinery Fluids Filtration	
Liquids & Gases	Membranes represent only a small fraction of the overall market with no current trend or future expectation for this to change significantly. However, there are a small number of critical applications that require finer filtration, e.g. aerospace, military hardware and nuclear plants use MF membrane particulate filtration to increase system reliability and performance
Power Systems	
Batteries	A film, the 'separator', is used to separate the positive and negative electrodes of a liquid electrolyte battery to prevent physical contact. Polymeric membranes are the most widely used, with increasing popularity of inorganic composite membranes, especially in larger battery formats
Fuel Cells	For vehicle transport the leading fuel cell format is the polymer electrolyte membrane fuel cell (PEMFC) – also called proton exchange membrane fuel cells. An alternative fuel cell format targeted at the small portable power market is the direct-methanol fuel cell (DMFC). The membrane is a critical component in both formats, and widespread research is ongoing to develop the most efficient membrane design
Textiles	
Protective Materials	The increased fear of bioterrorism has spurred a growing market for protective military clothing. The textile film acts as a barrier to microorganisms, providing the protection required for operational personnel working in a dangerous environment

Further discussion on each application may be found in Appendix VIII.

3.6 Membrane Technology in Medical Applications

Membranes are an integral part of biochemical processes. Although biological membranes are excluded from the scope of this report, there are many synthetic membrane applications in the medical field which are part of a large and growing industrial market segment. The most common membrane technologies utilised in medical applications are MF and UF membranes using pressure or concentration (dialysis) driving forces.

The medical membrane market is very competitive with generally high-volume low-margin products. Performance reliability and high-quality standards are required with regional regulatory directives controlling design and manufacturing activity. Membrane technology companies typically do not manufacture the final product but instead deliver membranes and associated components to medical device or diagnostic companies who in turn manufacture and supply the finished product. Health-care cost pressures continue to drive down margins as manufacturers seek lower cost supply-chain options. An overview of applications is presented in Table 3.9.

Table 3.9. Medical applications of synthetic membrane technology.

Blood Processing	
Haemodialysis	Blood purification is carried out in a membrane module (dialyser) which is generally a hollow-fibre device. The devices are reused a couple of times before being discarded. The global dialyser market was estimated at US$1.3b in 2004 (Baker, 2004), approximately 50% of the membrane medical application market
Blood Oxygenation	Blood is pumped through the shell side of a hollow fibre device while oxygen is pumped through the hollow fibres. The global market in 2004 was estimated at about US$500m (Baker, 2004), approx. 20% of the membrane medical application market
Blood-derived Products Filtration	Membrane devices are used to improve the quality of whole-blood or blood-derived products through pressure filtration. The membrane barrier can eliminate some contaminants and reduce the level of others. Membranes are also used to fractionate blood
Diagnostics	
Flow-through Diagnostic Testing	Microporous membranes act as a solid substrate for the reaction between the substance intended for detection and a detector biomolecule which has been bound to the membrane surface. The membrane also transports the sample solution from a reservoir to the detection site
Lateral Flow	As with flow-through testing, membranes make up only a small part of the overall product and market value. The estimated membrane-only market size in 2002 was US$25m
Molecular Diagnostics	There is a broad array of tests using the immobilisation substrate of a membrane for molecular diagnostic applications, e.g. nucleic acid probes
Filtration	
Drug, Intravenous and Ophthalmic Solutions	In some critical cases there is an enhanced risk of particulates, such as precipitate or vial fragments, impacting a patient. In such cases, a final membrane filtration device may be required at the point of final application
Medical Device Protection	
Vent	Typical applications include integrating a hydrophobic filter into the vent of a larger medical device to allow relatively free air movement and venting without the risk of microbial contamination
Phobic Barrier	Membrane filters also play a role in some medical instruments as a phobic barrier to protect transducers from liquid blood contamination
Controlled Drug Delivery	
Controlled Release	Membrane technology provides a useful tool to facilitate the controlled delivery of drugs through a number of potential mechanisms, including diffusion control, biodegradable release and osmotic action (Baker, 2004)

Further discussion on each application may be found in Appendix IX.

4 Status of Membrane Technology in Ireland

4.1 Introduction

Previous sections have reviewed the international situation. This section reviews the status of membrane technology in Ireland, exploring the macro and micro factors of the industry. The scope of membrane technology application in Ireland is mapped against each of the sectors previously reviewed, with greater attention paid to the water, pharmaceutical and food and beverages sectors, while indicating potential niches in the other sectors. Potential research and business opportunities relating to the field are identified.

4.2 Membrane Technology Suppliers and Sources of Independent Expertise in Ireland

4.2.1 Membrane technology suppliers

There are no Irish-based leading membrane companies. There is one large membrane manufacturing operation in Ireland, based at Millipore's manufacturing site in East Cork. This manufactures a large quantity of polymeric microporous membranes for laboratory and dead-end applications and is one of the largest facilities of its kind in the world. There is no evidence of any additional membrane manufacturing activities across the country. There are a number of device manufacturing sites, including Millipore in Cork, Pall in Tipperary, Filtertek in Limerick and a small number of medical or diagnostic device assembly operations at different medical device sites around the country.

The membrane supplier industry in Ireland is largely made up of local or UK-based sales personnel. They are supported by application and technology experts from internal company groups based at European, US or Asian locations. Most membrane technology suppliers do not have a local office in Ireland and instead work through engineering & design groups, distributors or UK-based offices. There is also no evidence of any specialist or expert application groups based at the Irish sites of membrane-technology suppliers.

4.2.2 Sources of independent membrane technology expertise in Ireland

In addition to end-user sites, there is a significant level of industrial membrane expertise in distributors and engineering & design offices. They have built up application expertise as intermediates or engineering support to end-users. In many cases they act as the interface between the membrane technology suppliers and the end-users. Examples include:

- EPS and Earth Tech in the water and wastewater industry;
- PM, Jacobs and DPS in the pharmaceutical industry; and
- FDT in the food and beverages industry.

In addition, there is no evidence of significant membrane research activity in Ireland within the supplier industry other than a small diagnostic membrane research group in Cork. There was also no evidence found of supplier-funded academic-based research in an independent institution. There is a small start-up membrane research company at University College Cork (UCC).

With regard to research institutions, expertise is dispersed and fragmented, with limited co-ordination. It must be emphasised that there may well be pockets of relevant expertise that have been omitted from Table 4.1, but their omission reflects their lack of promotion rather than their specific competence.

Table 4.1. Membrane expertise in research institutions.

Location	Area of Expertise
Cork Institute of Technology (CIT)	Department of Chemical and Process Engineering: treatment of wastewaters containing active pharmaceutical ingredients; PV for solvent recovery; organic solvent nanofiltration. With EPA funding, seminars have been held to facilitate and encourage communication and the sharing of research and end-user experiences. CIT also hosts the Clean Technology Centre (CTC), Centre for Surface and Interface Analysis (CSIA) and the Centre for Advanced Photonics and Process Analysis (CAPPA) providing surface analysis capability www.cit.ie
Dublin City University (DCU)	School of Biotechnology: Mathematical Modelling in Bioprocess Engineering with emphasis on the membrane separation techniques of MF, UF and diafiltration (DF). Membrane bioreactors for wastewater treatment. DCU also hosts the Biomedical Diagnostics Institute, National Centre for Sensor Research and National Institute for Cellular Biotechnology www.dcu.ie/biotechnology/theme1.shtml
National Institute for Bioprocessing Research and Training (NIBRT)	The NIBRT is located in Dublin and is a collaboration between UCD, Trinity College Dublin (TCD), DCU and the Institute of Technology (IT) Sligo. It has a remit to support the development of the existing bioprocessing industry in Ireland and to attract additional bioprocessing companies to Ireland by: training highly skilled personnel for the bioprocessing industry; conducting world-class research in key areas of bioprocessing, some in collaboration with industry; providing a critical mass of multipurpose bioprocessing facilities. Facilities are being expanded to include membrane-based harvest and UF systems www.nibrt.ie
National University of Ireland, Galway (NUI-G)	NUI-G hosts a Water Research Facility, located at Tuam, with capabilities for accepting municipal wastewater, subjecting it to pilot operations and returning the treated effluent to the municipal wastewater treatment plant. NUI-G also hosts the Enterprise Ireland Competence Centre in Bioenergy and Biorefining www.nuigalway.ie
Teagasc	Teagasc pioneered the application of RO for the recovery and concentration of whey solids – RO having been originally developed for clean up of brackish water. UF as a more porous type of membrane evolved and enabled the selective separation of valuable whey proteins. In the early 1990s, Moorepark successfully applied NF, a new form of membrane, for the combined concentration and partial demineralisation of whey www.teagasc.ie
University College Cork (UCC)	UCC's College of Science, Engineering and Food Science: the Dimensional materials group is concerned with the synthesis of inorganic solids – particularly complex oxides – and their structural and compositional characterisation. Many of these materials are prepared as thin films and as nanostructured solids. The associated spin-out company, Glantreo, has been involved in fabricating membranes www.glantreo.com
University College Dublin (UCD)	UCD's School of Chemical and Bioprocess Engineering: membrane bioreactors for wastewater treatment and for products; high temperature carbon dioxide separation using membranes. UCD also host the Nano Imaging and Material Analysis Centre www.ucd.ie/chembioeng/index.html
Queen's University Belfast (QUB)	The School of Chemistry and Chemical Engineering at QUB works with pressure-driven membrane separation processes (MF, NF, NF, RO) in industrial bioprocessing and water treatment, exploiting energy/process efficiency and taking advantage of ambient processing conditions to preserve delicate biological properties of macromolecules; process integration and intensification by simultaneous reaction and separation in new generation of membrane reactors; mathematical modelling of integrated reaction and separation processes www.ch.qub.ac.uk/staff/gan/

Table 4.2 below attempts to cross-index sectoral expertise versus location. Biopharmaceutical processing is addressed in multiple institutions, those in the Republic being linked with the NIBRT. The National University of Ireland Galway has been in receipt of funding to research wastewater treatment. While based on a municipal wastewater treatment plant, this could also have industrial relevance and might extend to water-supply issues. Membrane bioreactors may be applied for wastewater treatment and for the production of biological entities. Cork Institute of Technology has also undertaken a project using an MBR in connection with industrial water treatment and reuse. Cork Institute of Technology has also addressed industrial applications involving solvents, whether in wastewater or in connection with solvent recovery. Teagasc is renowned for its past research in the dairy and beverages area, and UCC's former Faculty of Dairy Science was associated with this. However, the overall picture, summarised in Table 4.2, indicates limited impact in this technology area.

Table 4.2. Cross-index of sectoral expertise versus research institution.

	CIT	DCU	NIBRT	NUI-G	Teagasc	UCC	UCD	QUB
Water supply				?				
Wastewater (municipal / MBR)		X		X			X	
Wastewater (industrial)	X			?				X
Pharmaceutical (classic)	X							X
Biopharma		X	X				X	X
Dairy					X	?		
Other beverages					?			
Pervaporation	X					X		
Membrane manufacture						X		
CO_2 separation							X	

'X' = identified current or recent membrane related research. '?' = either historical research, or potential to relatively easily extend current or recent membrane related research, into this area. CIT = Cork Institute of Technology; DCU = Dublin City University; NIBRT = National Institute for Bioprocessing Research and Training; NUI-G = National University of Ireland Galway; UCC = University College Cork; UCD = University College Dublin; QUB = Queen's University Belfast.

4.3 Membrane Technology in Water Applications – Ireland

4.3.1 Introduction

Section 3 above considered the application of membrane technology internationally to the water sector, in particular to the areas of:

- Potable water treatment;
- Desalination;
- Wastewater treatment, both municipal and industrial;
- Water reuse; and
- Production of purified and ultrapure water.

Each of these areas will now be considered from an Irish perspective, examining the application of membranes, specific indigenous membrane expertise, level of adoption in comparison with international experience and finally the implications for Ireland.

4.3.2 Potable water treatment

Microbial contamination is the biggest risk factor impacting public and private water supplies today in Ireland and it has been identified as the priority issue to be addressed. The status of potable water supply in Ireland has been well detailed and documented by the EPA. In a recent report, Page *et al*. (2009) describe the state of infrastructure and processes in place. For 2007, test results indicated 5% of public water supplies, and 31% of private group water schemes, showed at least one incident of *E. Coli* contamination. At the end of September 2008, 341 public water supplies had been identified in the EPA's Remedial Action List. Boil water notices or restrictions of use (e.g. 'do not drink') were put in place in 53 supplies serving approximately 118,000 persons in 2008. The confidence of general consumers in the quality of public water is reflected in the high level of activity and interest in home-based point-of-use systems.

In addition to the global trends outlined in Sections 2 and 3, there are important local factors affecting the water industry in Ireland: stricter regulation, recent capital investment and a move to outsource plant operation.

4.3.2.1 Regulatory framework – increasing control and rigour

The EPA was appointed in March 2007 as the supervisory authority, with regulatory and enforcement oversight, over public water supplies. This follows the enactment of the European Communities (Drinking Water) Regulations (No. 2), a development from the European Water Framework Directive. The EPA's new enforcement powers have significantly increased the pressure on local authorities to address the major systematic gaps in infrastructure and processes identified as causing water-quality issues such as microbial contamination. The new philosophy is based on a risk-management approach where targeted and prioritised pro-active improvements should prevent issues from arising compared to the more reactive approach adopted historically. In addition, a quality control end-of-pipe testing approach to guarantee water quality will be replaced by a risk-based supply-chain assessment combined with testing. One clear outcome from this trend will be the increased number of water treatment plants identified as needing upgrades and improved, more reliable processes.

4.4.2.2 Investment in infrastructural upgrades – major investment in water treatment plants

Historically, the level of investment in water treatment plants in Ireland has been very low. Ireland generates significantly more water from surface sources than Europe and the UK, which have a greater reliance on ground water. These factors, combined with increasing demand and a steady deterioration in source quality, have exposed the inadequate water infrastructure in Ireland. Recently, as part of the NDPs, there has been a major increase in the funds invested in water-treatment facilities. Ireland will continue to invest heavily in this area as it plays catch up, although it can be expected that the economic slow-down will reduce the finance available.

4.3.2.3 Public procurement design/build/operate (DBO) trend – move to 'outsource'

The increased trend towards design/build/operate (DBO) procurement processes for new and upgraded water-treatment plants will have a significant impact on the future direction of the technology and solutions adopted by the local authorities. It is difficult, however, to predict accurately how this will affect the adoption of membrane technology, as there are several confounding influences:

- The EPA does not plan to impose any 'best-available-technology' (BAT) guidelines but instead the final solution for a specific application will be driven by the lowest cost alternative which meets the output water specification defined. It is thus likely that technologies that deliver a higher potential quality solution at a higher cost will find it difficult to compete as decision makers select the lowest cost meeting the minimum acceptable specification. In such situations the potential to raise minimum quality specifications as required will be restricted greatly.
- Design contractors will have operational responsibility under the DBO and will thus also have to match carefully the capital investment costs versus the ongoing operational costs. This provides the opportunity to more effectively select the best solution for a specific application based on a full life-cycle cost as opposed to just the initial capital outlay.
- The use of DBO will help to overcome residual end-user resistance to change and to new technologies (such as membranes) as intense competition should render such approaches as ineffective and expensive.

There are only a small number of public and private water schemes in Ireland using membrane technology (less than 10). The largest unit is in Co. Westmeath on Lough Owel, supplying 22,000 m^3/day of water to Mullingar and surrounding areas (Fenton, 2006), detailed in Box 4.1. This was installed in response to increasing demand and a major Cryptosporidium outbreak in 2002 (Gilhooly and Green, 2003). A number of smaller systems have also been installed in private group schemes such as Donaghmoyne, Co. Monaghan (Rigney, 2007).

Box 4.1. Case study: Lough Owel.

Location:	Lough Owel, Mullingar, Co. Westmeath
Capacity:	22,000 m^3 per day
DBO Contractor:	Earth Tech
Process:	Flocculation, dead-end UF membrane and chlorination
Membranes:	Xiga UF (hollow fibres), Norit
Capital Cost:	€9.8m
Operating Cost:	2005 (excluding depreciation for plant and replacement membranes) at 17.5 cents per m^3
Water Quality:	Excellent microbial quality (minimum CFU counts and no cryptosporidium) Turbidity: 0.1 NTU average Minimum chlorination required (2 mg/L) – for distribution disinfection only
Observations:	• Poor pilot testing regime and full characterisation of feed water quality – need more thorough testing ahead of main design • Capital and operating costs higher than initially anticipated • Demand requirements under-estimated – need to carefully select design capacity ahead of detailed design • Flexibility and opportunity in 2008 to increase capacity by 30%+ by just changing membrane modules with more area per module at minimum capital cost
Summary:	Consistent high-quality water but at a cost

For microbial high-risk water supplies, conventional treatment technologies (such as sand media filtration) are not now generally considered sufficient to deliver a reliable quality water supply. In some cases, such as in Galway, UV treatment has been identified as a preferred disinfection technology for remedial action in an existing facility to address microbial concerns. It can be relatively easy to retrofit UV to an existing plant and thereby achieve an increased level of reliability and confidence in microbial quality compared to a conventional process without UV. The design selection for a new facility or major upgrade depends on the specific local factors, including feed-water quality, microbial risk assessment and cost-benefit analysis. In most cases, the selection will be between conventional treatment with UV or membrane technology.

The conflicting claims of membrane and UV suppliers as to the most appropriate technology to use to address microbial concerns can be confusing. However, in reality there is no single solution and the most appropriate design in any specific case depends on multiple factors, especially the quality of the feed-source water. Some level of pilot plant activity is always encouraged, although the challenge may well be to have these trials run and assessed independently from a specific product supplier. It is difficult to avoid conflicts of interest between the technology supplier trying to sell a specific product and the end-user. Feedback from personnel involved in the Lough Owel system suggests that there is a lack of independent professional expertise available in Ireland to assist end-users in selecting, designing, starting up or operating plants. Facilities and expertise for the ongoing training of personnel were also identified as current issues. The Water Services National Training Group exists (www.wsntg.ie), but perhaps greater promotion is required to raise its profile.

4.3.3 Desalination

There are no desalination plants of scale in Ireland. Desalination is also rarely used in the UK although some small-scale systems exist in remote areas, such as the Isles of Scilly where 25% of the island's drinking water is produced by desalination. In general, Ireland and the UK have an abundant supply of surface and ground water – though there are exceptions in large centres of population, for example, in Dublin or London. The cost of desalination is significantly higher than the treatment of fresh water supply. As a result, it is highly unlikely that desalination will be a significant part of the water-supply infrastructure in the future. Nonetheless, in a highly populated area like Dublin, water supply is a real issue and consideration has being given to desalination as a potential technology for future water supply. In the UK, Thames Water have opened a £270 million desalination plant at Beckton using four-stage RO (Flavell-While, 2010). The facility has been designed to draw from the Thames river at low ebb, when the salinity is lower, and can produce up to 140 million L/day, but is intended for use only in times of drought. Opponents have questioned the energy efficiency and carbon footprint of the desalination solution as opposed to more aggressively addressing water conservation, demand management and distribution losses. Such discussion and debate is also relevant to Dublin where distribution losses are very high and have been estimated at more than 30% of supply.

4.3.4 Wastewater treatment using a membrane bioreactor (MBR)

There are no large-scale membrane bioreactor (MBR) municipal applications in Ireland. However, there are now a significant number of large industrial units, including Pfizer (Cork), GlaxoSmithKline (Cork), Irish Distillers (Cork), Wyeth (Dublin) and Glanbia (Ballyragget) which have been installed since the late 1990s.

The selection of MBR technology for industrial application in Ireland is largely driven by the desire of these companies to achieve a high assurance level of compliance and to ensure ongoing operation well within licence limits. They are prepared to pay the extra costs to achieve the improved performance, reliability and business continuity. In some pharmaceutical API applications, MBR technology was chosen to address specific effluent toxicity concerns. It could be argued that the strictures of the Phosphate Regulations (Government of Ireland, 1998) and the Water Framework Directive (European Commission, 2000) will provide drivers for the adoption of MBRs. In addition, MBRs were also noted as providing resistance to shock loading, a higher degree of automation and the potential for limited water reuse. There was no real evidence to suggest that reuse has become a significant driver for MBR selection in Ireland, although a number of companies have begun to seriously consider their options.

The status of urban wastewater discharge in Ireland has been documented by the EPA (Monaghan *et al.*, 2009). The lack of any large-scale municipal MBR, compared for example to the UK and Europe, is striking. Although there has been a major investment in the secondary municipal waste infrastructure over the last number of years, it has been dominated by conventional processes. This in part can be explained by the fact that most large urban effluent-discharge points are into the sea and have less stringent limits compared to inland water discharge points in other geographies. However, some large Irish urban treatment plants discharge into sensitive coastal areas, such as popular bathing or shellfish regions. In such cases it would be expected that more stringent discharge limits would be required and thus improved treatment beyond conventional processes demanded. Similar situations in the south-west of England, Scotland and Northern Ireland have already led to the selection of MBR technology for some municipal sites with coastal discharge. There are now more than 50 municipal MBRs in the UK with 8 plants treating more than 5,000 m^3 per day. Additional local Irish factors impacting on the selection of MBR technology for large-scale municipal processes include:

- Ireland is still playing 'catch-up' with respect to the infrastructure required for urban wastewater treatment as detailed by the EPA. The focus is still largely on installing the basic infrastructure required for secondary treatment rather than tightening discharge regulations and using improved processes.
- Until recently, municipal waste treatment plants were operated and regulated by the local authorities, in contrast to EPA oversight of industrial wastewater treatment plants. Any real drive to improve discharge performance was countered by operational cost pressures. This has now changed and the EPA license municipal wastewater treatment plants through the Integrated Pollution Prevention and Control (IPPC) licensing process. This independent regulatory oversight will over time result in tightened discharge limits and improved operational standards. As a result, the probability of selection of new and improved wastewater treatment processes, even if they are initially more expensive, will also increase.
- MBR technology is often linked to applications where reuse is an important objective. This is unlikely to be a real driver in the Irish context at least over the short to medium term. Nevertheless, there may be specific local situations where reuse is a real option, especially in a concentrated urban/industrial area like Dublin.
- The EPA does not require sites to use best available technology (BAT). In addition, there are no independent centres of expertise guiding local authorities on what technology to use. Instead, the result is determined by contractors responding to a tendering or DBO process. The industry is largely dominated by civil and environmental companies who are very familiar and comfortable with conventional processes. Thus, there is an inherent resistance to new technology even though it has been well proven in other regions of the world.

Although there may be no large-scale municipal MBR sites, there are an increasing number of smaller MBRs installed at different developments around the country. A case study analysis on one such unit in Halfway, Co. Cork is detailed in Box 4.2. Around 20 additional units have been installed by EPS across the country, including locations such as Cliffs of Moher (500 population equivalent [PE]), K Club and Dunboy Castle (Buckley, 2007). In some cases, developments could not have proceeded if MBRs were not capable of delivering a consistent high-quality effluent discharge. It is clear that the MBR will become a more common technology in waste-treatment processes around the country although it is not the right answer for every situation.

Box 4.2. Case study: Halfway.

Location:	Halfway, Co. Cork (2005)
Capacity:	90 m^3 per day
DBO Contractor:	Brightwater FLI
Process:	Flat sheet UF MBR
Membranes:	Brightwater
Capital and Operating Costs:	Relatively high
Feed:	Domestic sewage from a 450 PE development
Effluent Quality Target:	5 mg/L BOD/5 mg/L Suspended Solids (ss)/5 mg/L Total Nitrogen (TN)/0.5 mg/L Phosphorous
Observations:	• Key driver for MBR selection was the stringent effluent quality targets and the very limited space available • Effluent targets achieved except for nutrient removal – potential infiltration issue • Recurring issues with fats/oils/greases (FOG)
Summary:	Consistent high-quality effluent from a 'tight' facility with no odours but at a cost

4.3.5 Water reuse

The level of water reuse in Ireland is very low. The readily available sources of supply combined with the lack of water metering and direct consumer charging have instilled a complacency and to some degree disrespect for the value of quality water. Municipal water reuse is extremely low and no real sample application of significant scale was uncovered during research. Although Ireland is still playing catch-up on basic water infrastructure, it is surprising that no foresight on reuse has been incorporated into the long-term investment programme. Although the economic benefits may not be fully evident today, it is almost certain that they will be readily identifiable in the not too distant future. Industrial water reuse was more evident in basic examples such as steam-condensate return (primarily driven by energy conservation), CIP reuse (primarily driven by chemical costs) and limited reuse in utility and waste-treatment areas. This was also the case at large facilities with onsite MBR treatment. Reuse was limited to wash-down water for waste treatment areas even though the effluent quality was at a good standard. Although currently at a very low level, there are however drivers that may change this over the next number of years:

- ***Water charging***: Water metering and associated direct charges are being slowly rolled out to consumers. The controversy relating to school water costs underpinned the determination of policy makers to assign cost to use. It is very difficult to impact and change behaviour if there is not a direct link between those who control the use of water and the cost. The sensitivity to water costs is also rising in the industrial base. A number of large companies indicated that they were in the process of outline-project planning to increase reuse and reduce costs. The cost-benefit analysis is shifting in favour of deploying reuse technologies.
- ***Water supply***: Although in general there is no water shortage in the country, there are regions of the country which will have to invest more heavily to secure future quality supply, such as Dublin. This will in turn raise water costs and increase the drive for reuse.
- ***Environmental sensitivity and awareness***: The increasing focus, general awareness and acceptance of environmental sustainability as a core philosophy have generated real impetus for conservation and reuse policies and projects.
- ***Long-term policies***: The impact of government policies and the general trend towards the 'green' political agenda is likely to spur increased water reuse activity through some form of incentives such as capital grant support, tax incentives or other such mechanisms. This may also be led or instigated through European schemes.

In summary, water reuse may grow in Ireland over the coming years, driven largely by consumer cost benefit.

4.3.6 Purified water

Membrane technology has been broadly adopted in specific industries such as the microelectronics, pharmaceutical and food and beverages industries for purified water generation. There are many examples including:

- ***API manufacturing***: United States Pharmacopeia (USP) purified water plants are an integral part of most pharmaceutical manufacturing sites. To varying degrees, membrane technology will be present in every system.
- ***Medical device manufacturing***: Purified water systems are commonly used for wash-and-test applications in medical device manufacture.
- ***Food and beverages***: A number of large dairy industries use membrane technology to generate purified water as boiler feed. This reduces the level of chemicals required compared to resin deionisation. For example, Carbery in west Cork use UF and RO treatment of surface feed water (4,000 m^3/day) to feed their steam boilers.

There is a lot of end-user expertise in running and maintaining purified water systems at the site level. In many cases, the purified water system is operated within the facilities or utilities engineering groups. Expertise is largely operational. Underlying process expertise and trouble-shooting are commonly supplied by the supplier and usually from sources of expertise based out of Ireland. Similarly, in system design there are many engineering personnel at leading Irish design contractors who are familiar with water system design but leave the complex process design to suppliers. Personal experience and verbal input from a number of sources suggests that there is very little truly independent water expertise available in Ireland. When real in-depth independent support is required, experts must be called in from abroad.

The potential may exist for technology transfer from the industries using membrane technology for purified water to a broader base of industries using purified water for boiler feed-water and who use conventional mixed bed ion exchange. As the cost of membranes has fallen dramatically, there may be opportunities to displace ion-exchange technologies, which require mixed acid and base chemicals, and replace them with small packaged membrane systems.

4.3.7 Research on membrane technology and potable water in Ireland

No evidence was found of any research activity under way in Ireland assessing and comparing alternative treatment technologies for potable water or exploring any related area of expertise. There were no relevant Irish-based publications or patents. Research activity in Ireland on water reuse is limited. There are concentrated areas of research focused on wastewater treatment in NUI Galway and on pharmaceutical wastewater treatment at CIT. However, in general the level of publications and patents originated from Ireland on water reuse is minimal (Nerac Inc., 2007).

The combined low level of application expertise and research suggests that the level of technical sophistication and capability resident in Ireland is low. This is supported by verbal observations from multiple industrial sources who have identified the lack of local independent expertise and support available to assess potential applications as a barrier to progress on expanded water reuse in Ireland. It is also clearly an opportunity for niche research and business activity.

4.3.8 Summary

A detailed review of the situation relating to Ireland for membrane technology applications in water has been assessed under each of the different sub-sections. In summary, the level of adoption in Ireland is significantly less than Europe, the US and Asia (Fig. 4.1).

Membrane separation technology has established a strong position within the water and wastewater treatment industry. Product design and operational flexibility has led to a broad range and diversity of applications. It is no longer a specialist or niche technology but has proven its effectiveness and efficiency at the small and large scale. It does not suit all applications, and conventional technologies will still play a significant role for the foreseeable future. On the broad scale, the current level of adoption can be described as low, but most experts predict a strong

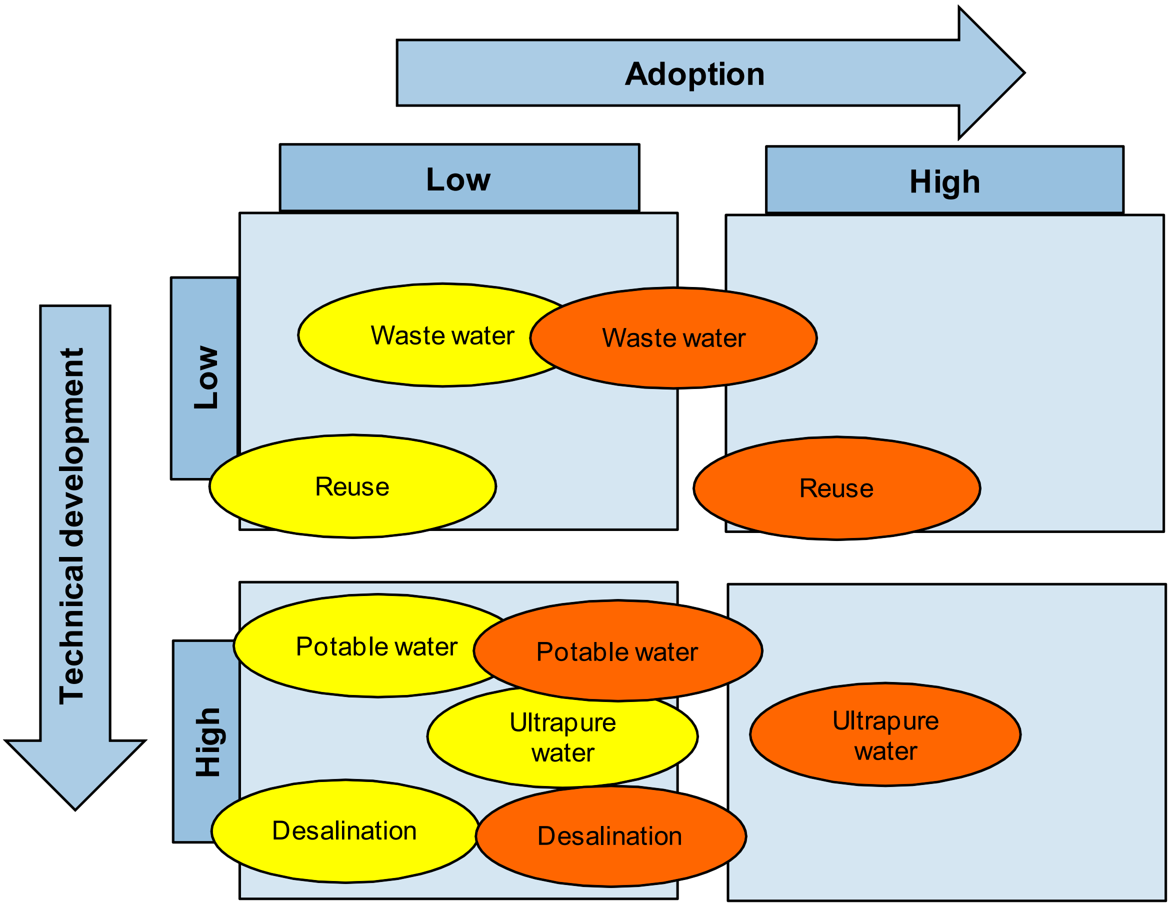

Figure 4.1. Comparison of membrane technology adoption levels versus level of technical development for the application – water – international (orange) versus Ireland (yellow).

future and a continued acceleration and growth in market share for membrane technology (Barbour, 2005; Cartwright, 2005). In many cases, membrane systems will be integrated with other technologies (hybrid system) to deliver optimum solutions. The external market forces driving the water industry are very positive and this in turn will drive future development and expansion of the technology. On the negative side, the relative high cost and sometimes questionable economic value of membrane systems versus alternative technologies remains the largest barrier, although the gap has narrowed significantly since the mid-2000s.

4.4 Membrane Technology in the Pharmaceutical Sector – Ireland

4.4.1 Overview

The application of membrane technology in the pharmaceutical industry mirrors international practice. Multinational pharmaceutical companies developed drug-manufacturing processes at laboratory and pilot plant scales and then transferred the technology to Irish sites. The processes are largely fixed and defined, and minimum opportunities exist for significant future change. This was largely the case in the organic API industry in the 1980s and 1990s and has also been the case since 2000 in the bioprocessing sector. In general, the expertise within the Irish pharmaceutical industry is on plant operation, manufacturing and troubleshooting and less on product and process development. However, more recently, a number of Irish sites have established process development groups focused on process optimisation and improvement, largely through incremental improvement. Although there has been an increased focus within such groups on exploring new technology, most control and decision-making authority remains at divisional headquarters.

The primary membrane technology suppliers to the pharmaceutical industry have only sales operations in Ireland. Some, for example, Millipore, operate direct-sales operations, while others, for instance, Pall, work through distributors or long-term partnerships. The product and application expertise is resident within expert support teams located in Europe or the US.

4.4.2 Research on membrane technology and (bio) pharmaceutical manufacture in Ireland

For organic API syntheses, there is no evidence of any significant level of research on membrane technology within Irish academic institutions (Nerac Inc., 2007). However, in terms of bioprocessing, the recently established NIBRT has the stated mission to support research and training in bioprocessing, including membrane separations technology. Training courses have already been delivered by NIBRT to existing and start-up biotech companies. The planned construction by NIBRT of a biotech pilot plant for research and training will provide additional impetus and support. Other institutions involved in biotech research and/or training include:

- FÁS, who have biotech training equipment in Carrigaline, Cork;
- DCU and QUB, who have undertaken research in membrane purification of bioprocessing streams (Foley, 2006; Ní Mhurchú and Foley, 2006; Sengupta *et al.*, 2005);
- National Institute for Cellular Biotechnology (NICB), also based at DCU.

There has been a lot of research activity on membrane technology in waste API streams and in solvent recovery at CIT. This has included collaboration projects with local industries. The increasing importance of waste management in the industry and the more local autonomy available at site level on waste-stream processing has contributed to the level of activity. New pilot plant equipment and capability is being added at CIT to broaden the research effort.

Some potential areas of opportunity for academic institutions identified during the course of this research include:

- The CIT focus on membrane technology in waste API streams is a solid strategy and consistent with future trends. This can be further enhanced by establishing higher levels of internal system and application expertise which can deliver supplier-independent consultancy and support to end-users.
- Provide end-users with pilot plant, laboratory and analytical equipment, techniques and expertise to test and recommend alternative filtration membranes and devices. Many end-users are tied into using very expensive membrane solutions for historical reasons and do not have the local capability to identify and test potential replacements. Supplier companies recognise this and charge accordingly. Major cost-saving opportunities exists to replace existing filtration products with high-quality low-cost equivalents.
- The level of biotechnology downstream processing expertise in Ireland is relatively low and is largely supported by external US expertise. Many Irish bioprocessing subsidiaries have had to appoint expatriate process experts as a result. One can also assume that this low level of downstream expertise is a barrier to small biotech start-ups and spin-offs. NIBRT can incorporate a more definite and focused downstream-processing objective to address this weakness over the next three to five years.
- Deliver membrane technology solutions for water reuse applications targeted at the pharmaceutical industry. Cost pressures on pharmaceutical manufacturing sites are rising: the cost of water is particularly significant.

- Provide comprehensive training programmes for operational and engineering personnel working on membranes in the pharmaceutical industry.

4.4.3 Summary

In general, pharmaceutical processing is a high-value-add application for membrane technologies. Exceptional high-quality, consistent performance is demanded by the pharmaceutical customer who in turn pays a premium price relative to other industrial membrane applications. Membrane-purification solutions are an integral part of bioprocessing and are widely adopted across the industry. In classical API pharmaceutical processes, some limited opportunity exists to exploit membrane separation technology in mainstream operations and in waste treatment more extensively. Potential benefits need to be compelling to overcome the inherent conservatism of the pharmaceutical industry and the rate of change and adoption is likely to be slow. Figures 4.2 and 4.3 illustrate the levels of development and adoption of membrane technologies in the pharmaceutical sectors, both classic API and bioprocessing. Practice in Ireland is similar to international experience.

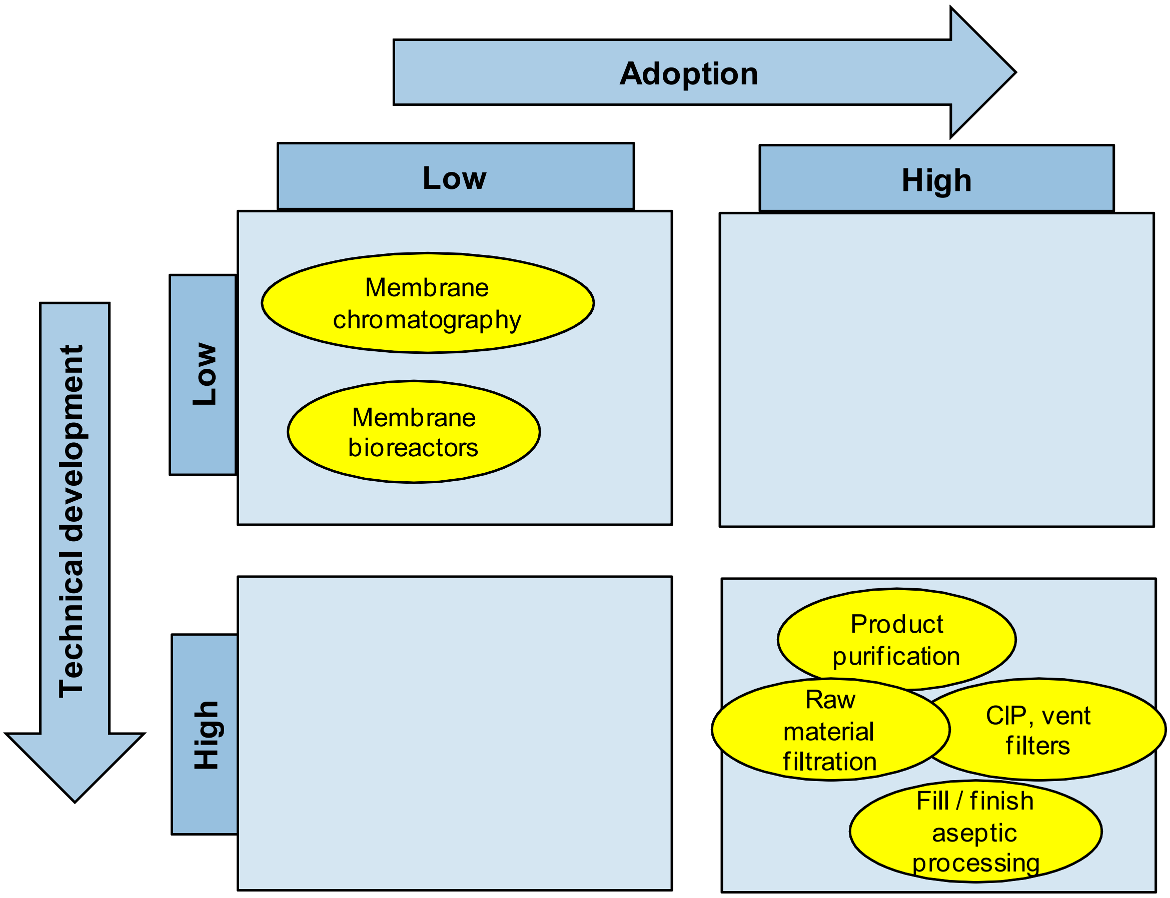

Figure 4.2. Comparison of membrane technology adoption levels versus level of technical development for the application – biopharmaceutical; CIP = cleaning-in-place.

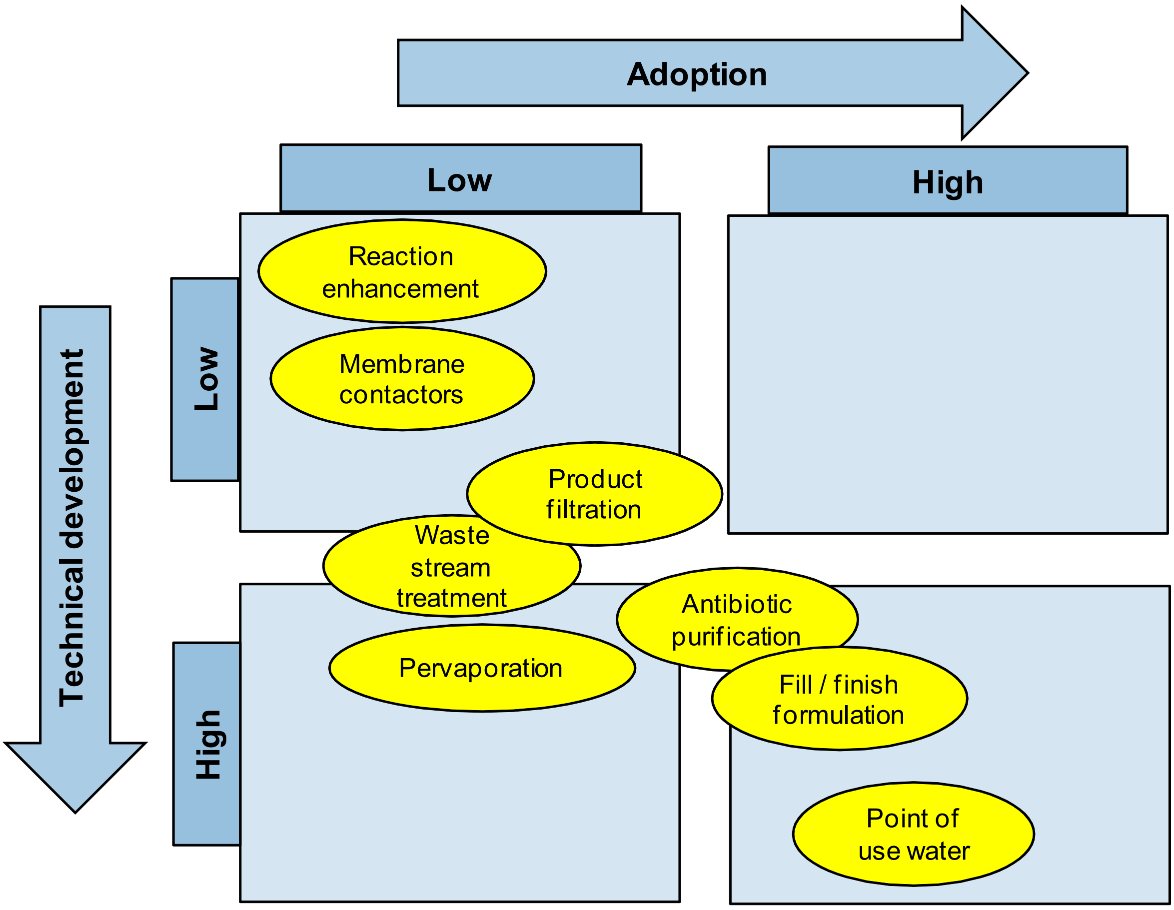

Figure 4.3. Comparison of membrane technology adoption levels versus level of technical development for the application – classic API manufacture.

4.5 Membrane Technology in the Food and Beverages Sector – Ireland

4.5.1 Overview

The food and beverages industry in Ireland is one of the core foundations of the economy with historical strengths in milk and meat production. The industry exported €8.2b of goods in 2008, and the Gross Value Added (GVA) for the food and beverages-processing sector in 2007 was estimated at €6.9b – 4% of total national GVA and 18% of manufacturing GVA. Beverages account for 25% of the sector's GVA, the meat sector 10% and dairy a further 8% (EGFSN, 2009). In addition, a number of global food and beverages multinationals have grown from the sector such as Kerry, Glanbia and Carbery. Thus, the indigenous food and beverages industry is strong with an extensive manufacturing and research network across the country. For example, one of the largest integrated dairies in Europe is located in Ballyragget (Glanbia). Company-based research programmes are supported by academic and government agencies such as Teagasc. However, in general, there is no real evidence of an integrated strategy for the sector coordinating end-users, suppliers and applied research. Moreover, there are multiple food regulatory agencies overseeing the industry.

Membrane technology is recognised universally as a core competency and critical enabling technology in separations for leading food and beverages industry segments, such as dairy, beverages, functional foods and food biotechnology processing in Ireland. However, there is a major lack of independent membrane expertise and support in the country. The larger Irish companies have some internal expertise and access their external needs from supplier expert groups abroad and from leading research organisations based in Europe and the US. However, smaller companies may not have the internal competencies and may well find it difficult to access cost-effective independent expertise. Training of company personnel in membranes is also generally accessed abroad, with no evidence that any such training has been available or delivered in Ireland.

4.5.2 Research on membrane technology and food and beverages in Ireland

In the past, Teagasc has played a leading role in membrane technology within the dairy industry with involvement in membrane applications back to the 1970s. Today, however, although there is still resident membrane application expertise in the organisation, membrane technology does not appear to be a core focus or research priority. In addition to a number of Teagasc publications, Greg Foley in DCU and Bhaskar Sengupta in QUB have been active in researching membrane separation applications in biotechnology processing, such as the microfiltration of microbial and yeast suspensions (Foley, 2006; Ní Mhurchú and Foley, 2006; Sengupta *et al.*, 2005). A number of membrane test rigs are available in DCU and QUB for such research. Nonetheless, the level of research and patent activity on membrane applications in food and beverages is very low relative to leading centres around the world and what would be expected for a core enabling technology supporting the leading indigenous industry (Nerac Inc., 2007). Funding levels are also low and the research activity is fragmented with no evidence of a strategic oversight with respect to membrane technology.

Some potential areas of opportunity for academic institutions identified during the course of this research include:

- Investigate the cause of fouling in real applications through defect analysis using leading analytical techniques such as scanning electron microscopes, Fourier Transform Infra Red and mass spectrometry. Develop application expertise and assist process redesign, including pre-treatment and cleaning regimes, to reduce fouling and extend module life.
- Establish representative pilot plant capability to investigate potential new process applications for industrial partners and provide supplier-independent local advice and guidance. For example, focus on membrane applications to displace evaporative steps and save energy. This will become an even bigger opportunity as energy costs continue to rise.
- Deliver membrane technology solutions for water reuse applications. Water is now a significant cost factor and reuse levels in Ireland are extremely low.
- Support the drive to isolate more specific proteins and components such as polyoligosaccharides through the development of technologies, such as high performance UF, designed to improve the separation capability for similar-sized proteins and molecules. Other supporting technologies include membrane adsorption using immobilised enzymes and membrane chromatography.
- Provide comprehensive training programmes for operational and engineering personnel working in the food and beverages industry. Automation has improved repeatability and general performance but it has also led to lower levels of on-the-ground troubleshooting expertise.

4.5.3 Summary

Many parts of the industry are very familiar and comfortable with membrane technology with experience in the dairy industry stretching back to the 1960s. Industrially, the level of adoption in Ireland is comparable with international standards, although the level of academic and supporting research in membrane technology for food and beverages is very low. Cost pressures continue to be a primary driver for technology selection in the industry, although there is a shift in the balance especially in the higher-end niche segments. There are many growth opportunities for membrane technology in food and beverages, but the focus needs to be on more breakthrough and innovative applications either to reduce input costs such as energy or achieve enhanced separation or purification for specialised foods or ingredients.

Figures 4.4 and 4.5 illustrate the levels of development and adoption of membrane technologies in the dairy and beverage sub-sectors. Practice in Ireland is similar to international experience. Other niche applications exist in relation to the wider biotechnology food processing sub-sector.

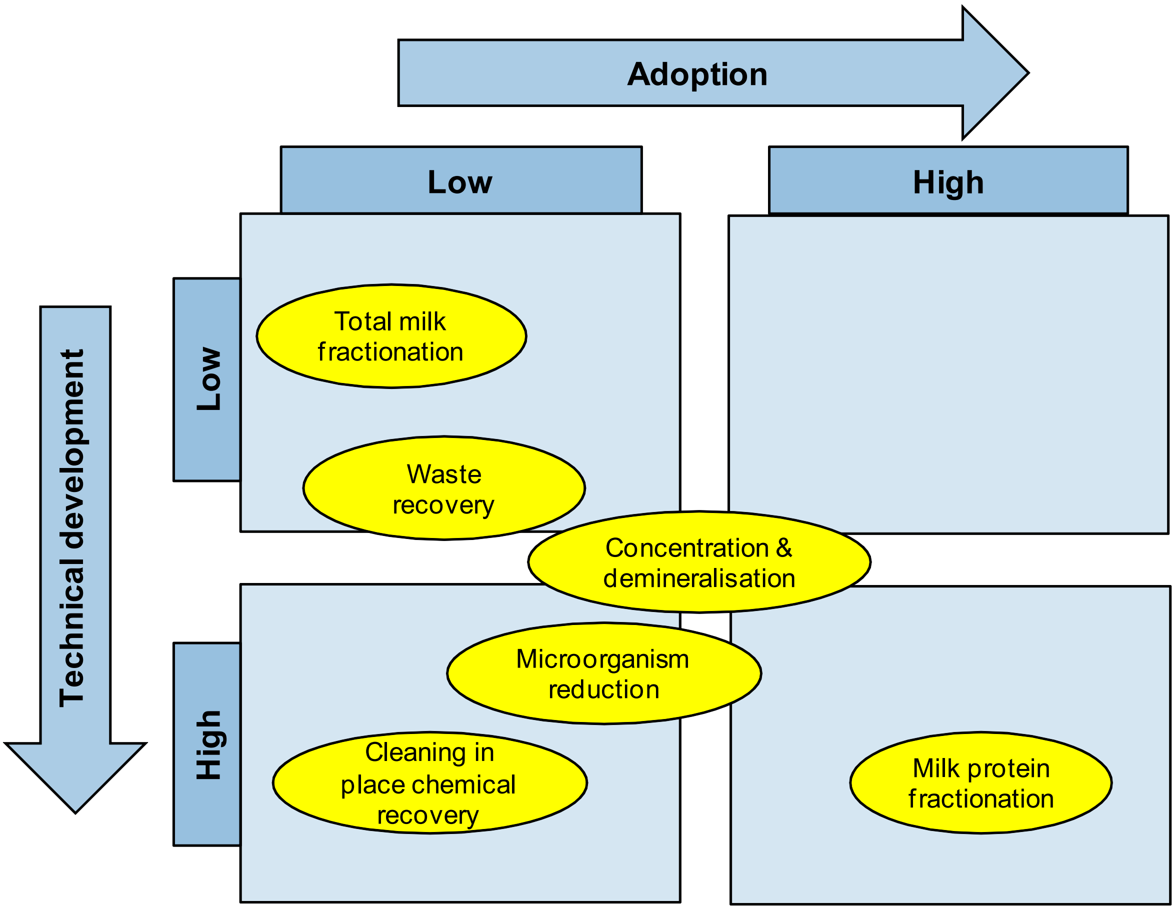

Figure 4.4. Comparison of membrane technology adoption levels versus level of technical development for the application – dairy.

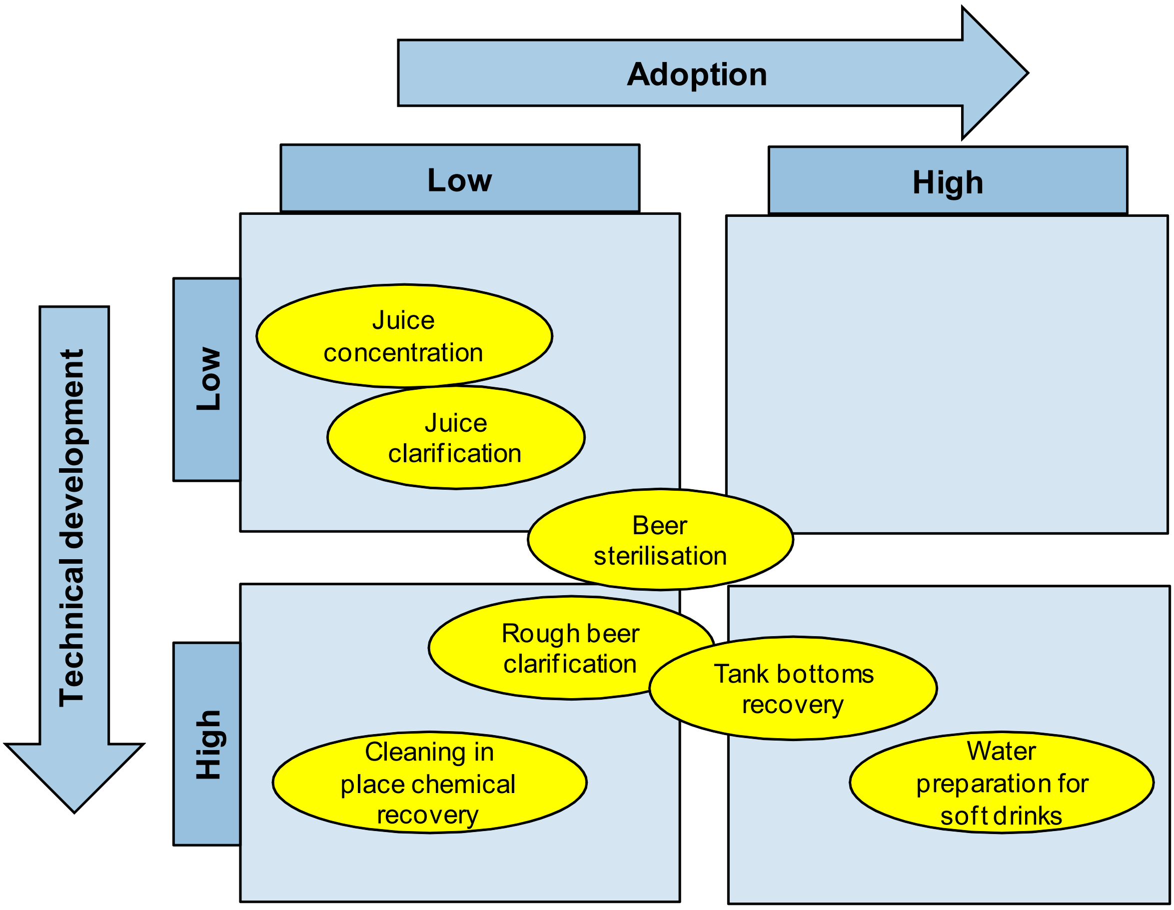

Figure 4.5. Comparison of membrane technology adoption levels versus level of technical development for the application – beverages.

4.6 Membrane Technology in Large-scale Applications – Ireland

4.6.1 Overview

The large-scale chemical manufacturing industry in Ireland is very limited. There is nonetheless a significant level of activity in a number of related fields, which are using or have the potential to use membrane technology. They include:

- ***Solvent recovery and dehydration***: Pharmaceutical bulk API synthesis plants use large quantities of solvents, generally derived from petroleum. The challenges of waste disposal and fresh supply costs have driven major and continuing investments in solvent recovery. The current technology is largely based on distillation, although a small number of membrane processes exist, for example, a PV plant at Pfizer in Cork (as per Appendix V). The need to achieve greater recovery of expensive solvents such as tetrahydrofuran (THF) at high purity levels is likely to lead to the further expansion of membrane technology in this field. This area is also addressed in Appendix V.
- ***Biofuels***: Ireland has very limited local energy sources. The growth in biofuels provides at least some potential to generate local renewable energy. Membrane applications have been researched in the manufacture of first-generation biofuels, but the longer-term prospects for these fuels is uncertain.
- ***Microelectronics processing***: The Intel plant in Kildare is one of the leading microelectronic plants in the world and has a vast array of separation and purification technologies, including membrane. The capability and technology to measure and achieve extremely high levels of fluid purity is an important

core competency for electronics research, process development and manufacturing. Future developments in nanotechnology and electronics are likely to present challenging purification challenges which need specialist capability to address.

4.6.2 Research on membrane technology and large-scale applications in Ireland

Independent membrane technology research in Ireland for large-scale industrial applications is limited. A leading group is the Pervaporation Research Group at CIT. Cork Institute of Technology has developed a core expertise in the field through leading research, post-graduate work, publications and regular participation at professional seminars. Pilot pervaporation equipment is also available on site for research and process trials. Suggested additional areas of research opportunity include:

- Leverage the existing CIT core competency on pervaporation and establish a centre of excellence in solvent processing and recovery. This can include training facilities for plant operators, research and providing pilot plant facilities (including distillation) to industry for applied research and process development.
- Biofuels may be an important element of the energy mix in the future. Recognising Ireland's strong historical and current agricultural technology sector, its lack of local petroleum sources and the cost of fuel, investment in biofuel research and manufacturing is attractive though speculative. This includes an investment in the core technologies required to support such an initiative, which includes biotechnology and membrane separation technology.
- Industry and technology advances will require increasing levels of purity in water, processing fluids, materials and components. Nanotechnology requirements are also likely to spur this specialist field. Primary technologies include low-level impurity analytical testing capability and the purification processes able to deliver these purity levels. Further research in association with nanotechnology experts could identify niche areas of opportunity for investment and focus. Membrane technology may well be part of the target areas identified.

4.6.3 Summary

Since the 1980s or so, the range of applications and the scale of installed capacity of membrane technology in large-scale applications has increased significantly. It is still however a niche unit operation in the chemical industry and has not yet achieved the potential that was initially forecast. However, the current trends suggest that membrane technology may steadily move up the adoption curve at an increasing rate and become a more integral and standard unit operation across a broad range of industries. Although evidence suggests that the level of independent research expertise in Ireland is low, there are a number of local areas of expertise that can be leveraged more fully.

4.7 Membrane Technology in Small-scale Applications – Ireland

Traditional fluid filtration markets such as the laboratory and machinery fluid market segments are mature sectors with limited growth potential. The technology and products are largely imported and there is no evidence suggesting any significant level of membrane technology research in Ireland focused on such areas. Niche opportunities are limited within the mature laboratory and machinery fluid market sectors, although there may be some specific laboratory research membrane tools and applications that present a research opportunity. This would need to be linked closely to an existing medical or life sciences research initiative to be able to compete effectively.

Fuel cell technology is advancing steadily and research publications have grown exponentially over the last few years. Nevertheless, sustainable energy generation is an important economic platform for Ireland and there may be some opportunity to target a specific membrane area of research supporting fuel cell development. This would also need to be linked closely with other energy research initiatives to achieve critical mass.

Membrane technology has been adopted extensively in numerous small-scale applications. With the broad scope of this report, it is not possible to identify targeted business or research opportunities in this narrow area for closer examination. However, it is suggested that membrane technology in the fuel cell and specialist laboratory area may merit examination in more detail.

4.8 Membrane Technology in Medical Applications – Ireland

4.8.1 Overview

Ireland has a large medical device and diagnostics industry sector. Currently, 140 medical technology companies operate in Ireland, exporting €6.2b annually and employing around 24,000 people. (Recent indicators suggest a potential shift, at least of the labour-intensive operations, towards lower-cost regions.) The current main development focus has been on promoting and encouraging research and development (R&D) activity on existing manufacturing sites. There is a medical membrane manufacturing operation in Cork and multiple membrane-based device operations around the country, including Pall, Millipore, Filtertek, Listal, Baxter, Trinity Biotech and Biotrin.

Membrane technology has varying levels of importance in medical applications depending on the sector – from a marginal role in some areas to a more central critical role such as in haemodialysis. Biological membranes are an integral part of life and it can be expected that the boundaries between bio-membranes and synthetic membranes will become less defined. Medical membrane technology traditionally operates as a separate sector to the synthetic membrane field, although there has been some convergence at the supplier level. There would appear to be real opportunity for enhanced technology transfer between medical and non-medical industrial applications.

4.8.2 Research on membrane technology and medical applications in Ireland

No evidence was found to suggest a significant level of activity in academic research or patent registration in Ireland for membrane technology medical applications. Nevertheless, a number of articles from the Filtertek (Limerick) company were noted on the subject (Hogan, 2002, 2006).

It is difficult to identify potential areas of opportunity for academic institutions in the membrane medical field. It requires the effective convergence of multiple disciplines in both the membrane and medical fields to generate a sufficient knowledge base that can drive innovative research and technical solutions. This is difficult to achieve within the more conventional academic structures and with narrow, discipline-based focus.

However, some potential opportunities include:

- Leverage the existing strength of medical filtration device manufacturing in Ireland and target research in specialised high-value applications.
- There are a number of research-led rapid diagnostic companies in Ireland such as Trinity Biotech. Millipore also has a small diagnostic membrane application research group in Cork. There are very few independent academic institutions researching the role and application of membranes within such tests. Many of the membrane companies currently supplying the market do not consider it a strategic sector and limit research investment. There may be real opportunities to carve out a niche area of expertise in rapid diagnostic membrane applications.
- Identify and exploit potential opportunities for technology transfer between medical membrane applications and the industrial field.

4.8.3 Summary

Medical technology has been identified as one of the key drivers for future economic growth in Ireland. Evidence suggests that the level of independent research expertise in membrane medical applications in Ireland is low. There is however a significant level of activity within the private and corporate sector. There should be real opportunity to exploit niche areas and to leverage technology transfer. A more detailed and focused research effort should yield specific areas of opportunity.

4.9 Summary of Observations

4.9.1 Major areas of potential

The water, wastewater, pharmaceutical and food and beverages areas represent the major growth areas (see Boxes 4.3, 4.4 and 4.5).

Box 4.3. Water.

- Overall trends suggest that the global water industry as a whole will grow at a significant pace over the coming years. This will also be reflected in Ireland. Major business opportunities are evident for water services and technology, locally and globally.
- Membrane technology will continue to take market share in the water sector and displace conventional processes at an increasing rate.
- The cost of quality-water supply will rise well above inflation.
- The application of membrane technology for water and wastewater treatment in Ireland lags well behind the developed regions of the world.
- The level of water reuse in Ireland is very low partially related to the lack of direct costing. It will grow rapidly at least in the industrial sector.
- Irish industry has incorporated some innovative water treatment membrane technology while the municipal industry has been very slow to adopt it even as part of major new infrastructural investment projects. They appear to be driven to conventional processes due to cost and/or inertia.
- The increasingly stringent quality requirements for water supply, water reuse and wastewater will drive higher growth in water membrane technology in Ireland.

Box 4.4. Pharmaceutical manufacture (classical and biopharma).

- General trends suggest that the range of applications for membrane technology in the pharmaceutical sector, globally and in Ireland, will remain steady or grow slowly over the next five years.
- Membrane technology is a critical core competency and enabling technology for bioprocessing.
- The level of adoption of membrane technology in pharmaceutical applications in Ireland is comparable with international practice.

Box 4.5. Food and beverages.

- General trends suggest that the range of applications for membrane technology in the food and beverages sector, globally and in Ireland, will grow significantly over the next five years.
- Membrane technology will continue to take market share and displace conventional separation processes such as media filtration using filter aids like diatomaceous earth and thermal processes.
- The level of adoption of membrane technology in Ireland for food and beverages is comparable with international practice.

4.9.2 Niche areas for investigation

In contrast to the above sectors, Irish applications at large scale in the commodity chemicals business are very limited or are very specialised at small scale in the medical devices, diagnostic technology, life sciences laboratory or microelectronics manufacture sectors. Success in these areas is likely to emerge as a result of relationships with existing manufacturers that desire an extension in research and development but have chosen to undertake this via partnerships or out-sourcing. Possible areas involve the interaction of nanotechnology and membrane technology in the development of fuels cells, novel diagnostic applications or achievement of very high-purity streams. Solvent-resistant membranes may have specific uses outside of the pharmaceutical manufacturing sector, for example, biofuel production.

5 Strategic Assessment of Membrane Technology in Ireland

5.1 Introduction

So far, this report has reviewed the scope of membrane technology activity across a number of industrial sectors, globally and in Ireland. Section 4 compared the experience in Ireland with the global situation. This section offers an overall strategic assessment of the technology in Ireland and has been generated based on the different insights compiled. It also identifies the primary opportunities and challenges that exist for membrane technology sector in Ireland.

In summary, the main objectives of this section are to:

- Present a top-level strategic assessment of membrane technology in Ireland;
- Identify significant opportunities that exist for 'Ireland Inc.' in the field over the next five years – both for Irish industry and the academic research community;
- Deliver specific recommendations which may help in the exploitation of these opportunities.

5.2 Strategic Analysis

A common framework used for business strategic analysis has been modified as a tool to structure and present the analysis. Although there is no formal strategic plan or process in place today for facilitating or promoting membrane technology within Ireland, the modified framework is a useful mechanism for analysis to help identify opportunities and suggest potential initiatives (see Fig. 5.1).

5.2.1 Macro environment

The most significant STEP factors impacting on the membrane technology industry in Ireland are detailed in Fig. 5.2.

Although the Irish trends mirror a lot of what is happening in the wider world, as discussed earlier, there are some specific points worth highlighting. Since the 1980s, Ireland has benefited from long-term strategic economic planning. The low-tax environment, a focus on targeted industrial sectors, foreign-direct investment and more recently the emphasis on R&D have all contributed to the high growth rate and economic transformation achieved over this period. The cultural shift towards a more entrepreneurial society and greater diversity are positive factors that should continue to promote growth. More specifically, with respect to membrane technology:

- The large pharmaceutical industry presence in Ireland, the increasing importance of biotech and the strong food and beverages sector, including functional foods, will raise end-user membrane technology competence levels and spur spin-off opportunities.

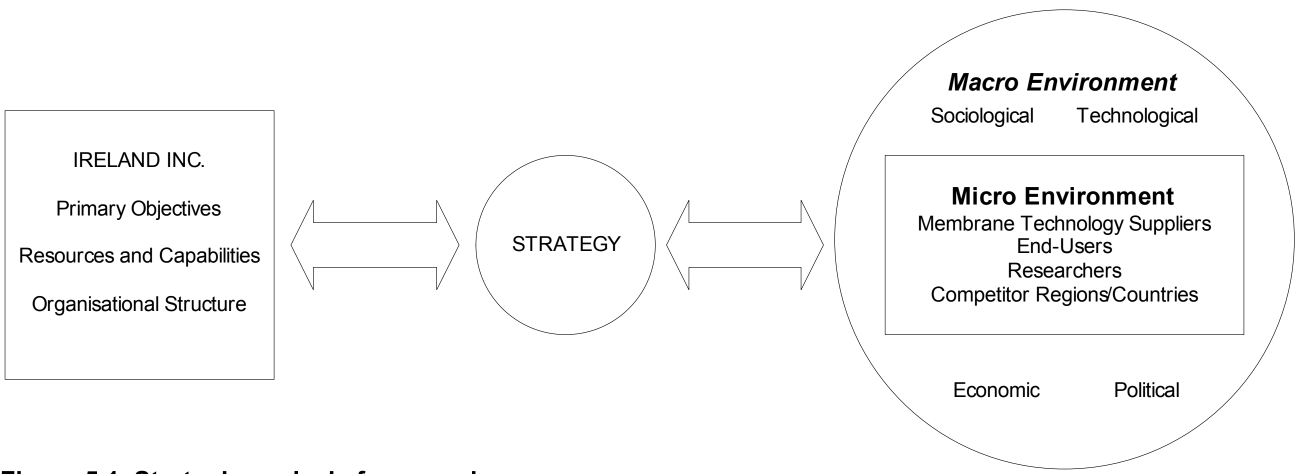

Figure 5.1. Strategic analysis framework.

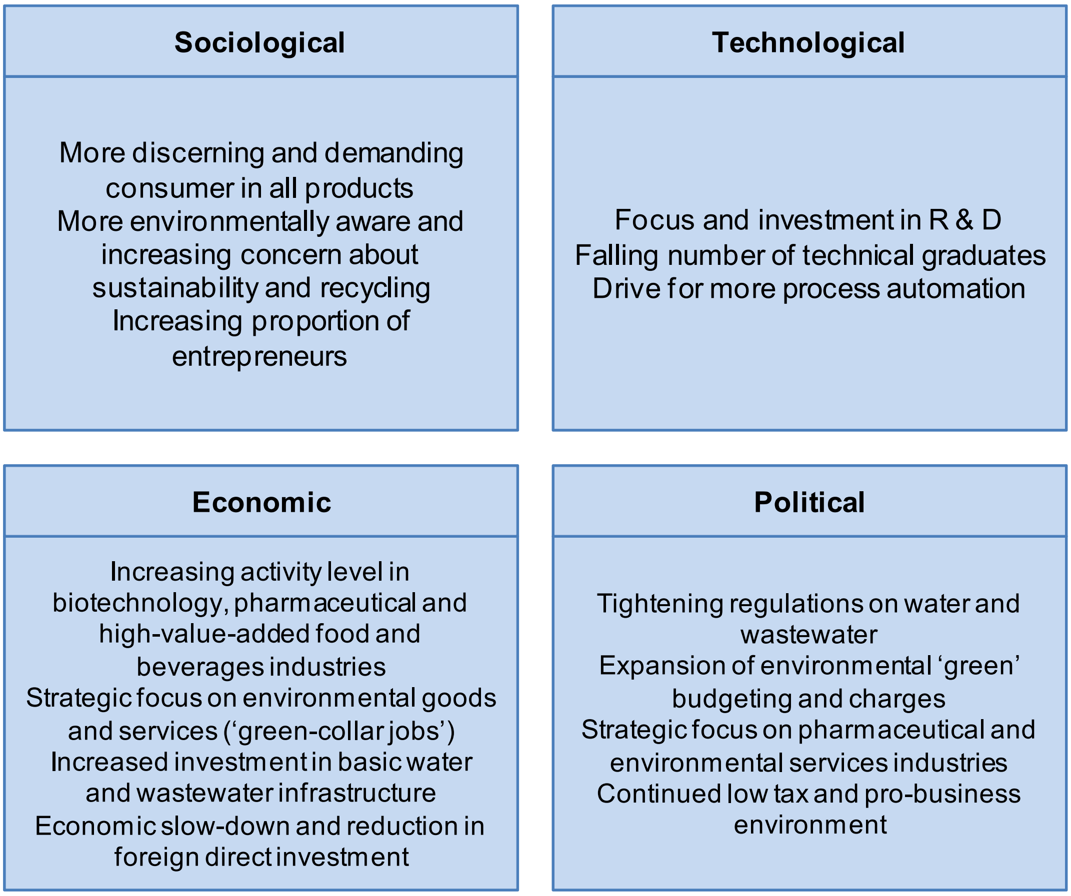

Figure 5.2. Sociological, technological, environmental and political (STEP) factors impacting on membrane technology in Ireland.

- The increased level of funding for R&D combined with a higher level of entrepreneurship creates a more supportive environment for new start-up enterprises.
- The rising cost of inputs in Ireland such as energy, water and labour increases the urgency and motivation for adopting more aggressive cost-reduction measures. In particular, the rising cost of energy will further shift the equilibrium in favour of low-energy membrane processes versus alternative thermal processes.
- More stringent regulations for water and wastewater will require more advanced treatment technology, especially in sensitive areas. Potable water availability in some regions, especially the greater Dublin area, may also act as a driver.

The combined impact of the macro factors supports, at least, the continued slow and steady trend of wider membrane technology adoption. This is already evident globally and to a lesser extent in Ireland.

5.2.2 Micro environment

Based on conclusions from earlier sections, the primary observations of the micro environment factors impacting membrane technology in Ireland are summarised in Boxes 5.1–5.4 below.

Box 5.1. Membrane technology industry and suppliers.

- Membrane technology is a critical core competency for biopharmaceuticals, high value-add food and beverages segments such as functional foods, some medical technology areas and a broad range of environmental goods and services.
- The membrane industry alone represents approximately US$10b out of the total US$35b global revenues of the filtration, purification and separation industry. The membrane industry is forecast to grow annually between 5 and 8% over the next five years. In 2009, the water portion of the membrane market was estimated at US$1.5b in one study, growing to US$2.8b in 2020; an alternative study provided an estimate of double this.
- There are no Irish-based leading membrane suppliers.
- Leading membrane suppliers have a minimal technical and research presence in Ireland supporting products or applications. However, one of the largest microfiltration membrane manufacturing plants in the world is located in Ireland.
- Ireland has a relatively small home market and would not support major investment in membrane technology products and services. Export opportunities or integrated end-user technology would need to be a critical part of any initiative.

Box 5.2. End-users.

- In general, the depth and breath of end-user expertise in membrane technology in Ireland is low and this is particularly true of small- and medium-sized enterprises.
- There is little evidence of technology transfer in Ireland between different sectors using membrane technology.

Box 5.3. Research.

- Academic research will play an increasingly important role in developing innovative and breakthrough membrane technologies as suppliers focus more on application.
- In general, the level of research activity in Ireland is low, fragmented and lacks strategic focus or coordination. However, there are a number of independent expert groups active in the field and executing quality work.
- The level of patents generated from Irish research on membrane technology is very low.
- The level of research funding invested in membrane technology is low.
- Irish professional institutes are not formally integrated or part of the leading multinational membrane professional groups.

Box 5.4. Regional competitors.

- Leading worldwide technology competitors such as Singapore, US, Japan and Germany have identified membrane technology as of strategic importance and have long-established and publicly funded networks overseeing and coordinating local activity.
- In contrast with leading geographical competitors, there are no independent membrane centres of expertise evident in Ireland that deliver expert advice to end-users, execute extensive application research or deliver training across different industry sectors.

In summary, Ireland lags far behind leading membrane technology centres or clusters around the world. Trends do not indicate that the gap is closing. The current level of activity and focus is not sufficient to have a significant impact.

5.3 Leading Areas of Opportunity for 'Ireland Inc.' in Membrane Technology

Based on the research completed for this report, the main areas of opportunity identified in membrane technology for 'Ireland Inc.' are summarised in Boxes 5.5 and 5.6.

Box 5.5. Business community.

Services

Provide supplier-independent integrated design expertise for membrane technology separation and purification applications across a number of identified areas including:

a. ***Biotechnology industry***: Develop processes for enhanced separation of high-value components in biopharmaceutical and food and beverages applications;

b. ***Chemical and pharmaceutical waste streams***: Provide solutions for the removal and potential recovery of products from waste streams;

c. ***Dairy and food and beverages***: Achieve final concentration levels exclusively by membranes and displace energy-intensive evaporators, e.g. whey processing. Support functional foods R&D and manufacturing;

d. ***Water purification***: Provide independent and objective design guidance (technical, quality and economic) on optimum water purification processes;

e. ***Water reuse***: Facilitate technology transfer and provide expertise in industrial, commercial and domestic water reuse;

f. ***Medical***: Membrane-based diagnostics and high-value add medical filtration applications.

Products

Supply integrated packaged systems for waste-stream processing and water reuse. The components should be sourced from a broad range of suppliers and integrated into a series of standardised and customised systems for the applications noted. The most appropriate membrane product can be specified so as to deliver the optimum solution.

Box 5.6. Research community.

Membrane Materials and Module Research

a. ***New membranes***: Membrane-based companies are moving more and more into application research. Over the coming years, a niche opportunity may exist in new membrane research and in improved module design. This research could overlap to some degree with research in nanotechnology and materials design.

b. ***Fouling mechanisms***: Fouling remains one of the main barriers to the economic application of membranes. Basic research on the underlying principles, mechanisms and dynamics is required. A fundamental understanding of fouling dynamics will feed very well into basic membrane material research and potentially deliver real competitive advantage in application design.

Applied Research

a. ***Application development & expertise:*** Similar to the product areas identified, develop application research and development expertise at academic institutions in biotechnology processing, food and beverages, including dairy, solvent and pharmaceutical waste stream processing, water purification and water reuse and select medical applications.

b. ***Pilot trials:*** Provide pilot plant capability for running and optimising membrane applications in each of the areas noted and include membrane and module performance comparison work.

c. ***Troubleshooting:*** Provide technical advice and diagnostics support on fouling, including defect analysis of failed modules and units.

d. ***Education & training***: Provide comprehensive multi-level training in membrane technologies and applications focused on targeted areas.

5.4 Estimates of Economic Potential

Various estimates of the value of the membranes technology market have been presented throughout the report. Where several sources are used, it is almost inevitable that there will be inconsistencies: however, the overall magnitude can be explored. These values are consolidated in Table 5.1.

Table 5.1. Estimates of market size.

Sector	Application	Value US$m	Date	Source
Membrane Technology	Overall	10,000	2006	Combination of sources
	Water 45%			
	Pharmaceutical 11%			
	Food and Beverages 5%			
	Large scale 10%			
	Small scale 5%			
	Medical 24%			
Water	Overall	4,500	2006	Frost & Sullivan (2006)
	Residential point of entry supply (US) (membranes only, at 50% of market)	400	2006	Frost & Sullivan (2005)
	Overall	1,500 rising to 2,800 in 2020	2009	Lux Research (2010)
	Membrane BioReactor global	320	2005	Judd (2006)
	Membrane BioReactor Europe	57	2005	Frost & Sullivan (2007)
	Industrial process water EU	360	2004	Frost & Sullivan (2004b)
	Industrial process water US	375	2004	Frost & Sullivan (2004b)
Pharmaceutical	Overall	1,100	2005	Combination of sources
	Non-sterile	140		Combination of sources
	Sterile	540		Combination of sources
	UF	100		Combination of sources
	Viral filtration	50		Combination of sources
	Housings, etc.	200		Combination of sources
	Other	50		Combination of sources
Life Sciences	Lab filtration	375	2003	Frost & Sullivan (2003)
	Protein research	84	2003	Frost & Sullivan (2003)
	Multiwell plates and membranes	209	2003	High Tech Business (2003)
Food and Beverages	Overall	210	2006	BCC Research (2006)
	Dairy 50%	105	2006	BCC Research (2006)
	Beverages 20%	42	2006	BCC Research (2006)
Medical	Overall	2,600	2004	Baker (2004)
	Dialysers (50% of membrane medical applications)	1,300	2004	Baker (2004)
	Blood oxygenation (20% of membrane medical applications)	500	2004	Baker (2004)
	Lateral flow intravenous (IV) testing (membranes only)	25	2002	Private report (2003)
Large- and Small-scale Applications	Very fragmented – no data			

The earlier analysis indicated the weaknesses in Ireland's membrane technology expertise and the opportunities identified the activities that could address these. These are now matched against the sectors, in the light of the above market sizes.

Table 5.2. Business benefits.

Sector	New business (product or service)	Sustain existing business
Water and Wastewater (Municipal and Industrial)	This is the dominant sector, with a growing global market for potable water production, wastewater treatment and, in particular, reuse. An annual total value of US$2b is expected (lower estimate). If Irish companies were to secure 0.5% of this, a national gain of US$10 million would accrue	Reduced costs may be achieved by supplying expert advice to users
Pharmaceutical	There may be niche applications in developing solvent-resistant applications and membrane contactors and reactors. This overlaps with biofuel synthesis (see below)	The biopharmaceutical sector will benefit from support in downstream processing, as is being provided via the NIBRT
Food and Beverages	Dairy processing has used membrane separations for a long time. New products may be feasible at the processing conditions provided by membranes – niche applications	Reduced costs may be achieved by supplying expert advice to users
Large Scale	New business pervaporation is dominated globally by a few suppliers; unless radical improvements in membrane performance are achieved it will be difficult to enter this market. Membranes for biofuel synthesis may be a niche application, dependent on the processing route	Solvent recovery operations may benefit from local support. Although the number of solvent recovery operations is low, this is a very significant national hazardous waste stream
Small Scale	Existing markets are mature, with the exception of fuel cells	
Medical	Though the second largest applications sector, it is quite mature. Niche applications may exist if different disciplines can converge to innovate	

5.5 Strategic Options

Ireland is a small country with limited resources. It cannot and should not attempt to be a leading centre for too many industries or technologies. It needs to identify and focus its resources, from a business and research perspective, on a relatively small number of strategic areas. A number of key sectors can be identified as of major strategic importance for economic development. They include environmental products and services (including water supply and wastewater treatment), pharmaceuticals and biotechnology, medical technology, and food and beverages. The achievement of long-term competitive advantage and a leading edge in these industries must include the development of the critical core competencies and technologies that underpin and enable their development. Innovation in this context is seen as a network, rather than a linear, process. Products, enterprises, marketers, researchers and developers co-exist, linked by multiple communication channels, i.e. a 'chain-linked' innovation model, rather than relying on a 'straightforward' linear pathway from research to consumer via manufacturer.

Five options are considered. Recognising the large gap that exists, one potential approach, Option A, is to accept the current reality as permanent and to conclude that membrane technology does not have strategic significance for Ireland. Instead, it is assumed that membrane knowledge and expertise can be imported as required from abroad. Consequently, Irish enterprise will be less well equipped to innovate and capture a portion of a US$10b per annum market. Existing key sectors will maintain their reliance on overseas expertise and not use membrane technology as a linkage with local R&D capability.

The remaining options, B, C, D and E, represent some form of a 'centre' of expertise. A 'centre' may be literally a single institution, or may extend to a network. The focus may lie along the spectrum from academic research to industry support.

Table 5.3. Advantages and disadvantages of options.

	Option	Advantages	Disadvantages
A	'Do-nothing', maintain Status Quo	No financial contribution No intervention	Lost opportunity to access markets worth US$10b, especially water, approx US$2b per annum Unenhanced innovation capability for Irish product and service providers, particularly start-ups and SMEs Reliance on non-indigenous technical support for key enterprise sectors Tendency to adopt traditional technology when undertaking infrastructural investment with long lifespan
B	Academic-led research centre or network	Familiar funding model using HEA-PRTLI or SFI If network, links existing researchers and research centres Uses existing capital equipment Experience from SFI Centres for Science, Engineering & Technology; SFI Strategic Research Clusters; and HEA-PRTLI Centres of Excellence	Tend to focus on fundamental research Less emphasis on technology transfer to industry or short-term problem solving A single location centre would involve duplication of existing dispersed expertise
C	Applied Research Enhancement (ARE) Centre	Familiar funding model using Enterprise Ireland Applied Research Enhancement (ARE) programme Its specific purpose is to ensure that applied expertise within the Institutes of Technology (IoTs) is made available to local and national industry Experience from 17 ARE centres	Confined to Institutes of Technology Supports a single institute, not network oriented Focused (though not exclusively) towards region
D	Competence Centre (network)	Familiar funding model using Enterprise Ireland/IDA Competence Centre scheme Industry led Focus on business opportunities More flexible in research strategy than pure academic research Builds on existing researchers and capital equipment Significant funding is not committed unless there is a viable proposal Experience from 6 centres Experience in establishing NIBRT as a sector-specific centre	Requires an initial 'promoter' to stimulate and assess interest and feasibility Lead time to establishment perhaps one to two years Even as a network, may include only three core partners, with further potential collaborations Dependent on research institutions agreeing to co-operate
E	Technology Transfer Centre	Reduced investment, confined perhaps to analytical services Strict focus on interacting with existing industry end-users	No opportunity to develop new products or processes outside individual company Difficult to achieve critical mass without duplication of existing expertise Might be argued as a duplication of existing consultancies.

Existing expertise is distributed across a number of locations (as shown in Tables 4.1 and 4.2), none of which is pre-eminent in this technology. Therefore, instead of selecting a single location, a *network model* is favoured, either Option B or D. In this manner, the existing expertise, industrial linkages and equipment can be used effectively, without undue duplication. The alternative of selecting a single location suggests neglecting the existence of substantial intellectual capital or choosing to confine the focus of a technology initiative to a single sector.

The next issues to consider are the primary focus and scope of the desired range of services, from research through consulting to training, of any initiative. Option E would have a focus on existing industry end-use, while Option D would appear to better provide for new product and process development. An intermediate approach, i.e. following the Enterprise Ireland competence centre model but modified to include the range of activities undertaken by NIBRT, is recommended. Hence, a *wide spectrum of services* will be achieved.

5.6 Lessons from Existing Models

Achieving this enhancement of membrane technology expertise and ensuring the economic benefits are reached requires the development of a measured strategic plan within the targeted research and business spectrum. It necessitates a collaborative approach *across* industry and academia and *between* multiple organisations and institutions across the country.

Enterprise Ireland and IDA Ireland have established 'competence centres'. These are described as: 'collaborative entities established and led by industry and resourced by highly qualified researchers associated with research institutions who are empowered to undertake market focussed strategic research for the benefit of industry' (http://www.enterprise-ireland.com). Groups of companies, intending to enhance their research and development capability, have combined to define their research needs. The strategic direction of the research is led and governed by industry. In addition to 'commercialisation of products and processes', 'less tangible impacts are expected in the two-way transfer of knowledge between the markets and academia and training of researchers, transferring to industry with improved skills and networks.'

To date, six centres have been established with four more in the pipeline. Each centre is based in one Higher Education Institution with zero to two co-hosts. Annual budgets range from €1 to €2 million for each of five years. The initial ten centres are expected to collaborate with over 180 companies in total. Further information is available at www.competencecentres.ie

A second model is the NIBRT, which is a consortium of UCD, TCD, DCU and IT Sligo. Its mission is to 'provide training and research solutions for the bioprocessing industry in state of the art facilities.' In addition to training and hosting pilot trials, it engages in collaborative research, contract research, funded research, consultancy and trouble-shooting, licensing and technology transfer with industry. Further information is available at www.nibrt.ie

Reviewing the above, it may be seen that:

- The EI/IDA competence centre model provides a model for industry-led research;
- NIBRT provides a sector-specific model that includes training and consultancy.

5.7 Recommendations and Conclusions

The membrane technology expertise in Ireland is fragmented across at least eight institutions, with an existing linkage via NIBRT for biopharmaceutical applications (as shown in Section 4.2.2).

The main recommendation of this report is that a formal membrane technology network-of-excellence (similar to the Enterprise Ireland/IDA competence centre model) should be established in Ireland to address the current gaps. As noted above, the typical budget for these centres is €1–2 million per annum for five years. It is not possible to quantify the gains with any level of certainty, except in the water sector, where a conservative estimate of 0.5% of a lower estimate of US$2 billion for the market leads to a national gain of US$10 million per annum. Efficiency gains equivalent to this might also be achieved by diverse technology users or niche-application development in other sectors.

As decision-making control is located abroad, this membrane technology network-of-excellence will not naturally arise or evolve from within the industry locally. Thus, it needs to be initiated and driven by centralised economic policy groups and structured in such a way as to deliver the required control and oversight, while still leveraging the capability and expertise of existing decentralised groups.

This network should be:

1. Industry led (similar to the EI/IDA competence centre model);
2. Composed of multiple (at least three) existing research institutions (similar again to the competence centres and SFI and HEA models);
3. Provide research (contract, collaborative and original), consultancy, education and training;
4. Capable of facilitating industry-driven pilot plant activity;
5. Focused on delivering technology transfer;
6. Facilitate and encourage communication and the sharing of research and end-user experiences;
7. Formally linked to international membrane bodies.

A network will emerge if the opportunity for funding presents itself, as has arisen with the EI/IDA competence centres. The network should be funded following a competitive tendering process (again in accordance with EI/IDA, SFI and HEA models). The funding model should be initially based on grant aid but progress to combine grant aid, membership fees and self-funding services. Having defined and quantified the objectives for the network, a cross-functional and cross-organisational (academic and industry) steering group should oversee implementation. These academic and industry representatives within the overall steering group would agree priorities, coordinate activities and oversee progress in relation to the range of activities in specific fields and applications across the different research institutions, in order to maximise the benefit to the Irish economy.

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Acronyms and Annotation

API	Active pharmaceutical ingredient
BAT	Best available technology
CAPPA	Centre for Advanced Photonics and Process Analysis
CDI	Continuous deionisation
CIP	Clean-In-Place
CIT	Cork Institute of Technology
CSIA	Centre for Surface and Interface Analysis
CSIRO	Commonwealth Scientific & Industrial Research Organisation
CTC	Clean Technology Centre
DA	Dialysis
DBO	Design build operate
DCU	Dublin City University
DE	Diatomaceous earth
ED	Electrodialysis
EDI	Electro-deionisation
EI	Enterprise Ireland
EMA	European Medicines Agency
EPA	Environmental Protection Agency
ETO	Ethylene dioxide
EU	European Union
FDA	Federal Drug Administration
FO	Forward osmosis
FOG	Fats oils grease
GMP	Good Manufacturing Practices
GP	Gas permeation
GVA	Gross value added
HEA	Higher Education Authority
IMB	Irish Medicines Board
INCMT	Irish National Centre for Membrane Technology
IPPC	Integrated Pollution Prevention & Control
IUPAC	International Union of Pure and Applied Chemistry
IV	Intravenous

IVD	In vitro diagnostic
LVP	Large volume parenterals
MBR	Membrane bioreactor
MD	Membrane distillation
MF	Microfiltration
NF	Nanofiltration
NIBRT	National Institute for Bioprocessing Research and Training
NICB	National Institute for Cellular Biotechnology
NUI-G	National University of Ireland – Galway
NWRI	National Water Research Institute
OEM	Other equipment manufacturer
POC	Point of care
POE	Point of entry
POU	Point of use
PRTLI	Programme for Research in Third Level Institutions
PV	Pervaporation
QUB	Queen's University, Belfast
RO	Reverse osmosis
SFI	Science Foundation Ireland
SWA	Singapore Water Association
UCC	University College, Cork
UCD	University College, Dublin
UF	Ultrafiltration
UK	United Kingdom
US	United States
USP	United States Pharmacopoeia
UV	Ultra-violet
VP	Vapour permeation
WFI	Water for injection
WSNTG	Water Services National Training Group

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government