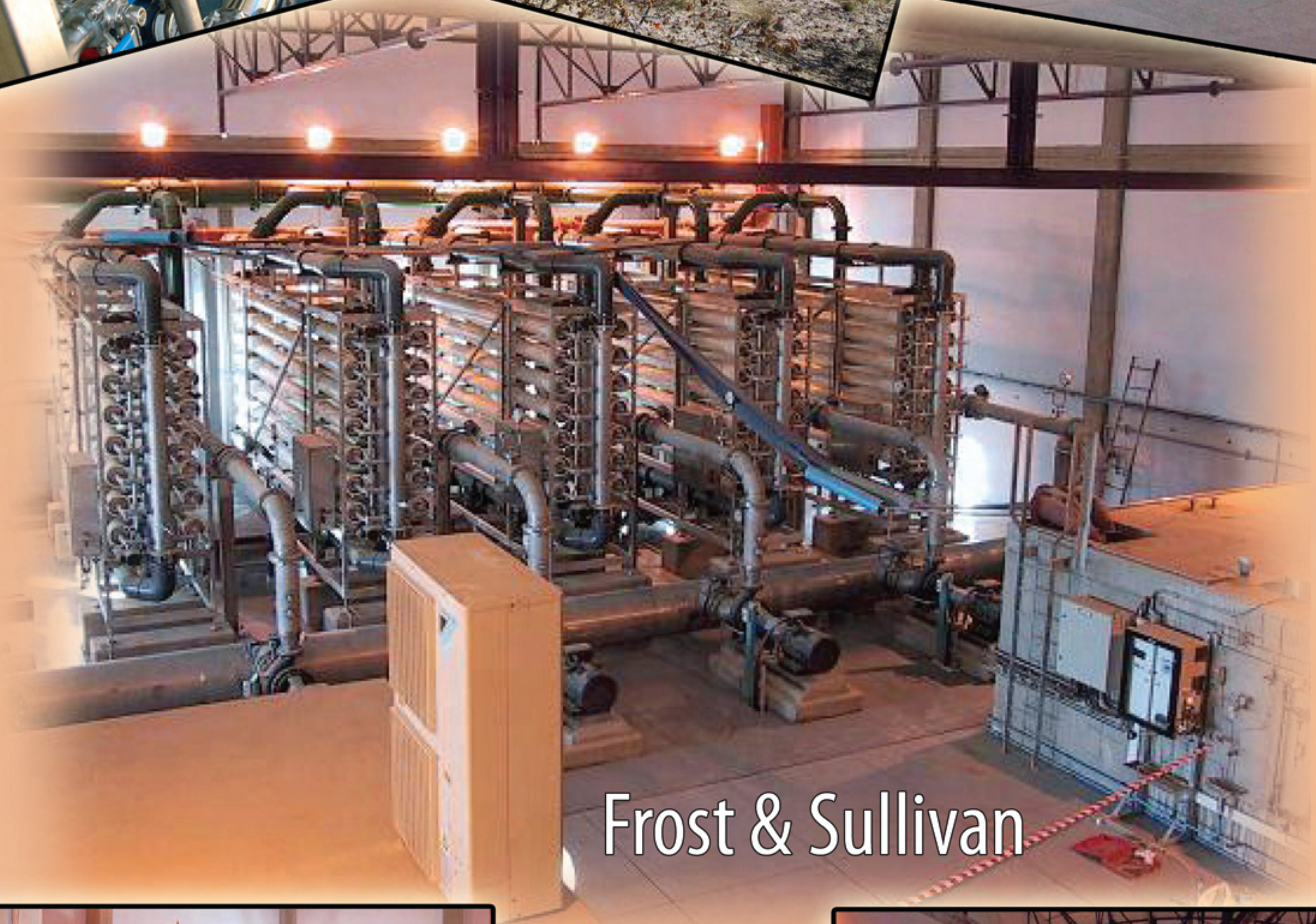
Membrane-Related Water Research Impact Assessment



Frost & Sullivan

TT 366/08

Water Research Commission

MEMBRANE-RELATED WATER RESEARCH IMPACT ASSESSMENT

Report to the

WATER RESEARCH COMMISSION

by

FROST & SULLIVAN

WRC Report No TT 366/08

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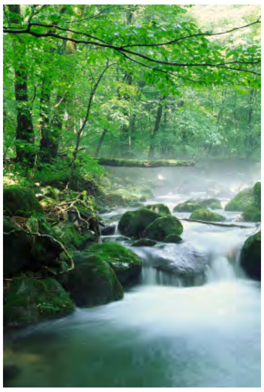



1. Executive Summary

Water-related membrane research in South Africa has, to a large extent, been driven through funding made available by the Water Research Commission (WRC). This research has resulted in increased awareness, utilisation and a better understanding of the applications for membranes in South African conditions. The aim of this document is to highlight the impact of these membrane-related research activities and their benefit to South Africa. These benefits are broadly classified according to the economic, social, health and environmental impacts that the research has had upon the South African population. Where possible, these benefits have been quantified.

The majority of membranes used in South Africa are still imported and valuable foreign currency is being spent on them. Through the research funded by the WRC, more opportunities for local companies are materialising and export opportunities are being created. This in turn is stimulating local economies and has a significant effect on the social wellbeing of individuals. Through the new products, processes and guidelines created by the WRC research, significant environmental and health benefits are also created.






2. Introduction

International growth consulting company Frost & Sullivan was commissioned by the WRC to conduct this research impact assessment. Frost & Sullivan has extensive experience in the water and wastewater sector, specifically in membrane research.

The Water Research Commission (WRC) plays an important role in the development of South Africa's water management industry. Through research projects identified by the Department of Water Affairs and Forestry (DWAF), water consulting companies, the research community and by the WRC itself, South Africa has become one of the leading locations for water based research projects. This is particularly important within the context of the country's increasing challenge of water scarcity. The expanding population and the greater demand for industrial and manufacturing uses of water have further exacerbated the problem.

Although the WRC is not the only institution in South Africa providing funds for membrane research projects, it certainly has been the most important. It is the largest funding institution for this type of research in the country and has commissioned extensive research into the broad field of membrane technology. The aim of this document is to highlight some of the contributions this research has made to the country.

2.1 Overview of the Water Research Commission

The Water Research Commission is a statutory institution established in 1971 by an Act of Parliament. The organisation represents a dynamic hub for water-centred knowledge, innovation and intellectual capital. The WRC provides leadership for water-related research and development through the support of knowledge creation, transfer and application. The WRC engages stakeholders and partners in addressing a wide variety of water related challenges, which are critical to South Africa's sustainable development and economic growth. The WRC funds its projects through levies on national water sales.

The WRC faces many challenges including:

- the creation of appropriate and relevant new water-centred knowledge,
- the dissemination and application of research,
- network creation and
- knowledge building capacity.

In an effort to retain and strengthen its position as a "value for money" institution delivering research and innovations that make a positive contribution to South Africa, the WRC has embarked upon a number of studies, including membrane R&D. The results of these studies will be shared with industry stakeholders such as government institutions, consulting engineers, and local government bodies.

There are a number of reasons for South Africa to invest in water research. Most importantly, research investment is required to ensure the water-related health and well-being of all people in South Africa. It is necessary to highlight ways to reduce water consumption and improve water utilisation efficiency to ensure that water is available for current and future use. Reducing the overall cost of water treatment is another important consideration. In this field, the development of skills and efficient products becomes imperative. It is also necessary to develop systems and guidelines to ensure that contaminated water is contained and/or treated in order to avoid additional pollution. In this way, specific corrective measures can be applied in a controlled environment to reduce the chance of further pollution and negative health impacts. Lastly, water research is aimed at ensuring that water users are able to comply with water, waste, environmental and related legislation.

How are research projects selected?

The WRC uses three main processes to select research projects. These include:

Project Type	Description
Solicited Research	• Proactively and strategically directed research and development into areas of greatest need or greatest potential impact according to Strategic Plans previously compiled with the help of stakeholders • Normally done by various research consortia and may take several years to complete • Calls for proposals for solicited research are issued annually
Non-solicited Research	• Promising and relevant research based on innovative thinking and with the potential to yield applicable and beneficial results • Proposed projects in this category are typically smaller than those in the category for solicited research and are mostly undertaken by one institution • Calls for proposals for non-solicited research are issued annually
Consultancies	• Short-term investigations (6-12 months maximum) which are crucial, urgent or exploit windows of opportunity • There is no annual call for proposals

Annual expenditure by the WRC on membrane-related research currently amounts to approximately R1 million. The WRC has been funding various types of membrane research, which are represented in figure 1.

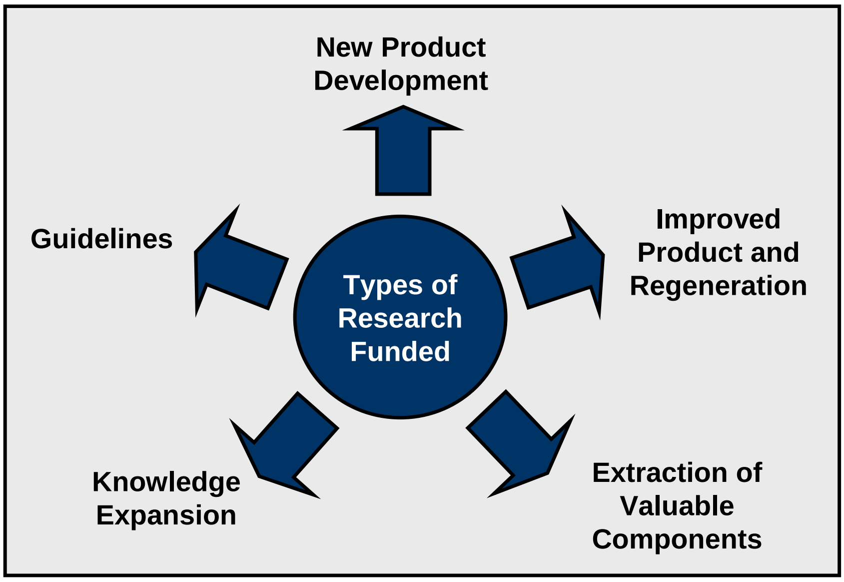


Figure 1: Types of Membrane Research Funded by the WRC

1. New product development

The WRC funds research into new product development. A variety of products has been developed in this way and has resulted in the formation of a number of companies. This has ensured employment creation as a key benefit. The WRC has funded 30 research projects aimed at producing new products or improving existing ones.

2. Improved product operation and regeneration

The WRC has also funded projects that have resulted in the improved use of membranes. These include defouling methods and processes to improve the operation of membranes. As a result of this research, membranes are becoming increasingly attractive and their efficiency has improved. The WRC funded 11 projects specifically in the field of defouling techniques and best practices since 1993.

3. Membrane research for the extraction of other components

Various projects have been completed (and are ongoing) for the use of membranes to extract valuable elements from waste water streams. These elements include metals, enzymes and anti-oxidants. Through the development of these processes, business opportunities are created that help to foster new employment opportunities. The WRC has funded 4 projects specifically aimed at extracting valuable components from waste streams since 1993.

4. Knowledge expansion

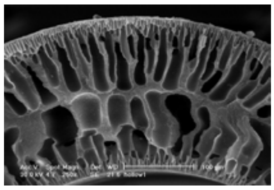
An important aspect of research is to better understand processes and technologies, as this leads to product and process improvement. The appropriate application of membranes is one such issue. For this reason, the WRC has funded 20 studies that have primarily resulted in a better understanding of membrane products and their operation since 1993.

5. Guidelines

Despite the efficient and cost effective use of membranes worldwide, there is still much room for improvement. In the early years of membrane use in South Africa, very little knowledge of their application and correct handling was available and as a result, membranes did not perform optimally. This led to a degree of resistance to their use. In order to address the potential for membrane application and advance the use of membranes in the country, the WRC, in conjunction with research institutions, embarked on the creation of various guidelines for the correct selection, installation and operation of membranes to increase performance. These guidelines are based on both laboratory testing and field application observations, and are aimed at membrane operators. As a result, the use of membranes has increased and their overall performance has improved.

2.2 Definitions of Membranes

Membrane technology is the application of a positive barrier or film in the separation of unwanted particles, micro organisms and substances from water and effluents. Other technologies for the removal of salts from water, such as ion exchange and evaporation are also covered under the broader WRC definition of membrane research.



View of a Membrane Profile

Membranes are typically used to extract specific unwanted constituents from a water stream – such as the desalination of seawater. They could further be used to effectively remove bacteria and viruses from a contaminated water source. They can also be used in a host of other applications in the pharmaceutical, chemical and related industry sectors. New applications for membranes are continually being explored.

2.3 Background to Membrane Technology in South Africa

The use of membranes in South Africa

Although it has taken time, membranes are now increasingly being accepted as a viable option in the treatment of water and effluents in South Africa and over 15 local and international companies are marketing membrane-based technologies locally. These companies are mostly based in Gauteng and the Western Cape but they serve projects across the country and even across South Africa's borders.

Some Membrane Technology Companies Active in South Africa		
Biwater South Africa (Pty) Ltd	**CHC Amnion (Pty) Ltd.**	**Consolidated Water Conditioning**
Degrémont (Pty) Ltd	**Explochem Water Treatment (Pty) Ltd**	**GE Water Technology**
Grahamtek Systems (Pty) Ltd	**Ikusasa Chemicals Water Treatment (Pty) Ltd**	**Keyplan (Pty) Ltd**
Pall South Africa	**PCI SA**	**Proxa (Pty) Ltd**
Quality Filtration Systems	**VWS Envig (Pty) Ltd**	

VWS ENVIG PROXA GrahamTek™ Tomorrow's technology, today CHC GROUP The Future Formula IKUSASA PCISA EXPLOCHEM WE ENGINEER SOLUTIONS® Biwater Degremont Consolidated Water Conditioning Keyplan Quality Filtration Systems PALL

Figure 2: Some Membrane Technology Companies Active in South Africa

Membrane technology is used in a wide range of applications. It is used to clean water for domestic and industrial use, for the treatment of effluent water and concentrated waste streams. Membranes are further used in the food and beverage industries where the highest quality water is needed to ensure compliance with health and safety regulations. They are also used in non-water related industries. An example of this is the use of membranes to extract medicinal enzymes from fungi under specific conditions. There are many other examples of the use of membranes which will be covered in more detail in this document.

The South African membrane market is showing strong growth. The Reverse Osmosis (RO) membrane type currently dominates the overall membrane market in South Africa due to its uses in seawater desalination and wastewater treatment projects. The Micro-Filtration (MF), Ultra Filtration (MF) and Membrane Bio-Reactor (MBR) market in South Africa was estimated to be worth R52.5 million in 2006, and growing at 11.2 per cent annually. As MF, UF and MBR represent only 4.8 per cent of the overall water and waste water equipment market, there is potential for this sector to reach a market size of R178 million by 2011 at a high projected compound annual growth rate of 24.8 per cent. This will translate into 7.8 per cent of all spending on water and waste water equipment in South Africa in 2011.

As the South African membrane technology market embarks on a high growth phase, there is expected to be an increase in the number of competitors. The decline in membrane prices over the past few years has facilitated the development of the overall membrane systems market in South Africa. Even though there was a slight increase in membrane prices in 2005, the trend of declining membrane prices is expected to return and facilitate further penetration of membrane solutions into the market.

With water demand set to exceed supply in cities like Cape Town, there is a trend towards translating present pilot projects into full-scale membrane based brackish water & seawater desalination projects. This will provide pre-treatment related opportunities for MF and UF membranes. However, most of the municipalities currently lack the resources in terms of knowledge, funds, expertise and skills to incorporate advanced technologies such as membrane solutions for water & wastewater treatment. Interest in the industrial sector for high quality process water is driven largely by sectors such as food & beverage and the power sector.

There is an increasing interest within industry for MBR systems, and municipalities will catalyse the growth of the UF and MBR systems market segments. With increasing levels of pollution and incidences of bacterial contamination in water supplies, the DWAF will need to tighten discharge limits and this is likely to provide impetus for the growth of advanced filtration including the MF, UF and MBR membrane systems market.

Local suppliers such as Grahamtek Systems are developing the world's first 16 inch spirally wound membranes. This could reduce dependence on overseas suppliers and also provide for a cheaper membrane solution with export opportunities.

High volume mine water with limited amounts of dissolved impurities could offer lucrative commercial opportunities for the utilisation of membrane treatment and reselling treated water to municipalities and industrial customers. The power sector will be one of the key catalysts for growth in the industrial sector as power stations are set to be recommissioned in the next few years. This will offer tangible MF and UF related opportunities in the pre-treatment stage.

3 Overview of Membrane Research

The WRC has funded a few projects on membrane research since its inception in 1971. However, most projects were funded after the establishment of a dedicated membrane programme in the early 90's. Sixty-six membrane projects were funded since 1993. Figure 3 represents the research that has been conducted as well as a number of ongoing projects.

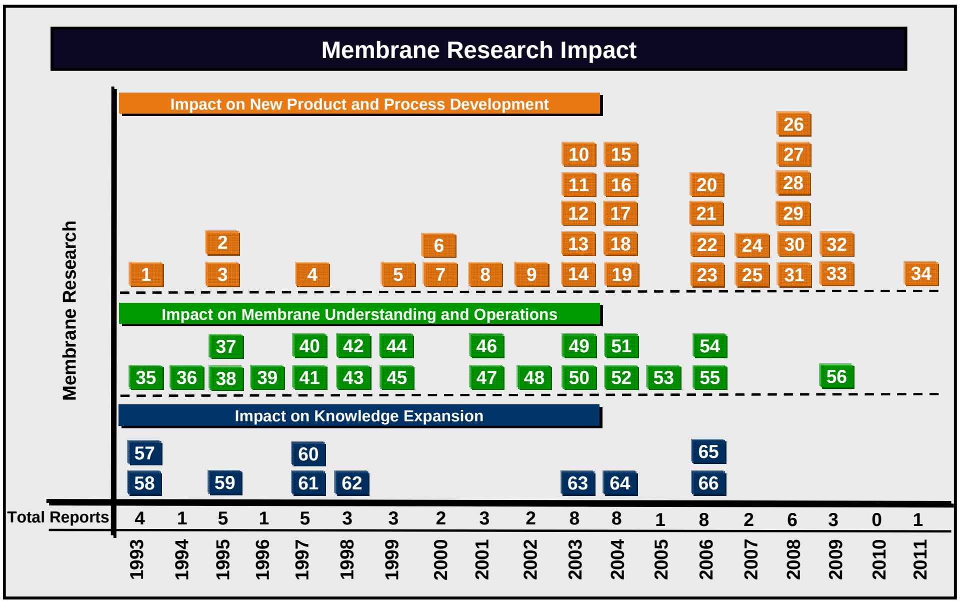


Figure 3: Membrane Research Impact Funded by the WRC

The impact of the research has been categorised into three broad categories:

Impact on new product and process development

Research in this segment has resulted in significant economic, social, environmental and health benefits. The projects in this category have further helped to develop guidelines for best practices and are expected to be important within the water industry in South Africa for some time to come. Projects in this category have often led to the commercialisation of new products. They have further resulted in guidelines that have significantly impacted membrane project operational improvement, helped to decrease fouling and created methods to extend the life of membranes.

Impact on membrane understanding and operations

Projects in this segment have not been as successful as high impact projects but have still helped to increase the understanding of membranes. They have created new ideas for high impact research and contributed positively to the understanding and operation of membranes in South Africa.

Impact on knowledge expansion

These projects did not result in new technologies or guidelines, but have still been important as various hypotheses have been tested and knowledge expanded. These projects also contributed to an increased awareness of membranes and have also highlighted the limitations of the technology.

A complete list of membrane research projects funded by the WRC can be found in Appendix A. The table below gives a clear outline of the various high impact projects and the associated benefits will be discussed in more detail in the rest of this document.

Table 1: Specific Outcomes of selected projects funded by the WRC

Year	Project Number	Project Outcome
1993	1	Development of small membrane systems - for rural water supply and also industrial effluent treatment
1995	2	Used in seawater desalination systems and later also in cooling water treatment systems
	3	Knowledge increase on electrodialysis (ED) systems and their application to industrial effluent
1997	4	Knowledge increase on ED systems and their application to industrial effluent
1999	5	Lead to a patent to grow fungi in outer skinless capillary membranes in such a way that they manufacture enzymatic drugs for cancer research
2000	6	Rural water treatment system developed
	7	Development of small membrane systems - for rural water supply and also industrial effluent treatment
2001	8	Transverse-flow module developed – Impact on future research
2002	9	Lead to a patent to grow fungi in outer skinless capillary membranes in such a way that high-value enzymatic drugs for cancer research are being manufactured
2003	10	Meter to measure the membrane fouling layer in-situ (fouling meter) developed
	11	Development of a very promising micro filtration system for both potable water and industrial effluent treatment
	12	Rural water application developed with commercial value
	13	Treatment of difficult effluent (better understanding)
	14	Development of small membrane systems - for rural water supply and also industrial effluent treatment
2004	15	High impact on safe rural water supply from boreholes with high nitrates content
	16	Knowledge increase on ED systems and their application to waste dump leachate purification
	17	Fouling meter further developed
	18	The development of small-scale ultra filtration systems for potable water production
	19	Woven-fiber tubular filtration system was developed for mining sludge dewatering
2006	20	Guidelines how to plan, design and execute a water desalination plant
	21	Development of a simple endocrine disrupting compounds (EDC) dipstick detector
	22	Improvement in the understanding of the use of membranes to treat sulphate-containing mine water
	23	Testing and facilitating the use of membranes for water supply in rural communities
2007	24	System developed which shows excellent properties to remove organics from industrial effluents and potable water

Year	Project Number	Project Outcome
	25	Recover valuable anti-oxidant by-products from the effluents of olives
2008	26	Fouling meter further developed and being produced internationally
	27	This project is developing a chlorinator to disinfect water for rural communities
	28	High impact on safe rural water supply from boreholes with high nitrates content
	29	Produce guidelines for the use of immersed membranes in sewage effluent treatment
	30	Further development of a simple EDC dipstick detector
	31	A pamphlet is being produced to create awareness of the use of membranes in SA
2009	32	Various membrane cleaning innovations are being built into current membrane systems and evaluated
	33	The specific unit developed will have a big impact on simplifying treatment systems for rural water supply.
2011	34	Desalination of seawater using a wave powered reverse osmosis (RO) system

The research funded by the WRC has led to knowledge expansion. This knowledge and the applications thereof will further build the membrane industry in South Africa. An overview of the knowledge created is represented in figure 4.

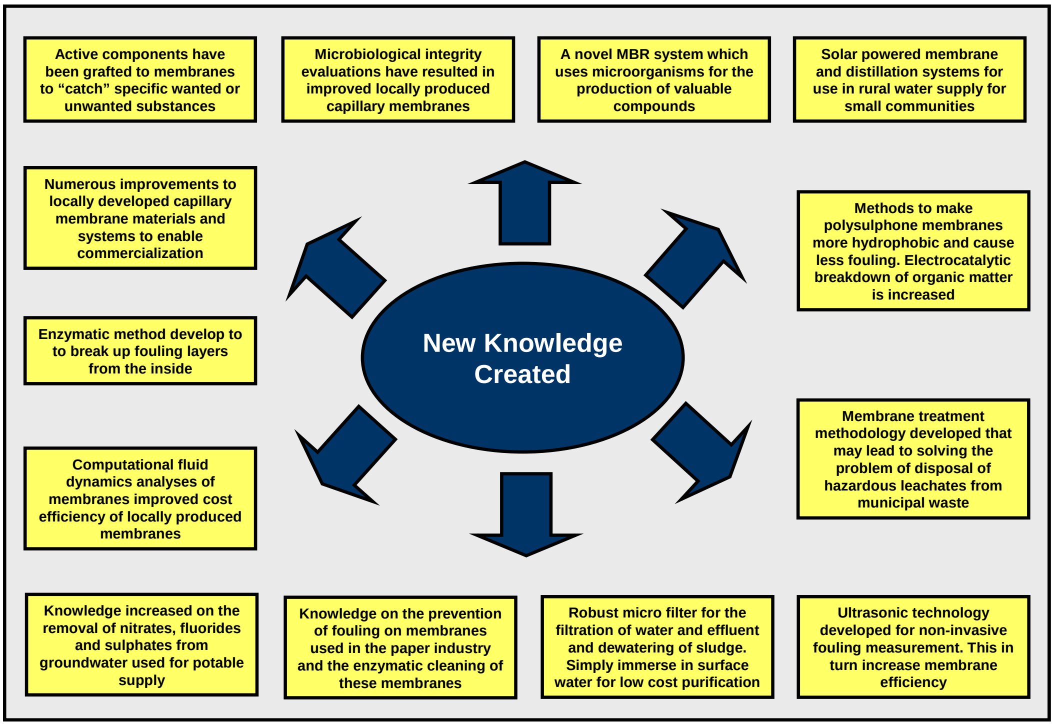
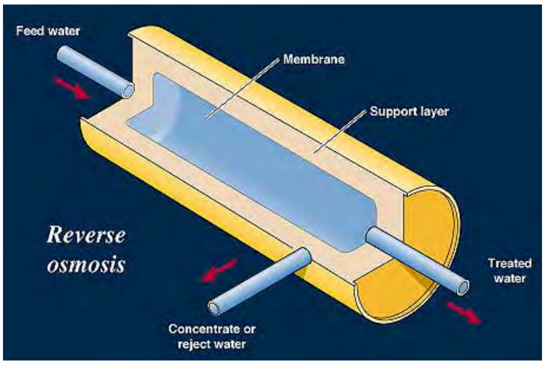


Figure 4: New Knowledge Created through WRC Funded Research Projects

The history of membrane research in South Africa

The earliest fundamental membrane research in South Africa started in 1953 on electrodialysis (ED) systems and their membranes at the Council for Scientific and Industrial Research (CSIR). This research laid the foundation for a better understanding of the thermodynamic and physical processes involved in ED. Parchment paper membranes were developed and piloted for the low-cost desalination of brackish gold-mine underground waters. Initial research on polymeric membranes, utilising WRC funding, started in 1973 at the Institute for Polymer Research (IPS), University of Stellenbosch, leading to the establishment of the first local membrane manufacturing company in 1979.

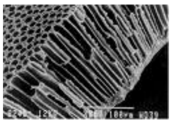
The IPS developed low cost tubular RO and UF systems in the 1980s. The tubular UF systems were later successfully combined with anaerobic digestion and commercialised as the "ADUF" process. From humble beginnings, these activities have grown to the current situation where R&D on membranes is actively pursued not only at a number of tertiary educational institutions, but also by private companies and water and power utilities.

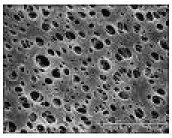
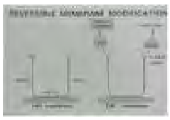


Reverse Osmosis Process

The figure below gives an overview of some of the types of products that have been developed through research.

Table 2: Products Developed through WRC Funded Research

Some Products Developed through WRC Research		
	Type of Technology	**Description**
	**UF Membranes**	• Used for producing ultra pure water • Able to remove bacteria from water • Ideal for rural water applications for small communities
	**Reverse Osmosis (RO) Developments**	• Used to desalinate water sources • Increase available water resources
 	**Woven Fibre Microfiltration**	• The tubular system consists of two layers of a woven polymer material, stitched together to form rows of parallel filter tubes, called a "curtain" • Liquid is fed from the inside and clear water permeates from the membrane (clarification process) • Can be used for sludge dewatering • A simplified, immersed, flat-sheet system was later developed for potable and industrial water treatment

	**Electroconducting Membranes**	• Membrane systems that use positive and negatively charged membranes to remove particles from the stream. • Some of the systems are able to produce sodium hypochlorite or ozone as by-products.
	**Supported Liquid Membranes**	• Shows the potential to extract metals such as nickel from liquid streams.
	**Membrane Bioreactors (MBRs)**	• Most of the studies are using the outer-skinless UF membrane as reactor (fungi are used in bioremediation of waste water). Flat-sheet woven microfilter units have lately showed great promise as inexpensive, robust, immersed MBRs.
	**Membrane Fouling Studies**	• Research on membrane fouling centres around three aspects: electromagnetic defouling; enzymatic and chemical defouling; as well as surface modification.
	**Affinity Separation**	• A process that involves extracting "wanted" elements from the stream through chemical reaction. It is being developed as an EDC detector.
	Nanostructured Membranes	• Nanotechnology can aid tailoring of membrane thickness, pore size distribution, permeability, and surface chemistry. Membrane design via templating chemistry allows entirely new and more effective membrane architectures to be engineered and developed. A new, nano-membrane has already been developed at UCLA which claims to provide RO quality water at much lower pressures.

Some of the major challenges facing research institutions in South Africa are how to 1) protect their intellectual property and 2) commercialise research. The figure below shows how the research process can eventually lead to benefits through project commercialisation. Additional funding for technology commercialisation and business skills development for researchers could significantly increase the successful commercialisation of research projects. Some examples of how WRC research has led to commercial implementation are represented in figure 5.

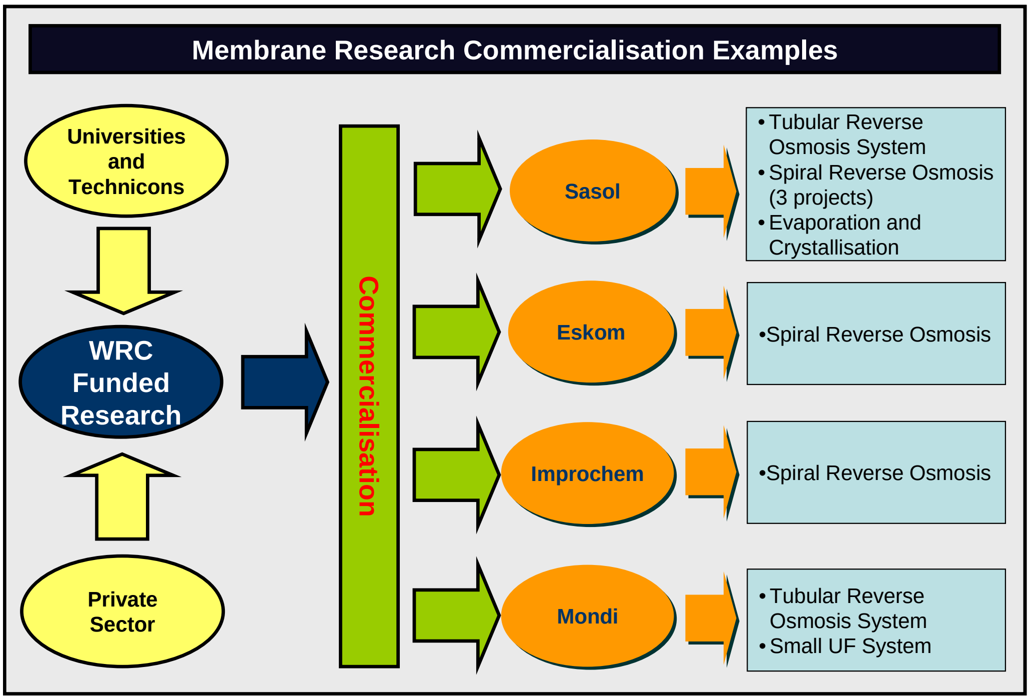


Figure 5: Membrane Commercialisation Examples

4. Impact of Membrane Research in South Africa

The membrane research funded by the WRC has had a number of benefits to South Africans. Some of these benefits are very obvious and can be both qualified and quantified. Others present more of a challenge in terms of quantification and as a result more emphasis will be placed upon those benefits that can be quantified. The benefits shown here are therefore not exhaustive, but should serve as a guideline highlighting some of the key achievements of the WRC.

The products from R&D funded by the WRC on membranes show specific benefits according to their economic, social, environmental and health impacts and these benefits are discussed below in more detail.

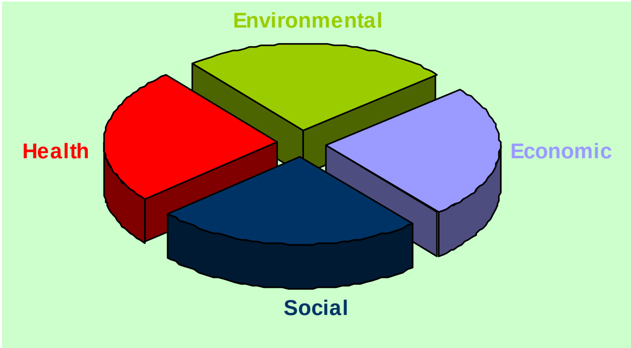


Figure 6: Benefits Quadrant

Several of the benefits that have been identified will result in further advantages, but only the most relevant ones have been selected and expanded upon. Figure 7 represents some of the key benefits that have resulted from WRC funded research.

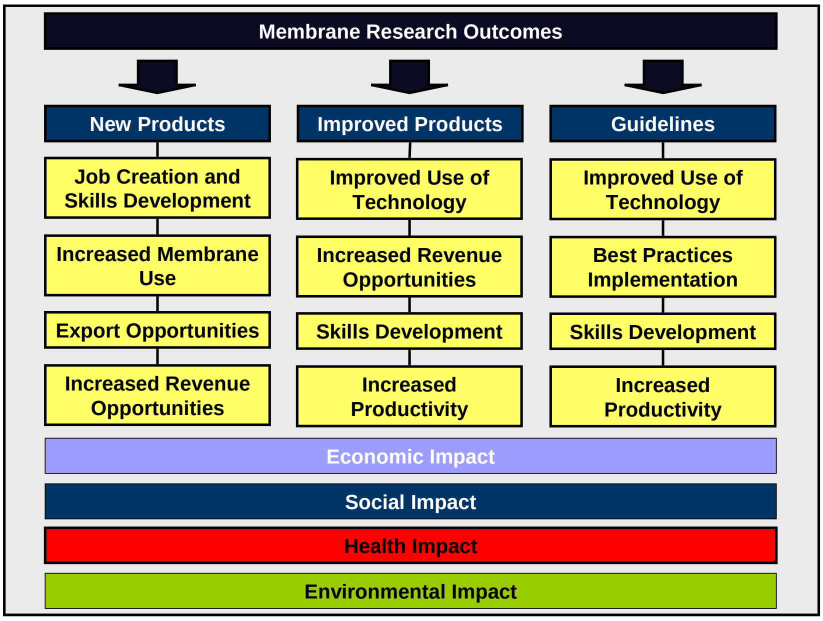


Figure 7: Membrane Research Outcomes

4.1 Economic Impacts

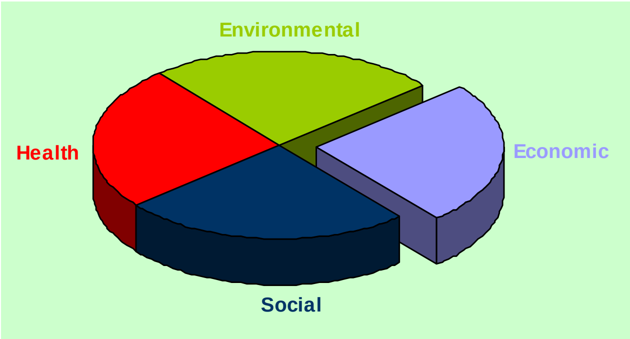


Figure 8: Benefits Quadrant (Economic)

Introduction

In a country's efforts to develop its economy, the development of new products and services becomes a critical element in generating growth. However, this growth can only occur through the development of expertise through research and training. As a result, it is essential for Government to facilitate the existence of an environment where creative ideas can be tested and developed further (as is being done by the WRC). This leads to increased economic activity and growth. Specific benefits that have derived as a result of WRC research funding are represented in figure 9 and are outlined in more detail in the following section.

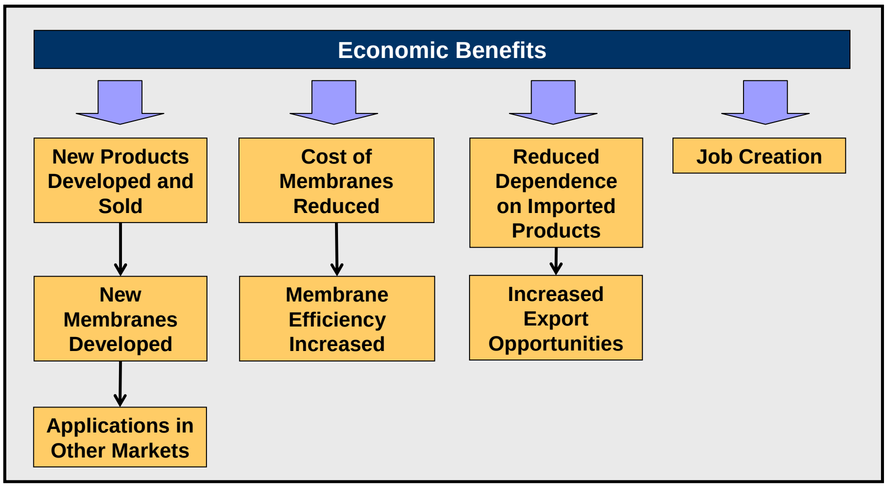


Figure 9: Key Economic Benefits Derived from WRC Funding

New products developed and sold

Through research funded by the WRC, South African researchers have developed a number of membrane products that were subsequently commercialised. These products are used for the treatment of industrial effluent, increased access to water for rural communities and the treatment of municipal waste streams. The development of such products decreases the need to import membranes and has a positive effect on economic growth.

Various products have been developed and sold to the local market. One such product is a solar powered reverse osmosis plant. The Solar RO Unit is an innovative system that uses reverse osmosis to desalinate salty borehole water. Designed for applications in areas with low or limited access to electrical power, the Solar RO Unit is simple to use and, once set up, will start automatically when exposed to the sun. It can provide up to 3 000 litres of purified water per day, is easy to maintain and is fully portable.

The table below outlines a few specific examples of where membrane technology developed through WRC research – either directly or indirectly – has been implemented:

<table>
<tr><td colspan="3">Sasol</td><td colspan="2">sasol reaching new frontiers</td></tr>
<tr><td colspan="5">Project Description</td></tr>
<tr><td colspan="5">Tubular Reverse Osmosis (TRO)
Local TRO development was one of the earliest membrane activities funded by the WRC. Sasol commissioned VWS Envig to design, supply, deliver, manage the erection and commission reverse osmosis units for two of its units in Secunda in 1995 and 2001. The water feed is from clear ash effluent that has been saturated with calcium sulphate ($CaSO_4$), calcium carbonate ($CaCO_3$) and calcium fluoride (CaF_2). The capacity of the first unit is 14 000 m^3 per day, and the capacity of the second unit is 21 630 m^3 per day. The technologies used included screening and chemical conditioning, tubular reverse osmosis membrane units, as well as feed suspended solids (SS) of 300mg/ℓ and feed total dissolved solids (TDS) of 6 000 mg/ℓ. Eleven trains were used for the first unit and 16 for the second. The value of the first installation was R25 million and the second was R45 million.</td></tr>
<tr><td>WRC Funded Research</td><td>Economic Impact</td><td>Social Impact</td><td>Environmental Impact</td><td>Health Impact</td></tr>
<tr><td>Projects on membrane development</td><td>• Job creation
• Revenue for project company</td><td>• Process water cleaned
• An improved environment</td><td>Reduced pollution</td><td>Reduced contamination and human health risk</td></tr>
<tr><td colspan="5">Project Description</td></tr>
<tr><td colspan="5">Spiral Reverse Osmosis
Sasol also commissioned VWS Envig in 1997 to design, supply, deliver, manage the erection and commission spiral reverse osmosis units for its Unit 68 SSFWest in Secunda. The feed water came from TRO permeate clear ash effluent. The capacity of the installation was designed to treat up to 7 440 m^3 of waste water per day with a feed TDS of 300 mg/ℓ. Three trains were used in this specific installation. The combined process has been highly successful with up to 90 per cent collection of waste particles. Pre-treatment for this project includes cartridge filtration and chemical conditioning.</td></tr>
</table>

WRC Funded Research	Economic Impact	Social Impact	Environmental Impact	Health Impact
Membrane improvement	• Job creation • Revenue for project company	• Process water cleaned • An improved environment	Reduced pollution	Reduced contamination and human health risk

Project Description

Spiral Reverse Osmosis

In 2002, Sasol also commissioned VWS Envig to design, develop and implement a turnkey spiral reverse osmosis plant with a capacity of 4 500 m^3 in Secunda. The feed TDS has between 50 and 1000 mg/ℓ and the single train installation has a design recovery of 78 per cent. Pre-treatment utilises the existing EDR and reverse osmosis capacity and the new installation forms part of the existing mine water desalination plant.

WRC Funded Research	Economic Impact	Social Impact	Environmental Impact	Health Impact
Membrane improvement	• Job creation • Revenue for project company	• Process water cleaned • An improved environment	Reduced pollution	Reduced contamination and human health risk

Project Description

Evaporation & Crystallisation

In 2001, VWS Envig was commissioned by Sasol to design, supply, install and commission Africa's largest evaporator. The feed water for the installation is EDR brine from mine water with 2 per cent dissolved solids containing calcium, magnesium, sodium, sulphate and chlorine ions. The installation has an evaporation capacity of 134 tonnes per hour as a result of forced circulation evaporation. The brine is pre-treated through acidification and de-aeration. The remaining product is calcium sulphate ($CaSO_4$) and sodium sulphate (Na_2SO_4).

WRC Funded Research	Economic Impact	Social Impact	Environmental Impact	Health Impact
Projects on membrane development	• Job creation • Revenue for project company	• Process water cleaned • An improved environment	Reduced pollution	Reduced contamination and human health risk

Amandelbult	ANGLO PLATINUM

Project Description

Spiral Reverse Osmosis

VWS Envig was commissioned to develop a mine waste water treatment facility that resulted in a facility that treats mine water that can be used for human consumption. A spiral reverse osmosis treatment system was implemented in 2003 at the Amandelbult mine in Thabazimbi. The facility has a capacity to treat 4 200 m^3 of waste water per day with a feed TDS of 1 500 mg/ℓ making use of only one train. The product was designed to recover 70 per cent of the water in the effluent stream after the water went through clarification, filtration and chemical conditioning.

WRC Funded Research	Economic Impact	Social Impact	Environmental Impact	Health Impact
Projects on membrane development	• Job creation • Revenue for project company	• Process water cleaned • An improved environment	Reduced pollution	Reduced contamination and human health risk

Chevron	

Project Description

Spiral Reverse Osmosis

The reuse of wastewater in the industrial market is a growing international trend. South Africa, in keeping with global water reclamation trends, is realising the potential that the recycling of wastewater holds. The Chevron/ImproChem project in Milnerton, Cape Town, involved the design, building and commissioning of an ultra filtration plant and a reverse osmosis desalination plant. Domestic and industrial effluent from a nearby wastewater treatment plant is directed to the water recycling plant. VWS Envig was contracted by ImproChem, the overall designer, owner and operator of the plant, to supply selected technology and equipment for the project. The water then goes through a series of clarification steps, including dissolved air flotation, ultra filtration and reverse osmosis, and is upgraded to process water that is used and reused in the refinery.

WRC Funded Research	Economic Impact	Social Impact	Environmental Impact	Health Impact
Projects on membrane development	• Job creation • Revenue for project company	• Process water cleaned • An improved environment	Reduced pollution	Reduced contamination and human health risk

Eskom	

Project Description

Spiral Reverse Osmosis

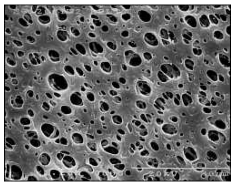
VWS Envig was commissioned in 1998 to implement a Spiral Reverse Osmosis plant at the Tukuka power station in Standerton. It was responsible for the design, supply, delivery, construction and commissioning of the spiral reverse osmosis units. The feed water comes from mine water that has been pre-treated through lime softening, clarification filtration and chemical conditioning. It has a capacity to treat 10 800 m^3 of water per day and the water is then used as cooling water for the

<table>
<tr><td colspan="5">power plant. The recovery rate of the project is up to 87 per cent and it makes a significant contribution to the reuse of water.</td></tr>
<tr><th>WRC Funded Research</th><th>Economic Impact</th><th>Social Impact</th><th>Environmental Impact</th><th>Health Impact</th></tr>
<tr><td>Projects on membrane development</td><td>• Job creation
• Revenue for project company</td><td>• Process water cleaned
• An improved environment</td><td>Reduced pollution</td><td>Reduced contamination and human health risk</td></tr>
</table>

Research into increased membrane efficiency

Research conducted at various research centres and universities in South Africa has led to the development of locally produced membranes. At the same time, extensive research into the improved use of membranes through various techniques for defouling, as well as the development of mechanisms to measure fouling in membranes, has resulted in increased efficiency and overall productivity. Membrane fouling is universally accepted as one of the most critical problems limiting the wider application of membranes in liquid separations.

Research into fouling prevention in South Africa has been ongoing since 1993 when research was started by using ED in membrane plants. Electro dialysis is a membrane process, during which ions are transported through a semi-permeable membrane under the influence of an electric potential. The membranes are cation or anion selective, which means that either positive or negative ions will flow through them.



View of a Clean Membrane

Cation selective membranes are polyelectrolytes with negatively charged matter that rejects negatively charged ions and allows positively charged ions to flow through. By placing multiple membranes in a row, which alternately allow positively or negatively charged ions to flow through, the ions can be removed from wastewater.

Research into understanding crystallisation and developing methods to decrease the fouling of membranes, has also had a significant impact. It has led to the better understanding and functioning of membranes. Chemical specialists were consulted and conducted research to improve the understanding of the membranes. Detailed research was conducted to analyse crystallisation in membranes and specific guidelines were developed to assist membrane users to decrease the impact of fouling. This type of research has had a significant effect on understanding the pre-treatment that is required in membrane applications, especially for the treatment of various industrial effluents.

An innovative product that has been developed as a result of WRC funding by the Institute for Polymer Research, University of Stellenbosch, is an ultrasonic device that is able to perform non-intrusive membrane fouling measurement. This method is based on the use of differential ultrasonic waves and fouling can be detected on a membrane surface, in the membrane module, within 10 seconds of initiation thereof. The results were used to produce a fouling meter that will be able to measure the fouling, and change in fouling, on a flat-sheet membrane inside a module in real time. From the research, a membrane fouling meter was developed in conjunction with a German company. This was subsequently patented and the unit is now being marketed (see figure 10).

Figure 10: Commercial membrane fouling meter developed from the ultrasonic time domain reflectometry research

The product has significant economic potential and further benefits to society will accrue from the many benefits achieved through the ability of this technology to monitor the fouling of a membrane surface in real time and without disturbing the membrane at all. This technology will, for example allow the parallel comparison of various membrane types with regard to fouling propensity, in-line and in real time. Various flow, backwash and cleaning regimes can easily be compared to see how fast the fouling layer develops and what layer thicknesses are experienced under varying conditions. This will also enable operators on a membrane plant to optimise plant operational parameters and thereby improve water production. Development of improved and more hydrophilic membrane materials will be simplified. Students of membrane processes will be able to see what is happening on a membrane under various hydraulic and feed material conditions.

Increased water quality improves the quality of life

Access to clean and safe water is a basic human right. There is no denying that improved water availability and quality increases the quality of life for any community. As a result, membranes have emerged as a superior product in the treatment of water for human and industrial consumption. Most of the projects financed through the WRC have focussed on improved water quality and have made a significant contribution to various communities and industrial water users.

An example of this is the development of a mobile testing RO unit being used by Ikusasa. Ikusasa is a South African company involved in the sale of chemicals and water related products to industry. Ikusasa Water Treatment provides technology and expertise for the installation and upgrading of water treatment processes. It develops modern, cost effective solutions according to the end user's specifications. It also offers related services such as general consultation and water analysis. The unit can be taken to a water source where the elements in the water are identified by analysing the waste stream collected through RO. The unit is designed to assist municipalities and industrial users to determine what pre-treatment, membrane type and post treatment is needed to ensure that clean water is supplied to the community. The unit has already been used in the Morreesburg area and is currently stationed in Agulhas, where it is expected to deliver additional drinking water to holiday visitors during the peak December period. This unit will also be used for sea water desalination in future. In this way, the full tourism potential of an area can be developed without limited water supply being a restrictive factor.

Development of products that can be used in other industries

One of the key benefits of membranes is that they can be used for various applications. Through the extraction of particles from a liquid stream, these membranes are able to selectively extract specific particles from the stream during certain processes of filtration. As a result, a number of interesting projects have been conducted to develop processes to extract certain valuable components from waste streams.

One such project is the ongoing development of a simple testing kit to analyse water at source. This reduces the cost of lab testing and helps to quickly identify those elements present in the water in order for the correct membrane application to be selected. The product is still in the development phase, but holds significant cost benefits over conventional lab testing.

Another success story is that of Synexa Life Sciences, (a Cape Town-based biotechnology company). It is organised into three business units that:

- develop novel bioprocess technologies,
- produce biologically interesting small molecules and
- provide specialised bioanalytical services.

Bio Process Technology

Synexa is a bulk producer of Leptomycin B (LMB) which was originally discovered as a potent anti-fungal antibiotic. Leptomycin B was found to cause cell elongation of the fission yeast *Schizosaccharomyces pombe*. Since then this elongation effect has been used for the bioassay of Leptomycin. However, recent data (2003) showed that Leptomycin causes G1 cell cycle arrest in mammalian cells and is a potent anti-tumour agent against murine experimental tumours.

Previously, Rhodes University had developed a proprietary bioprocessing technology called the Membrane Gradostat Bioreactor (MGB). This work, funded by the WRC, was aimed at utilising fungi and membranes to degrade and treat recalcitrant organisms in water. The MGB addresses the problem of conventional reactor and bioprocess inefficiency by fundamentally reinventing the way in which natural and recombinant products are produced and more closely mimicking the natural environment in which most production organisms have evolved to survive. In the MGB process, the organism grows on the outside of a special capillary membrane, through the centre of which liquid nutrients are fed in a controlled manner. The system works by maintaining nutrient gradients across a biofilm of the production organism, immobilised onto the surface of the membrane. This biofilm contains both actively growing biomass in the nutrient rich zones and nutrient stressed and highly productive biomass in the nutrient poor zone. In this way, the required product is very efficiently produced in the nutrient stressed zone, without undue stress on the organisms as a whole, thereby greatly increasing efficiency above that of conventional systems.

The MGB system allows continuous steady-state production of secondary metabolites or recombinant products, but can also be operated effectively in batch or fed-batch mode if required for regulatory reasons. Continuous MGB production delivers the inherently high productivity of modern perfusion systems, but with higher yields and therefore lower medium, downstream processing and waste disposable costs.

The Synexa Life Sciences technology has been proven to be successful in producing compounds that are very valuable but at the same time difficult to generate. Most of the products they produce are exported to the USA and Europe, earning valuable export revenues for South Africa. The products are mainly used in the pharmaceutical industry for antibiotics and cancer research. Synexa holds the patents for the technology and utilise a ceramic membrane. One of the key advantages of the Synexa system is that is does not have to engage in research to improve the hardiness of its organisms as its process allows the organisms to operate in a “natural” environment.

Anti-oxidant Removal	University of Cape Town
Project Description	
Membrane technology can be used to reduce the overall waste in a stream of water. It can also be used to extract valuable components from the waste stream. Through research that has been funded by the WRC, a new product is being developed that will not only purify the effluent produced, but will also be able to extract valuable anti-oxidants from waste water from the growing table olive industry in South Africa. The table olive industry in South Africa currently represents approximately 60 commercial farmers with an annual turnover of around R150 million. Annual revenue growth within the industry was over 16 per cent in 2006. These farmers produce approximately 430 tons of olive oil and 3 500 tons of table olives and employ more than 3 600 employees. A lot of water is needed in the production process and increased utilisation of waste water could therefore contribute positively to water management. Through the innovative utilization of	

membrane technology, researchers have been able to extract valuable anti-oxidants form the waste water streams. The anti-oxidants have high resale value in the cosmetics, pharmaceutical and food industries as a natural preservative. Natural anti-oxidants extracted from the table olive waste streams can be sold on the local as well as international markets. In this way, the sales of the "by-product" produced from the treatment of the effluent more than pays for the treatment costs.

WRC Funded Research	Economic Impact	Social Impact	Environmental Impact	Health Impact
Projects on membrane development	• Job creation • Revenue for project company	Student capacity building (further degrees)	Reduced biological matter (pollutant)	Increased health benefits (anti-cancer)

Securing future business based on current conditions

Although the WRC has developed and commercialised a number of products, many more products are currently being investigated that could have far reaching effects on the overall use of water membranes in future.

4.2 Social Impacts

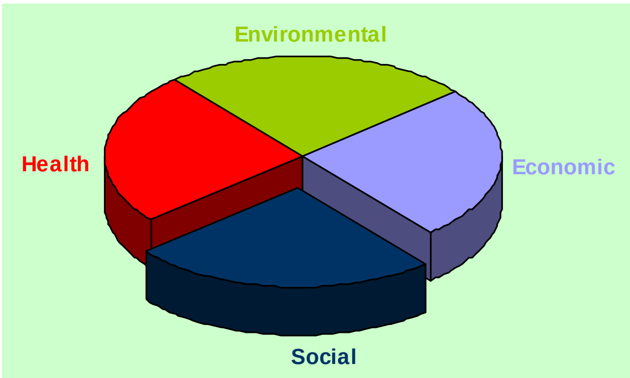


Figure 11: Benefits Quadrant (Social)

Introduction

The identification of benefits in the social segment of this research seeks to build understanding of the impact that membrane research can have on social transformation and development. It does so in the context of extending water services to both urban and rural water users in an ecologically sustainable manner. The main benefits have been identified in figure 12.

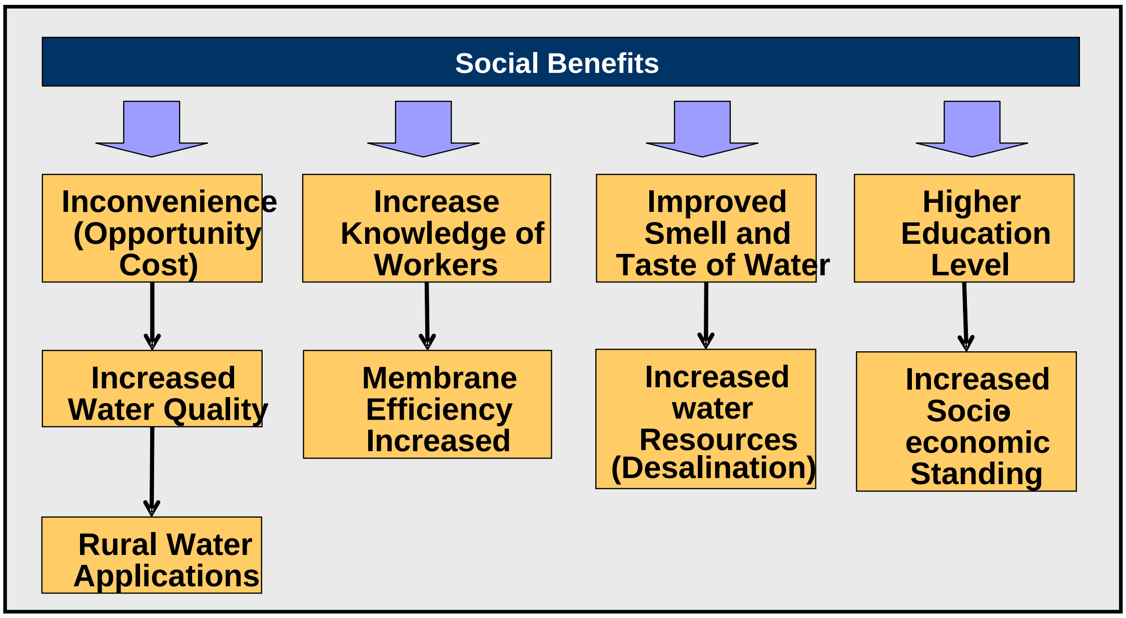


Figure 12: Key Social Benefits Derived from WRC Funding

Inconvenience / opportunity cost

A substantial portion of rural residents has to spend more than two hours per day collecting water for household use. Under government's GEAR programme, developing reliable water systems for all South Africans is an identified aim. However, many locations are so remote that water systems can not be cost-effectively installed. It is therefore essential that small, portable water treatment systems are developed. Membranes are ideally suited for such applications and through the research funded by the WRC a number of projects has been initiated to assist in the development of rural water access.

Increased knowledge of workers (capacity building)

Further education and training are important prerequisites for job creation and many students have benefited from their involvement in WRC research projects. This has resulted in a stream of qualified and knowledgeable employees coming into the South African water management community. More than 70 people have received degrees in membrane related research and most of these have entered the private sector. Their knowledge is passed on during project development and implementation. During many of these projects, co-operation between various universities and technical universities is increased, as is knowledge sharing. The publication of articles relating to WRC funded research projects in both local and international publications is testimony to the far-reaching impact of the organisation's research. The advanced education and training of people further enhance their socio-economic standing in the community and assist in general social upliftment.

Although university education and training play an important part in the development of skills, many smaller communities have benefited from knowledge transfer to local community members who are involved in the maintenance and daily operations of rural water projects (this is both in pilot projects as well as commercial installations).

Improved taste and appearance of purified water

Membranes are able to extract impurities from water and this could include viruses and bacteria. Water treated through a membrane process is therefore of a higher quality and more attractive to end users. This applies to both domestic and industrial applications.

A good example of this is the Bitterfontein application, in the West Coast Municipality, with a RO system for municipal potable water use. The system can process in excess of 30 cubic metres of water per day and sources its water from three boreholes.

The system is important as it serves a community of more than 5 000 people that has previously only had access to brackish water. Effluent is discarded into an open dam from where it evaporates and only the salt remains. In addition to supplying fresh drinking water to the community it has also created employment for between 15 and 20 people, as the system needs to be monitored locally. The system needs to be backwashed every couple of days to ensure the membranes remain clean, and from time to time the membranes are chemically-cleaned too. The original RO membranes used in the system were developed by the University of Stellenbosch through funding supplied by the WRC. This project has not only improved the livelihoods of the community, but has further increased awareness about membranes and the suitability of use in isolated communities with poor quality water sources.

South Africa is a water scarce country and all potential water sources should be protected and exploited in a sustainable manner. South Africa has constructed many dams, but the potential for increased dam construction without biodiversity destruction has become a problem. As a result, scientists are increasingly looking at alternative water sources. One such alternative is the utilisation of the RO process to extract the salt from sea water so that it can be used for human consumption. An example of an actively functioning RO plant is at Bushman's River Mouth, near to East London, where up to 480,000 litres of water is desalinated per day for a nearby community. Small coastal RO plants have been erected around the South African coastline and larger water providers, such as the City of Cape Town and Umgeni Water in KwaZulu Natal, are currently investigating seawater desalination to augment their potable water supplies. It is expected that RO technology will become increasingly essential for South Africa coastal communities.

Increased water quality improves the quality of life

A major problem facing authorities in South Africa is the delivery of clean water to communities that are far removed from developed zones. Many South Africans still do not have access to clean water and the bucket system is still fairly widely used.

One of the direct benefits of membranes is that they can function well in isolated areas and deliver high quality water even from relatively poor sources.

However, South Africa has a number of unique challenges in terms of its geography as well as the water quality in certain places (i.e. brackish water) and hence it is essential that research is conducted to 1) develop products that can be used with minimal maintenance and support and 2) develop guidelines and operational practices that will improve the operation and reliability of membrane technologies.

As a result of research that has been conducted by the WRC, a number of rural water products, processes and guidelines has been developed. These are used to facilitate increased use and improved performance of rural water membrane products.

One example where membranes have made an impact on water quality was in the Stellenbosch area. In 1995 the University of Stellenbosch opened a conference centre close to the University for which the water was obtained from a borehole. However, the waste water facility was located higher than the borehole. As a result of gravity and underground water movement, the borehole became contaminated. The University then commissioned one of its researchers to develop a system to treat the water. Through a novel tubular membrane system that was implemented on the premises, the contaminated water was treated and resulted in water with a quality that is suitable for human consumption. This membrane technology was later further developed with WRC funding and now forms the basis of the rural membrane system currently being commercialised.

Strong focus on rural water applications increases water access to communities

South Africa has a fairly well developed urban water delivery and effluent waste collection network, but still faces major challenges in providing safe drinking water to rural communities and the effective development and management of effluent waste in these areas. Ground water contamination as a result of poor waste water practices is a particular concern and many diseases can be prevented through increased clean water access.

However, the cost of developing and connecting communities to water systems remains a significant barrier to increased service delivery. Projects that have the ability to utilise available sources of water and deliver this in closed systems to communities are therefore essential.

Through research conducted by various universities, a number of rural water projects has been launched and the use of solar power to drive membrane systems in particular seems to hold much potential for South African conditions. One such example is on Robben Island where an RO system is installed that provides for the water needs of the entire island and no fresh water needs to be ferried to the island.

A number of products has been developed with research funded by the WRC, such as the capillary membrane water treatment system, which is ideal for use in rural applications. Water is processed through the system and almost all dirt particles and microbes are removed making it safe for human consumption. One benefit of this system is that limited operator knowledge is needed and locals can easily be trained to be responsible for the operation of these systems. “Roving technicians” could also occasionally come from urban centres to maintain these systems to ensure their sustainability.

4.3 Health Impacts

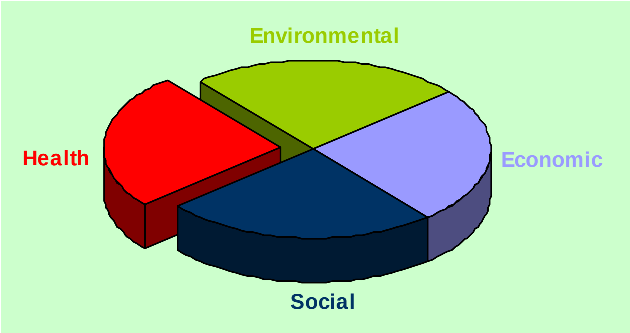


Figure 13: Benefits Quadrant (Health)

Introduction

The WRC organises its research projects into impact areas, one of which one is the “Water and Health Impact Area”. The primary objective of this impact area is to highlight the contribution that is being made to the increased health welfare of people and animals as a result of research that is being conducted by the WRC. It focuses predominantly on the understanding and reduction of water-related diseases and other health problems. It is specifically aimed at developing techniques, technologies and systems to monitor potentially harmful pollutants in water.

The aim is to create access to water that does not contain pathogenic organisms and should be free from biological forms that are aesthetically objectionable. Rural communities rely on untreated river, stream and pond water sources. Rural communities are therefore prone to the devastating effects of water borne diseases. Water borne diseases are responsible for a substantial degree of morbidity and mortality across different age groups worldwide. Methods of rural water purification for households should therefore be vigorously encouraged and sustained.

The specific benefits that WRC membrane-research projects have had in this regard are represented in figure 14.

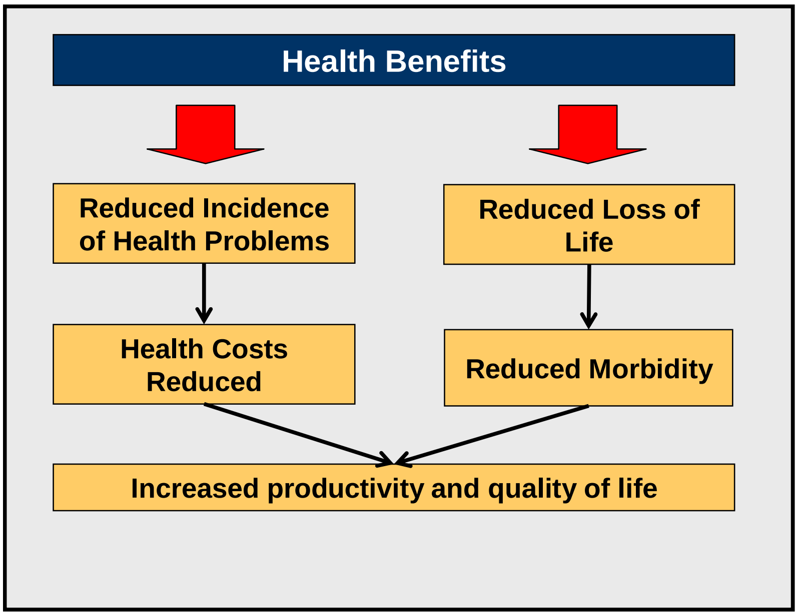


Figure 14: Key Health Benefits Derived from WRC Funding

Reduced Incidence of health problems

Human waste in water is associated with numerous diseases including diarrhoea, dysentery, cholera and typhoid. Human waste in water is indicated by the count of *Escherichia coli* in the water. Other water borne diseases include hepatitis and bilharzia.

Most of the projects funded by the WRC have some health improvement impact, although this was not normally the main aim of the project and therefore not often measured.

A recent example of poor water management occurred in October 2007 when more than 1 000 residents in Delmas in Mpumalanga were treated for diarrhoea after the town's drinking water was not sufficiently treated. The contaminated water came from 10 boreholes. The town consumes 160 000 cubic metres per day and this is only treated with chlorine to rid the water of viruses and bacteria. As underground water becomes more contaminated, it can be expected that more such cases will occur. The current solution being considered is a new pipeline from Rand Water at a cost of R53 million, whereas membrane systems could potentially be more efficient (although more expensive at present). For this reason it is essential that research in membrane systems continues as these systems are very adept at removing microorganisms.

One solution to treat brackish and contaminated water could be the implementation of a solar RO system. These systems cost between R40 000 and R45 000, which includes 4 to 6 solar panels, all the piping, pumps and membranes needed. The advantage of such a system is that it can operate between 18 months and 2 years before maintenance is required. Maintenance costs are estimated at around R1 800 per service. The system starts automatically in the morning and is fully automated. A system of this nature can clean between 2 000 and 3 000 litres of water per day and the final product can be compared with distilled water. Membranes for this type of system are imported from India as a result of the high pressure that is required (between 8 and 11 bars), but all other components are produced locally. Such systems will have a massive impact on future small communities. At present RO solar systems have been implemented at Eksteenfontein (in the Richtersveld) outside Montagu and also north of Concordia.

Health cost of treating people as a result of contamination

Diseases caused by untreated water result in costs for treating those who are infected. This cost is mainly borne by the state as people without water often do not have the funds required for medical treatment. As a result this places an additional burden on the already stretched medical system. Since most of these cases can be avoided, it is in the interest of government and other stake holders to invest in research to develop systems that can effectively treat water in rural areas.

The WRC is playing an important role in funding projects that will help to decrease the overall incidence of disease as a result of contaminated water.

Reduced loss of life

Although not a common phenomenon in South Africa, contaminated water can cause death, especially in children younger than five years of age. This can be due to hazardous waste water from industry or through human waste that has not been properly treated. A drop of faecal matter may contain millions of microorganisms, some of which are aetiological agents of diseases. Sewage or waste water is not supposed to be released untreated into the environment. The poor microbiological quality of effluents from waste water treatment plants may contribute to surface water pollution. In rural areas, the occurrence of pollution by untreated sewage is very high due to lack of proper treatment facilities.

4.4 Environmental Impacts

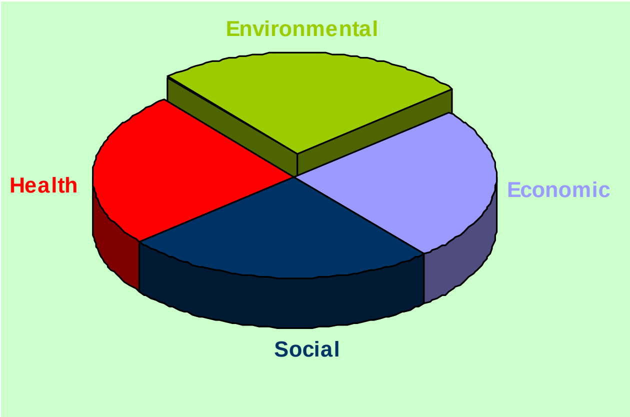


Figure 15: Benefits Quadrant (Environmental)

Introduction

The objective of this segment is to portray the contribution made by research funded by the WRC in achieving a situation where our governance systems and our understanding of environmental processes and functioning within the hydrological cycle are aligned to support sustainable water management. The benefits that have been derived from WRC-funded membrane research in this segment are represented in figure 16.

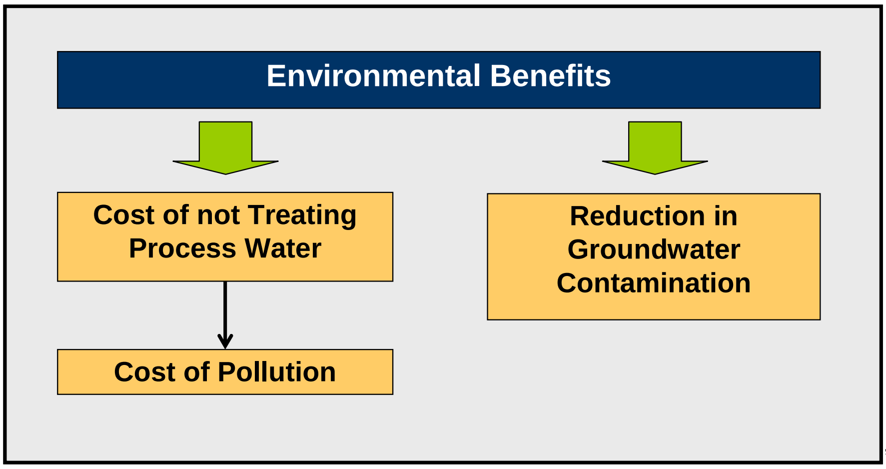


Figure 16: Key Environmental Benefits Derived from WRC Funding

Cost of not treating process water

There are significant environmental social, health and economic costs of not treating process water. These include the destruction of biodiversity, the increase in illness through pollution, loss of productivity as a result of illness and ultimately increased cost to treat polluted water sources. It is therefore essential that polluted and dirty water sources are treated as close to the source as possible to prevent downstream problems.

Pollution cost

It has been proven that it is less costly to prevent pollution than it is to treat polluted environments. For this reason, South African water legislation is geared to ensure water users consider downstream users and prevent pollution. Through the increased utilisation of membranes, water can be treated at the source of pollution and treated water can be released (or re-used) to reduce pollution.

Reduction in groundwater contamination

One of the more serious consequences of not treating waste water is the contamination of ground water resources. This can have a significant effect in areas well away from where the original contamination has taken place. Ideally all waste water should therefore be treated at source and sufficient infrastructure should be developed to deal with human effluent. This is not always practical or cost effective using traditional methods and alternative ways of treating water at source should also be encouraged.

The WRC has completed a number of projects that improve the quality of water extracted from the ground water table. Examples of projects that have played (and continue to play) an important role in the development of products for water treatment include projects such as the pilot project at Suurbraak in the Western Cape, where an innovative tubular RO system was tested to remove brown water used in the town. The water is obtained from boreholes and has a brown colour which is not suitable for human consumption. The project was successful in providing clean water for human consumption and similar projects are expected to make a real difference to people's lives in rural communities.

5. Potential Future WRC Research Involvement

Through the research conducted, a number of important areas of further development may be highlighted as experienced by various stakeholders in South Africa.

The first of these is the important role that South African researchers have to play in international research. It has been mentioned that South African researchers have much to gain from attending international conferences specifically aimed at membrane research. At these conferences researchers are able to source membranes for further research in South Africa. Ideally, products can then be improved and adapted to operate in the unique South African environment.

Through a system of using steering committees to assist in research projects, very valuable contributions to research projects are made by membrane experts. Knowledge on membrane technology is further disseminated to a large number of researchers and stakeholders in membrane R&D. This system contributes significantly to membrane research and increasing awareness of research that is ongoing or has been completed in the field.

A third important aspect is the management of intellectual property stemming from R&D. The WRC has in the past been involved in patenting various ingenious products that were developed through WRC-funded research. Through WRC funding of meritorious membrane technologies, local innovations were protected, allowing the free development and commercialisation of these technologies. Although the WRC's brief does not allow it to perform commercialisation *per* se, the WRC assisted in a number of cases to patent worthy inventions which the developers themselves would not have had the means to do.

6. Conclusions

Water will in future become an increasingly important commodity. It is needed in many processes ranging from agriculture, mining and industrial production to electricity generation. During these processes water is often polluted, but there are many ways of treating it so that it can be utilised again. It is essential that increased spending on water research is encouraged. This will result in the improved quality of discharged water and at the same time improve potable water supplies. Further water resources need to be developed to position the country for the expected future water shortages. In this regard, the desalination of sea and brackish water will increasingly have to be implemented to ensure a constant and reliable supply of potable water to the country's people and industry.

The WRC is playing an important function in fostering a strong and vibrant research culture in membrane technologies in South Africa. It is of the utmost importance that this research be continued and expanded so that creative ideas can be developed for commercial implementation. This will result in a host of positive spin offs for the economy, society, the environment and also the health of people and animals. The WRC has been identified as a key stakeholder in the South African membrane research and development environment and without its dedicated efforts many of the positive benefits of the research conducted would not have materialised. South Africa has a wealth of research talent and all stakeholder support in the continued development thereof is critical.

Appendix A

See http://www.wrc.org.za/publications_reports.htm and click on “Membrane Technology” for a list of all membrane-related reports available

IMPACT OF MEMBRANE RESEARCH FUNDED BY THE WRC				
Number	**Date**	**Report Number**	**Report Name**	**Author(s)**
1	1993	632/1/97	Capillary membrane production development. (Linked to 764, 769, 931, 965, 1034 &1070)	Jacobs EP; Sanderson RD
2	1993	467/1/93	Development of an ultrafiltration pre-treatment system for seawater desalination by reverse osmosis	Strohwald NKH; Jacobs EP; Wessels A
3	1995	532/5/95	Electrically driven membrane separation processes for the treatment of industrial effluents	Schoeman JJ; Steyn A
4	1995	275/1/95	Evaluation of membrane technology for electroplating effluent treatment	Schoeman JJ; Steyn A
5	1999	791/1/99	Defouling of ultrafiltration membranes by linkage of defouling enzymes to membranes for the purpose of low cost, low maintenance ultrafiltration of river water (linked to 932)	Leukes W; Buchanan K; Rose PD
6	2000	TT 124/00	Defluoridation, denitrification and desalination of water using ion - exchange and reverse osmosis	Schoeman JJ; Steyn A
7	2000	764/1/00	Water supply to rural and peri-urban communities using membrane technologies (Linked to 632, 769, 931, 965, 1034 &1070)	Jacobs EP; Pillay VL; Pryor M; Swart P
8	2001	931/1/01	Transverse-flow module fabrication development (linked to 662, 1369 & 1598)	Jacobs EP; Van der Walt A; Nel C; Rose PD; Hendry BA
9	2002	932/1/02	Enzymatic defouling of ultrafiltration membranes: A defouling-on-demand strategy using immobilised enzymes (linked to 791)	Leukes W; Edwards W; Buchanan K; Bezuidenhoudt J; Jordaan J; Watcham C; Way-Jones N
10	2003	930/1/03	A preliminary investigation into the application of ultrasonic techniques to membrane filtration (Linked to 1166 & 1441)	Sanderson RD; Jianxin Li; Hallbauer DK; Koen LJ; Halbauer-Zadorozhanya VY; Hurndall M
11	2003	662/1/03	Evaluation and optimization of a crossflow microfilter for the production of potable water in rural and peri-urban areas (linked to 931, 1369 & 1598)	Pillay VL; Buckley CA
12	2003	769/1/03	Fabrication and production protocol for capillary ultrafiltration membranes and modules	Jacobs EP; Yanic C; Bradshaw SM; Marais C; Bredenkamp MW; Swart P
13	2003	1167/1/03	Treatment of landfill leachate from hazardous and municipal solid waste	Schoeman JJ; Steyn A; Slabbert JL; Venter EA

IMPACT OF MEMBRANE RESEARCH FUNDED BY THE WRC				
Number	**Date**	**Report Number**	**Report Name**	**Author(s)**
14	2003	965/1/03	Ultrafiltration capillary membrane process development for drinking water (linked to 632, 769, 931 965 & 1070)	Jacobs EP; Pillay VL; Botes JP; Bradshaw SM; Pryor M; Swart P
15	2004	1230/1/04	Evaluation of nanofiltration for the treatment of rural groundwater for potable water use (linked to 1529)	Modise SJ; Krieg HM
16	2004	1370/1/04	Evaluation of microfiltration, ultrafiltration and nanofiltration for salt and chromium recovery from spent pickling and tanning effluent	Schoeman JJ
17	2004	1166/1/04	Real-time observation of fouling in membrane filtration by non-invasive ultrasonic techniques (Linked to 930 & 1441)	Li J; Sanderson RD; Hurndall MJ; Hallbauer DK; Hallbauer-Zadorozhnaya VY
18	2004	1070/1/04	The development of small-scale ultrafiltration systems for potable water production. (Linked to 932)	Pillay VL; Jacobs EP
19	2004	1172/1/04	The evaluation and design of sludge dewatering and water filtration systems using tubular woven fabric technology	Rajagopaul R; Pillay VL
20	2006	TT 266/06	A desalination guide for South African municipal engineers	Du Plessis JA; Burger AJ; Swartz CD; Musee N
21	2006	1165/1/06	Development of technology for the selective removal of bioactive pollutants by ligands, non-covalently immobilised on membranes	Jacobs EP; Swart P; Bredenkamp MW; Allie Z; Govender S; Liebenberg L; van Kralingen; Williams WT
22	2006	1372/1/06	Prevention of calcium sulphate crystallisation in water desalination plants using slurry precipitation and recycle reverse osmosis (SPARRO)	Lewis A; Nathoo J
23	2006	1227	Technical and social acceptance evaluation of microfiltration and ultrafiltration membrane systems for potable water supply to rural and remote communities	Chris Swartz
24	2007	1374/1/07	Development of a combined activated carbon/microfiltration process for the treatment of industrial effluents	Pillay VL; Jacobs EP
25	2007	KV 186/07	Implementation of a generic membrane-based system for beneficiation and treatment of Agro-Industrial wastewater	Clive Garcin and Stephanie Burton
26	2008	1441	Membrane fouling and visualisation studies (Linked to 930 & 1166)	Prof Ron Sanderson
27	2008	1442	Development of appropriate brine electrolysers for disinfection of rural water supplies	Prof David Key
28	2008	1529	The testing of a membrane technology unit for the removal of nitrate, chloride, phosphate and sulfate pollutants from groundwater (linked to 1230)	Prof Mbhuti Hlophe

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29	2008	K8/514	Investigation of the performance and kinetics of biological nitrogen and phosphorus removal with ultrafiltration membranes for solid-liquid separation (Linked to 1537)	Prof George Ekama
30	2008	1534	Development and implementation of a non-sophisticated qualitative assay for EDCs in drinking water. (Linked to 1165)	Prof Pieter Swart
31	2008	K8/738	Membrane pamphlet	Wimpie van der Merwe
32	2009	1593	Development of improved local anti-fouling spiral wrap membranes	Dr Ian Goldie
33	2009	1598	The development of immersed membrane microfiltration systems for the treatment of rural waters and industrial waters	Dr Lingam Pillay
34	2011	1716	Development of a durable and reliable wave-energy Reverse Osmosis system	Mr Simon Wijnberg
35	1993	396/1/93	An investigation into the organic fouling of ion-exchange membranes	Schoeman JJ; Hill E; Steyn A
36	1994	361/1/94	Development of tolerant membranes	Sanderson RD; Hurndall MJ
37	1995	362/1/95	Industrial applications of membranes	Malherbe GF; Morkel CE; Bezuidenhout D; Jacobs EP; Hurndall MJ; Sanderson RD
38	1995	325/1/95	Research on the modelling of tubular reverse osmosis systems	Brouckaert CJ; Wadley S; Hurt QE
39	1996	531/1/96	The development of characterising and cleaning techniques to classify foulants and to remove them from ultra and microfiltration membranes by biomechanical means (linked to 1165 & 1534)	Swart P; Maartens A; Swart EP
40	1997	548/1/97	Investigation to upgrade secondary treated sewage effluent by means of ultrafiltration and nanofiltration for municipal and industrial use	Jacobs EP; Barnard JP
41	1997	619/1/97	Preparation of tolerant membranes	Hurndall MJ; Sanderson RD; Morkel CE; Van Zyl PW; Burger M
42	1998	847/1/98	Development of transverse-flow capillary-membrane modules of the modular and block types for liquid separation and bioreactors	Domrose SE; Finch DA; Sanderson RD
43	1998	687/1/98	Membrane-based biotechnological systems for the treatment of organic pollutants	Burton SG; Boshoff A; Edwards W; Jacobs EP; Leukes WD; Rose PD
44	1999	844/1/99	Research into polymeric and ceramic-based membranes for use in electromembrane reactors (Linked to 852 & 964)	Linkov VM
45	1999	201/1/99	Research into the treatment of inorganic brines and concentrates	Buckley CA

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Number	**Date**	**Report Number**	**Report Name**	**Author(s)**
46	2001	1035/1/01	Cleaning and pre-treatment techniques for ultrafiltration membranes fouled by pulp and paper effluent	Domrose SE; Sanderson RD; Jacobs EP; Burch G
47	2001	1042/1/01	Development of a solar-powered reverse osmosis plant for the treatment of borehole water	Louw GJ
48	2002	964/1/02	Electromembrane reactors for desalination and disinfection of aqueous solutions	Linkov VM
49	2003	1103/1/03	Development of a membrane photobioreactor for the study of microsystin production by cyanobacteria	Leukes WD; Strong J; Downing TC
50	2003	852/1/03	Preparation and characterisation of electrodes for the electrochemical conversion of organic pollutants in water (Linked to 844 & 964)	Hurndall MJ; Sanderson RD
51	2004	1033/1/04	Caustic management and reuse in the beverage bottling industry	Pillay VL
52	2004	1034/1/04	Guidelines for routine monitoring of membrane performance for potable water production in small water treatment plant	Odhav B
53	2005	1229/1/05	Removal of organic foulants from membranes by use of ultrasound	Aldrich C; Qi BC
54	2006	1373/1/06	Evaluation of locally manufactured membranes for oil/water separation of industrial effluent	Telukdarie A
55	2006	1268/1/06	Hydro-philisation of hydrophobic ultrafiltration and micro-filtration membranes	Jacobs EP; Roux SP; Meinchen M; Van Reenen A; Morkel C
56	2009	1592	The defouling of membranes by moving magnetic dipole polymer beads, containing nano magnetic particles in a scouring motion across the membrane using external magnetic fields	Prof David McLachlan
57	1993	402/1/93	Mathematical modelling of flow-through porous membranes	Du Plessis JP
58	1993	431/1/93	Uitvoerbaarheidstudie op membraan karakterisering deur elektrochemiese metings en membraanoptimisering met berekeningsvloeimeganika	Smit JJ; Meyer JP; Van der Schijff OJ
59	1995	585/1/95	Modelling of flow phenomena in porous media	Du Plessis JP
60	1997	529/1/97	Characterisation of membranes using electro-chemical impedance spectroscopy (EIS) and computational fluid dynamics (CFD)	Smit JJ; Greyvenstein GP
61	1997	547/1/97	Sintese van organiese uitgangstowwe vir die ontwikkeling van unieke buismembrane vir die behandeling van nywerheidsuitvloeisels (Linked to 467)	Human M-L; Schneider DF
62	1998	618/1/98	Development of specialised cross- and transvers-flow capillary-membrane modules	Domrose SE; Sanderson RD; Jacobs EP
63	2003	846/1/03	Development of a continuous flow membrane bioreactor catalysing the solubilisation of hydrphobic pollutants by rhamnolipid-producing bacteria	Brozel VS
64	2004	723/1/04	Designed functionalized polymers by anionic macromolecular engineering for membrane development and fabrication	Summers GF

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65	2006	1241/1/06	The Application of Pinch Technology in Water Resource Management to reduce water use and wastewater generation for an area	Strauss KJ
66	2006	1268/1/06	Hydorphilization of polysulphone ultrafiltration membranes by polar polymeric solute incorporation	Jacobs EJ; Roux SP; Meinchen M; Van Reenen AJ; Morkel CE