Government of South Australia
Green Industries SA

# CIRCULAR SOLUTIONS FOR MEMBRANE MANAGEMENT IN THE WATER INDUSTRY


## Green Industries SA Women in Circular Economy Leadership Scholarship

## Project Report


Prepared By
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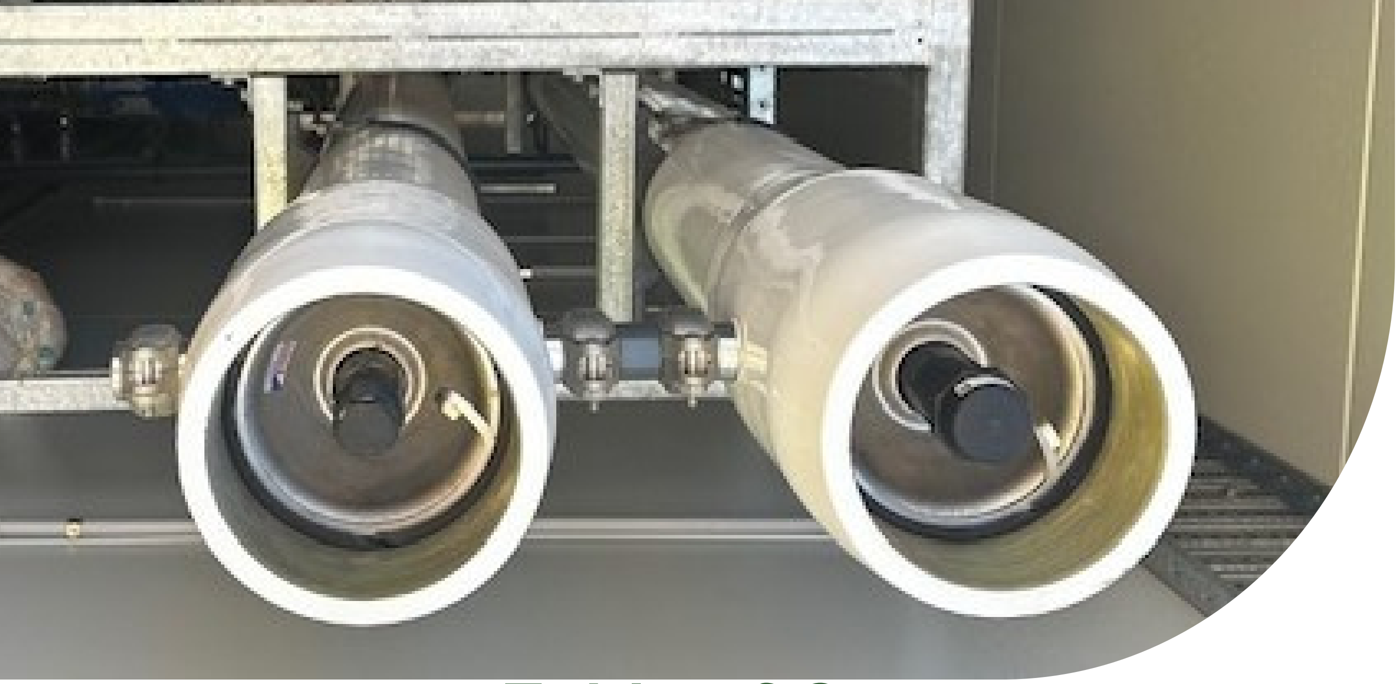

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# EXECUTIVE SUMMARY

Membrane-based treatment technologies, including reverse osmosis (RO) and ultrafiltration (UF) are now critical to Australia's drinking water, wastewater, and industrial treatment systems. However, their growth has created a rapidly expanding end-of-life waste stream. RO membranes are typically constructed from polyamide thin-film composites, PET non-woven backing layers, polypropylene (PP) housings, and ABS/PVC structural components, materials with high embodied energy and significant manufacturing impacts. When these modules are landfilled, not only are valuable polymers lost, but the opportunity to reduce the extraction of virgin resources is forfeited. This represents a substantial missed circular economy opportunity for South Australia.

Currently, no large-scale material recovery, polymer recycling, or component separation processes are commercially operating in Australia. While international projects have demonstrated partial recovery of membrane components (e.g., spacer plastics, membrane sheets), these remain mostly at pilot or early commercial stages. This project, therefore, examined the technical, organisational, and policy conditions required to transition membrane management from a linear "use–dispose" model toward circular strategies aligned with **Accelerating SA's transition to a circular economy: South Australia's Waste Strategy 2025–2030**, which emphasises designing out waste, keeping materials in circulation at their highest value, and reducing reliance on virgin resources. The study combined literature review, stakeholder interviews, case study analysis, and examination of global innovation pathways to assess circularity options for RO and UF membranes in the South Australian context.

## Key findings:

### Growing waste stream

With RO modules typically replaced every 5–10 years and weighing ~13.5 kg each, membrane waste volumes are increasing rapidly, presenting a significant environmental and resource management issue.

### Membrane composition matters

Typical RO modules include polyamide thin-film layers, PET backing, polypropylene spacers, and ABS endcaps. These polymers are technically recoverable, but require dismantling processes not yet established in Australia.

### Circular opportunities exist but commercially immature

While material recovery and reuse pathways (e.g. conversion to UF, mechanical recycling) are technically viable, they remain underutilised due to low commercial returns, limited awareness, and lack of regulatory drivers.

### Stakeholders see value but face barriers

Interviews with utilities (SA Water, Water Corporation, PUB Singapore), manufacturers (Osmoflo), recyclers (ResourceCo), and innovators (SkyJuice, AquaTip) expressed strong interest in reuse trials and collaborative solutions. However, logistical complexity, uncertain markets for recovered materials, and the absence of regulatory drivers limit investment.

### International models offer valuable lessons

Projects such as LIFE REMEMBRANE (Spain) and MemRE (Germany) show that membrane recovery can divert large waste volumes and reduce emissions when supported by coordinated collection systems, funding mechanisms, and enabling policy frameworks. However, replicability in the Australian context will require tailored adaptation.

## Strategic insights

- **Circular membrane management will require a phased approach**: from raising awareness and conducting pilot trials, through to creating policy levers and establishing regional recycling infrastructure. This aligns with the Waste Strategy 2025–2030 emphasis on systems-level change.
- **Practical reuse options** (e.g., irrigation, low-spec treatment) and selective material recovery (e.g., polypropylene spacers) and research partnerships are near-term entry points for industry engagement.
- **Integration of circular design principles**, such as modular components and recyclable housing, can reduce future disassembly costs and environmental impacts, aligning with the Strategy's *"design out waste and pollution*" principle.
- Without **regulatory mandates or extended producer responsibility** (EPR) frameworks, market incentives alone may not be sufficient to drive systemic change.

## Expected outcomes of this project:

- Actionable recommendations tailored to South Australian utilities, technology providers, and recycling partners.
- A consolidated knowledge base of global best practices and local readiness for circular membrane solutions.
- A shared platform to drive future innovation, co-investment, and regulatory engagement.
- Contribution to the Waste Strategy 2025–2030 goals of **resource efficiency, waste minimisation, and circular economy innovation** in South Australia.

**By highlighting the resource value embedded in membranes, identifying the gaps in current disposal systems, and outlining feasible pathways for reuse, repurposing, and material recovery, this report provides a structured roadmap to transition from a linear, disposal-driven model to a more sustainable, circular membrane management system. This transition will help South Australia reduce reliance on virgin materials, avoid landfill burden, stimulate innovation, and reinforce its national leadership in circular economy practices.**

# PROJECT OVERVIEW

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This investigative project was undertaken as part of a prestigious scholarship awarded to support emerging or established female leaders in South Australia who are contributing to the advancement of the circular economy. Funded by Green Industries SA (GISA), the scholarship provides an opportunity to explore innovative approaches not readily available within South Australia, with a strong emphasis on action-oriented research that can be practically applied to benefit local industry, government, and business.

## Background and context

Over the past decade, the global desalination landscape has witnessed a remarkable rise in reverse osmosis (RO) desalination plants. In Australia, major coastal cities have responded by investing in desalination infrastructure to strengthen water security. This response has seen a proliferation in both the size and number of desalination facilities across the country, with six major municipal seawater desalination plants (Figure 1) and over a hundred commercial counterparts, along with several new projects under construction [1,2].

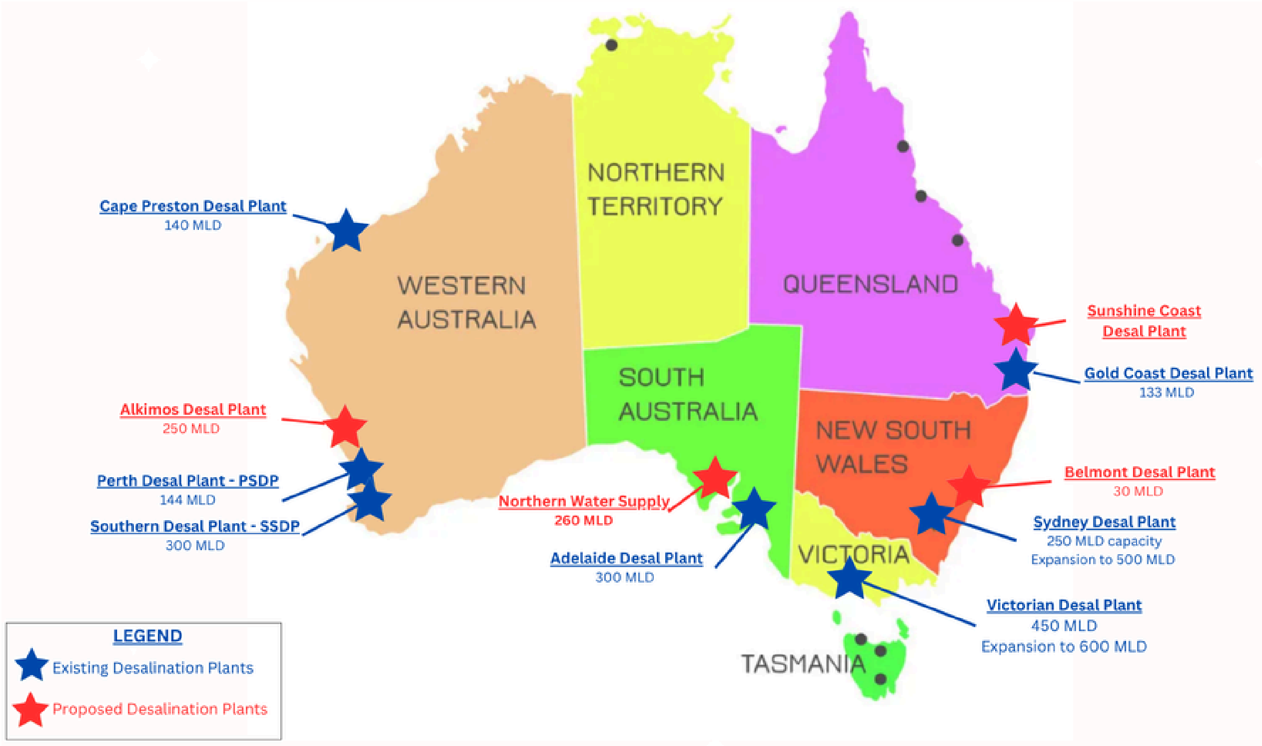


***Figure 1:*** *Desalination facilities across Australia (2022)*

However, these gains in water security have not come without challenges. The desalination process is extremely energy-intensive, although steps are being made through the adoption of renewable energy sources and process optimization. Additionally, the disposal of brine byproducts into the ocean is raising environmental concerns, prompting efforts to repurpose brine for alternative applications and reduce its production. However, a substantial worry arises from the rapid accumulation of discarded RO membrane modules. In 2015, Australia generated ~800 tonnes of these modules annually [2], while on a global scale, the annual discard of RO membrane elements accounted for about 14,000 tonnes [3]. Typically, RO membrane modules need replacement every 5–10 years to maintain water quality and productivity standards [4], resulting in disposal in landfills. With the increasing number of desalination plants in Australia for water security, the amount of waste generated is expected to escalate, leading to a significant rise in landfill deposition compared to current levels.

This multidisciplinary project brings together industry, academia, government, and utilities to address the formidable challenges surrounding the disposal of end-of-life RO membranes and propose innovative solutions to enhance their environmental sustainability. By conducting interviews, site visits, and discussions with key stakeholders, the project seeks to gather insights and identify opportunities for circularity in membrane management. Through collaborative efforts, the project aims to chart a more sustainable and eco-conscious path for the desalination industry, meeting with the evolving demands of a changing world.

## Project aim

The core aim of this project is to explore and develop circular solutions for the end-of-life management of membranes used in the water industry. These membranes, vital in desalination and water treatment, pose significant sustainability challenges due to their limited lifespan and complex material composition.

The project seeks to generate actionable insights and provide strategic recommendations that can guide the reuse, recycling, and repurposing of membrane materials, thereby reducing waste and improving resource recovery. The research is grounded in both national and international engagement to capture a broad spectrum of best practices and innovative technologies.

## Strategic relevance to Green Industries SA

This project directly supports and accelerates South Australia's transition toward a circular economy, as outlined in the SA Waste Strategy 2025–2030 and GISA's Strategic Priorities (2021–2025) [5]. By addressing the growing challenge of end-of-life membrane waste, the work contributes to the State's goals of designing out waste, keeping materials in circulation, and reducing reliance on virgin resources.

The project aligns with GISA's priorities in the following ways:

**Circular products and services**
Advances understanding of how RO and UF membrane products can be redesigned, recovered, or repurposed at end-of-life, supporting the Strategy's objective to *design out waste and pollution* and extend product longevity.

**Consumption and production**
Promotes more sustainable patterns of membrane procurement, use, and replacement by engaging both suppliers and end users, consistent with the Strategy's aim to *keep products and materials in use at their highest value.*

**Resource recovery**
Identifies emerging opportunities for material recovery, from polypropylene spacers to potential polymer separation, directly contributing to South Australia's commitment to *improve resource efficiency and reduce waste to landfill*.

**Industry sector development**
Strengthens capability within the water, manufacturing, and recycling sectors through evidence gathering, case studies, and collaborative analysis, supporting GISA's role in *fostering innovation and circular business models*.

**Capability and collaboration**
Builds partnerships among utilities, technology providers, recyclers, researchers, and government agencies (local and international), enabling the coordinated, systems-level action required to achieve the circular economy ambitions outlined in the **2025–2030 Strategy**.

# Methodology overview

The project is structured into four sequential phases as described below:

| Phase 1 **IDENTIFY** | Phase 2 **UNDERSTAND** | Phase 3 **EXPLORE** | Phase 3 **REPORT** |
|---|---|---|---|
| • Conduct literature review<br>• Develop a questionnaire for data gathering | • Engaging with stakeholders through interviews, site visits, and data collection. | • Mapping of technical and commercial reuse/recycling options relevant to the Australian context | • Preparing a final project report summarising all the findings, recommendations and next steps of GISA |
| Summary of existing options | Qualitative insights & data assessment | Identify pathways, gaps & opportunities | Final project report |

### Identify

This phase focused on evaluating the current state of knowledge and practice around membrane usage and end-of-life management. A comprehensive literature review was conducted to assess existing membrane management technologies and circular economy approaches within the water sector, as detailed in Section 2 (Literature Review).

This review drew on peer-reviewed publications, industry reports, and international case studies. To complement the desk-based research, a structured questionnaire was developed and disseminated to gather quantitative data on the types, volumes, and current handling practices of used membranes across industrial and utility stakeholders.

### Understand

This phase involved direct engagement with key stakeholders through interviews and site visits to gather qualitative insights into real-world practices, barriers, and opportunities across the membrane lifecycle. The table below summarises each stakeholder, their role, and their relevance to advancing circular membrane solutions.

| Stakeholder | Details: who and what | Role & importance to membrane circular solutions |
|---|---|---|
| Osmolfo (SA) | A leading Australian desalination and water treatment technology provider specialising in membrane-based systems. | Provided operational and technical insights into membrane types, materials, and failure modes; essential for understanding upstream design factors affecting recyclability. |

| Stakeholder | Details: who and what | Role & importance to membrane circular solutions |
|---|---|---|
| **ResourceCo (SA)** | A major resource recovery and recycling company processing construction, commercial, and industrial waste streams. | Explored feasibility of incorporating end-of-life membranes into existing recycling pathways; critical for identifying potential material recovery markets. |
| **SA Water (SA)** | South Australia's primary water utility managing treatment plants and long-term asset planning. | Shared operational lifecycle data, replacement frequencies, and disposal practices; important for understanding waste volumes and practical implementation pathways. |
| **Water Corporation (WA)** | Western Australia's principal water utility and one of Australia's largest users of membrane systems. | Provided perspectives on cross-jurisdictional challenges, procurement considerations, and opportunities for consistent industry-wide recovery approaches. |
| **Waste Transformation Research Hub (University of Sydney)** | A research hub specialising in advanced materials recovery, polymer processing, and composite recycling technologies. | Offered scientific insights into potential recycling and reprocessing methods for membrane materials; key to bridging operational and scientific feasibility. |

In addition to these planned engagements, other relevant organisations were identified and contacted during the course of the project. Notably, Aqualia (Spain), operators of the LIFE REMEMBRANE Project, were approached but did not respond to communication attempts.

**Explore:** This phase focused on investigating emerging technologies and practical reuse or recycling options that could be applicable in the Australian context. This involved engaging with technology developers, recycling firms, and innovative startups to identify both near-term and future-oriented solutions for circular membrane management. Insights from these consultations informed the feasibility analysis and guided the development of recommendations tailored to local operational, regulatory, and economic conditions.

**Report:** The final step was to compile findings into a report capturing:

- Opportunities for membrane reuse and recycling in the Australian context.
- Case studies and comparative analysis of international practices.
- Recommendations for industry, government, and research sectors.
- Roadmap for implementing circular economy principles in water treatment membrane management.

# LITERATURE REVIEW

# LITERATURE REVIEW

## Membrane management practices in the water industry

Over the past two decades, the global adoption of membrane-based water treatment technologies has accelerated substantially. There are around 22,000 desalination plants worldwide, with some of the largest most advanced facilities located in Saudi Arabia, the Middle East, and parts of Asia and Europe (Figure 2).

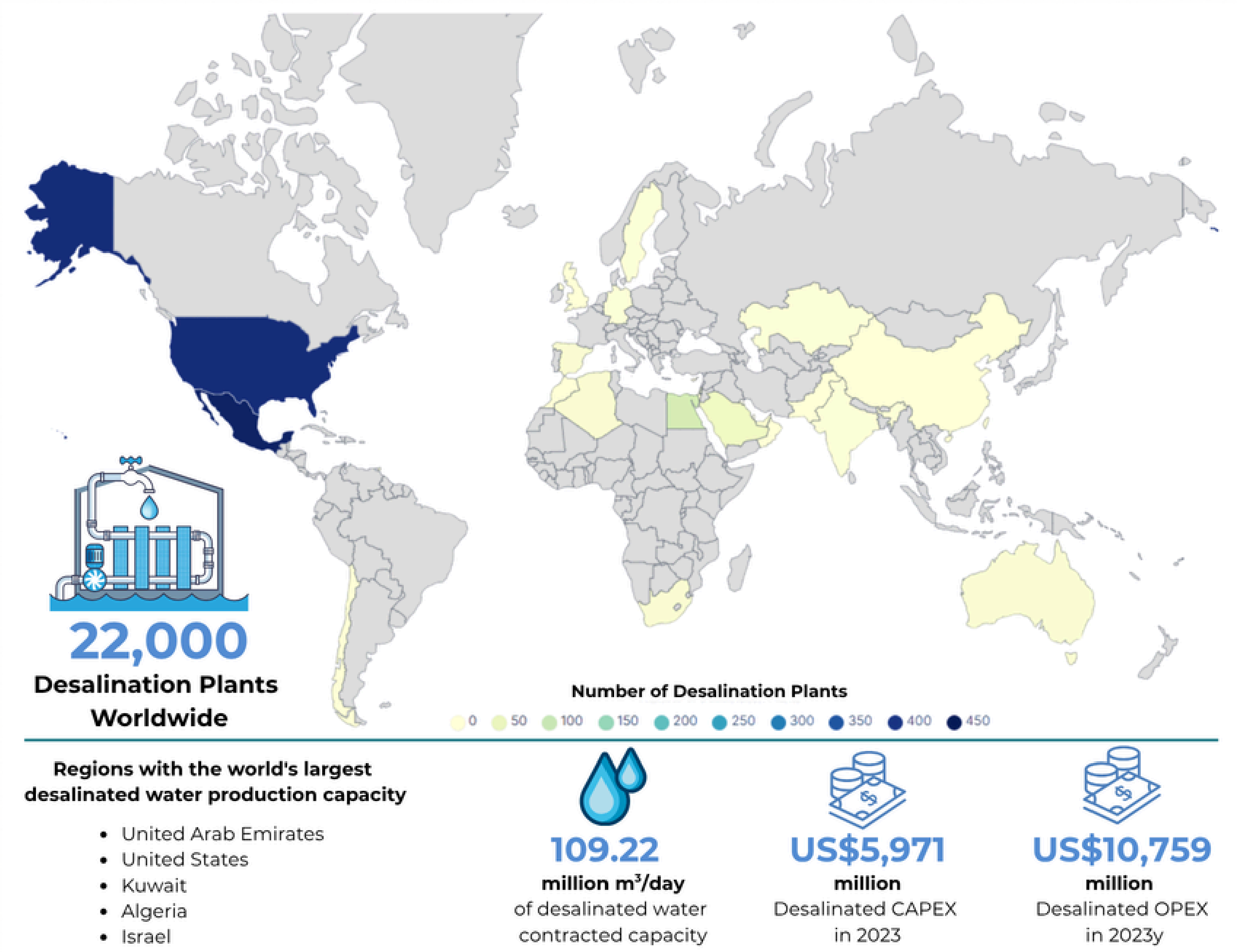


***Figure 2:*** *Overview of desalination plants globally (2025): Data and Map from World Population Review [6]*

Membrane processes, particularly microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and RO, have become essential components of modern water treatment and desalination systems. These technologies offer high removal efficiencies for pathogens, suspended solids, salts, and emerging contaminants, making them integral to municipal, industrial, and resource-recovery applications. Their use supports the growing transition toward decentralised, energy-efficient, and circular water management solutions. Figure 3 shows membrane filtration technologies ranked by pore size and operating pressure, highlighting the distinct functions and performance of each method in relation to specific treatment needs.

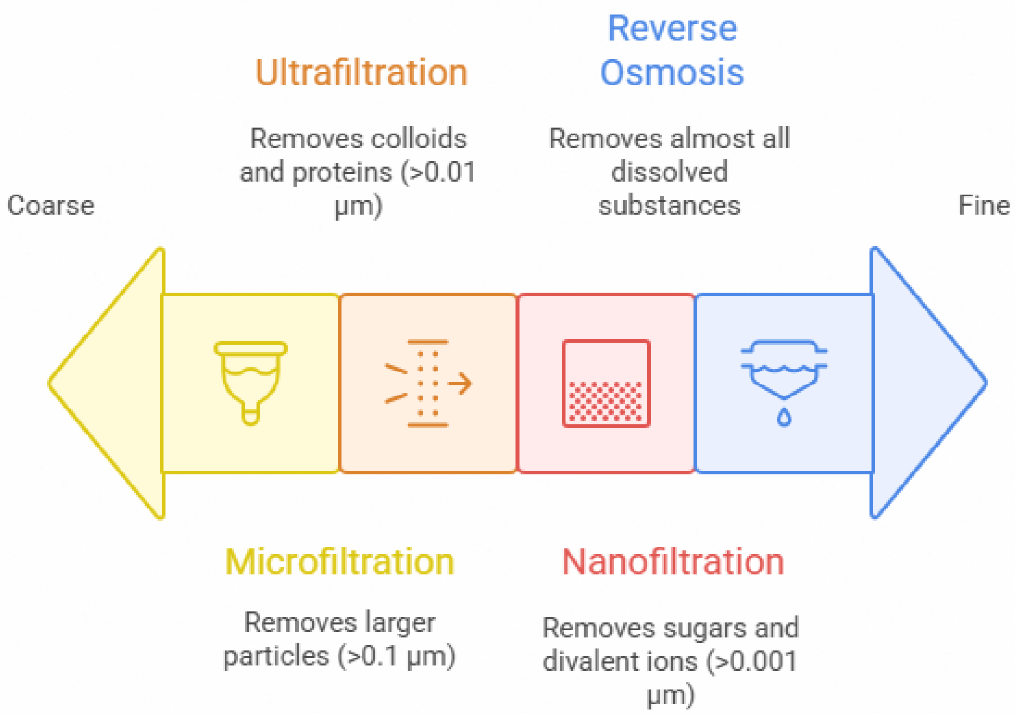


***Figure 3:*** *Membrane filtration methods ranked by pore size and pressure*

RO in particular dominates the desalination landscape. The number of RO-based desalination plants have nearly doubled in the past decade, with an annual growth rate of 6% to 12%.  RO, in particular, has experienced a 70% increase in global plant installations, with about 21,000 desalination facilities currently in operation worldwide [7]. Many of these are large-scale municipal or regional plants, some exceeding 500 megalitre per day (MLD) capacity, designed to serve growing populations in water-stressed regions such as the Middle East, Southern Europe, Southeast Asia, and Australia.

However, the proliferation of RO systems has led to a rapidly expanding and largely under-addressed waste stream: end-of-life membrane modules. Most polymeric membranes (thin, plastic-like filters used in water treatment to remove salts and contaminants) used in water treatment have a lifespan of 5 to 10 years, depending on operating conditions such as feedwater quality, cleaning frequency, and system pressure. At the end of their service life, these membranes are typically disposed of via landfill or incineration, with little recovery of embodied energy or materials. Each 8-inch RO module weighs approximately 13.5 kg, and about 100 modules are required per MLD of treated water. As replacement rates rise in tandem with global water demand, membrane disposal has become a non-trivial environmental and resource management challenge.

According to Yuanzhe Liang et al. (2023) 840,000 RO modules (>14,000 tonnes/year waste of membrane materials) are discarded every year worldwide, and by 2025, this number is projected to rise to two million, equivalent to roughly 30,000 tonnes of polymeric waste [8,9]. These projections account for rising desalination capacity, increasing membrane replacement rates (5–20% per year depending on feedwater quality), and the cumulative volume of common elements (8-inch spiral-wound modules) reaching end-of-life. The analysis underscores the urgent need for lifecycle management and circular economy interventions in the membrane sector. A key technical challenge is that RO membranes are complex composite structures comprising multiple polymers, including polyamide, polysulfone, polyester, polypropylene, and acrylonitrile butadiene styrene (ABS), often bonded with thermoset adhesives. This composite construction severely limits conventional recycling options, particularly for mechanical separation [8].


RO Membrane from SA Desalination Plant Top: Exposed internal structure showing permeate tube and membrane layers; Bottom: Intact Hydranautics SWC6 MAX RO membrane with outer fiberglass casing.

Membrane aging typically results from a combination of irreversible organic, inorganic or microbiological fouling; chemical degradation due to oxidants and cleaning agents; and long-term compaction or polymer creep under sustained pressure. These degradation mechanisms eventually reduce salt rejection efficiency or hydraulic throughput, prompting replacement. Despite the significant material and energy embedded in their manufacture, end-of-life membranes are still largely managed through linear practices, primarily landfilling and, in some cases, long-term stockpiling with minimal integration of recovery or reuse strategies.

Cutaway showing the spiral-wound membrane sheets and central permeate tube within the fiberglass pressure shell.

End cap view showing the feed water inlet, radial flow channels, and O-ring seal of an intact RO membrane module

Recent literature reveals growing recognition of the need to shift toward circular economy models, yet practical application within the membrane industry remains promising. Various reuse and recycling pathways have been proposed, though implementation remains limited by technical, economic, and institutional barriers.

One area of emerging interest is the direct reuse of membranes. Studies have shown that old RO elements, after cleaning, can sometimes demonstrate performance similar to NF membranes [10,11]. While salt rejection may be lower, these reused membranes can be deployed for non-potable applications such as brine concentration, mine water treatment, or low-spec industrial processes. A practical example comes from Djibouti (East Africa), where a pilot study successfully reused discarded RO membranes to treat domestic wastewater for agricultural irrigation. The reused elements reduced salinity, turbidity, and microbial contaminants to levels that met World Health Organisation water reuse standards, demonstrating the viability of membrane repurposing in real-world, resource-constrained settings [12].

In terms of system-level innovation, hybrid configurations are being explored where high-rejection membranes are positioned upstream, while older or converted elements are used downstream. This approach improves utilisation across a membrane's performance life and potentially extends overall system lifespan.

Material recycling options are also being considered, albeit at early stages. Mechanical recycling of polypropylene feed spacers and membrane housings has been piloted in Europe (e.g., Spain and Germany), including reuse in lightweight construction and geotextile applications. However, these initiatives remain small-scale due to low material recovery value and labour-intensive dismantling. Chemical recycling methods such as depolymerisation and thermal breakdown are largely limited to laboratory-scale research due to high energy demand and low economic viability [8]. Thermal valorisation, or energy recovery through controlled combustion or gasification, is used in parts of Europe as an alternative to landfill and offers clear benefits such as energy recovery and avoidance of long-term stockpiling of composite wastes; however, it remains underutilised in Australia.

Several innovative second-life applications are also being explored globally, including reuse of cleaned RO membranes for low-specification water treatment. A notable example comes from Djibouti (East Africa), where cleaned and converted RO membranes were successfully reused to treat domestic wastewater for irrigation [12]. Collectively, these examples demonstrate the environmental benefit of avoiding landfill disposal while extending the value of membrane materials and components.

Despite these technical possibilities, there remains a significant gap between feasibility and commercial viability. One of the most critical limiting factors is the absence of regulatory or market-based drivers. Used RO membranes are not currently subject to mandatory diversion, extended producer responsibility, or landfill restrictions, unlike more regulated waste streams such as e-waste or PFAS-contaminated materials. As a result, membrane disposal continues to follow a "business-as-usual" model, despite industry-wide awareness of the environmental impact.

Stakeholder interviews and literature suggest that meaningful change will require external drivers such as landfill bans, specific targets for resource recovery, or government-led procurement mandates. In parallel, improved communication across the value chain, from membrane manufacturers to utilities, recyclers, and regulators, is essential to support data sharing, performance validation, and coordinated reuse & recycling strategies. At present, a lack of consistent membrane lifecycle data and standardised testing protocols limits opportunities for second-life deployment.

In summary, this review highlights a rapidly expanding membrane waste challenge within the global water sector. While technological pathways for reuse, conversion, and recycling are increasingly understood, they remain constrained by a lack of scale, commercial feasibility, and supportive governance. The Australian context presents both a challenge and an opportunity: to move beyond technical innovation and establish a coherent policy, research, and industry framework that enables circular economy practices in membrane management.

# STAKEHOLDER INSIGHTS & FINDINGS

# STAKEHOLDER INSIGHTS AND ENAGAGEMENT FINDINGS

To understand the current state and future potential for circular approaches to membrane management in Australia, this project undertook a targeted program of stakeholder engagement. Semi-structured interviews, technical discussions, site visits, and strategic dialogues were conducted with representatives from utilities, technology providers, recycling companies, research institutions and water sector subject matter experts (SMEs).

This section synthesises the key insights from those engagements and integrates globally recognised circular models that were identified during these discussions. These findings highlight the complexity of transitioning from a predominantly linear model of membrane use and disposal to one that embraces reuse, reconfiguration, or recycling.

## End-of-life practices: Linear default persists

A consistent theme across utilities and industry stakeholders is that end-of-life membranes, particularly RO and UF modules, are predominantly disposed of in landfill. While some membrane modules may exceed their rated life due to conservative operational practices, once replacement is deemed necessary, disposal typically follows a default linear path.

**SA Water,** in collaboration with SUEZ, is conducting a pilot initiative to characterise end-of-life membranes and evaluate alternatives to landfill for modules at Christies Beach and Aldinga treatment plants. The project includes performance analysis, material characterisation, and assessment of technical barriers.

Desalination operators such as **Adelaide Aqua** noted that operational lifespans of RO membranes can extend to 7+ years under controlled fouling conditions, but upon decommissioning, modules are landfilled due to lack of viable alternatives. Although some modules have been in operation since 2012 for the desalination plant with acceptable performance, landfill remains the standard disposal route.

**PUB Singapore**, a major water utility and technology leader in Asia, noted a high dependency on membranes (MF, UF, RO) across NEWater and desalination facilities. Although circularity is a growing interest area, PUB noted that economic constraints and warranty conditions currently limit the adoption of second-life reuse applications, where membranes are repurposed for lower-spec treatment rather than returned to their original function.

## Technical and operational barriers to circularity

Despite growing awareness of sustainability imperatives, there is minimal demand for circular approaches to membrane end-of-life management in Australia. Stakeholders highlighted a range of technical and systemic barriers that inhibit the reuse or recycling of membranes:

### Complex material composition

RO and UF membrane modules are made from several different plastics and composite materials that are permanently bonded together, which makes them difficult to dismantle or recycle using standard methods. A typical module weighs around 12–15 kg and includes a hard fibreglass outer casing, plastic spacers, adhesive resins and thin filtration layers. Most of the weight comes from the outer housing and internal plastic supports, while the actual filtration material makes up only a small proportion.

### Manual dismantling costs

Unlike e-waste, where complex products are recycled at scale due to higher material value and established recovery systems, RO membrane modules contain mainly low-value plastics and composites. Component separation is therefore, largely manual and labour-intensive, with dismantling costs typically exceeding the value of recovered materials, limiting commercial viability.

### No return schemes

Suppliers generally do not offer take-back or extended producer responsibility programs for membrane modules, unlike other water sector components (e.g., UV lamps).

### Uncertainty in reuse viability

In the absence of robust, standardised testing for residual performance (e.g., flow, salt rejection), stakeholders lack confidence in redeploying used membranes, particularly in applications where warranties or compliance are critical.

### Handling and logistics constraints

Limited storage, workforce availability, and site access restrict the feasibility of bulk module reuse or interim storage.

> “Change won’t happen until someone tells us we can’t landfill them anymore.”
>
> WATER UTILITY STAKEHOLDER

## Structural and market-level inhibitors

Importantly, technical issues are compounded by the absence of market and regulatory drivers, there is no imperative to change current practices:

- **Absence of crisis or risk driver:** End-of-life membrane disposal does not currently pose an immediate or visible safety risk, such as the fire hazards associated with lithium-ion batteries or the health impacts of PFAS. As a result, membranes have not attracted the regulatory urgency that has driven rapid reform and product stewardship schemes in other waste streams, limiting investment and systemic change despite increasing waste volumes.

- **Fragmented communication**: Limited cross-sector communication and lack of visibility into membrane retirement volumes exacerbate fragmentation. This has led to isolated decision-making, redundant trials, and limited knowledge exchange on feasible reuse or recycling solutions

- **Uncertain economics and market size**: Without a clearly defined commercial value chain or local reuse markets, membrane recycling initiatives struggle to achieve scale. Logistical challenges, labour requirements for dismantling, and quality uncertainties further discourage uptake and pilots.

- **No policy signals -** e.g., landfill bans, circular procurement targets, or mandatory take-back- exist to shift industry behaviour.

This reflects a broader behavioural inertia, wherein the absence of external pressure results in continued linear disposal (landfill disposal or onsite stockpilling), despite acknowledged environmental downsides.

# Reuse & repurposing pathways

## Local and global examples

Despite barriers, stakeholders identified specific pathways for reuse or recycling - some operational, others under active investigation.

**SkyJuice Foundation, Australia,** presents a compelling counterpoint to industry inertia by actively operationalising circular membrane reuse. As one of the few entities undertaking practical reuse of end-of-life UF membranes, SkyJuice offers both a scalable model and a demonstration of technical feasibility under constrained conditions.

SkyJuice has implemented a range of reuse strategies that address both humanitarian and environmental objectives, as detailed below.

### Reuse Strategies

- Reconfigures validated UF modules into SkyHydrant™ units for remote or emergency potable water systems.
- Repurposes outer fiberglass housing into garden irrigation and lightweight concrete panels.
- Demonstrates low-cost, low-spec reuse for humanitarian applications where maintenance is flexible and water quality demands are modest.

SkyJuice's work highlights a viable circular model focused on decentralised water provision. While it may not directly apply to large-scale utilities or regulated potable systems, the initiative illustrates several critical enablers, including:

### Enablers

- Demonstrates that functional reuse is achievable with modest reconfiguration & quality control.
- Aligns circularity with social impact outcomes, enhancing public and stakeholder buy-in.
- Provides a low-barrier entry point into membrane reuse without requiring full system overhaul or regulatory change.
- Could be scaled or supported through partnerships with utilities and manufacturers as part of corporate social responsibility or extended producer responsibility programs.

> "The Australian water industry has been aware of this issue for over 15 years. It starts with collectively admitting there is a problem, then working out a pathway forward. Right now, it's still business as usual."
>
> — Rhett Butler
> *Chairman of Skyjuice Foundation, Australia*

**Water Corporation (WA)** provided in-depth insights into internal strategies to extend membrane life, including:

- Membrane autopsies and performance benchmarking of new units before installing
- Explores converting failed RO modules to NF or UF function for use in brine, mine tailings, landfill leachate, or sacrificial startup use cases.
- Investigating use in construction materials and low-spec industrial water treatment (e.g., landfill leachate, mining).

ResourceCo (SA)

As a leader in commercial waste transformation, ResourceCo expressed interest in trialling new recycling streams for End-of-Life membranes, particularly where material separation is feasible. While no current membrane-specific program exists, their existing infrastructure for plastics, rubber, and mixed materials could offer a starting point, especially if membrane material flows become consistent.


*Picture: Water Corporation (WA Perth) showing Connor's water supply scheme*

*Picture: Osmoflo membranes in a container*

## Osmoflo (Australia) – Balancing circularity challenges and technological innovation

Current attitudes towards reuse & recycling

| | |
|---|---|
| **Position on Circularity** | Open to exploring reuse and recycling pathways for end-of-life RO membranes. |
| **Main Barriers** | • Unclear ownership of membrane waste responsibility.<br>• Poor commercial feasibility for large-scale recycling.<br>• Informal discussions only on potential repurposing in low-income regions. |

At the same time, Osmoflo is advancing circular economy principles through investment in next-generation filtration technologies, like its Cerflo platform, which uses ceramic membrane.

These membranes are more durable, offer substantially longer service life, greater resistance to chemical and thermal stress, are easier to clean, and generate less waste than traditional polymeric membranes. However, ceramic membranes involve higher upfront capital costs and limited applicability in high-salinity desalination. Polymeric membranes remain vital for many water treatment applications.

Sustainable alternative - Ceramic membrane technology:

| | |
|---|---|
| **Drivers** | • Durability<br>• Environmental sustainability<br>• Energy efficiency |
| **Vision** | A complete overhaul of traditional membrane systems, leveraging over 30 years of experience to deliver robust, low-waste, and long-life water treatment solutions. |
| **Strategic Fit** | Aligns with global trends toward energy-conscious, circular water infrastructure. |

**Filtration tower configuration**

## SA Water – Operational insights into end-of-life membrane management

As South Australia's principal water utility, SA Water plays a pivotal role in managing a large fleet of membrane systems across desalination and wastewater treatment operations. With significant operational experience and responsibility for membrane replacement and disposal, SA Water's practices and perspectives offer valuable insight into the systemic challenges of circular membrane management.

### Current practices & circularity readiness

| | |
|---|---|
| **Membrane use** | Operates large-scale RO systems across metropolitan and regional sites. |
| **End-of-life management** | Primarily landfill disposal due to lack of local recycling options. |
| **Operational constraints** | • Risk aversion in core treatment processes.<br>• Cost and regulatory challenges limit repurposing/recycling pilots. |
| **Circularity outlook** | Supports the idea of circular membrane solutions in principle but notes lack of a viable local recovery pathway. |

### Institutional role & collaboration

| | |
|---|---|
| **Engagement** | Active participant in stakeholder interviews and discussions throughout the project. |
| **Potential role** | • Anchor utility for trialling pilot recycling solutions.<br>• Data provider for lifecycle assessments.<br>• Advocate for state-level policy support. |
| **Strategic position** | Positioned to influence broader sector adoption, especially if supported by state incentives and cross-agency collaboration. |


*Picture: SAW- Glenelg RWTP - UF membranes*

**Aquatip,** the only specialist provider consulted that collects and transports used RO membranes; however, demand remains low, and margins are limited.

> There's simply not enough margin in it."
>
> *Aquatip Director Australia*

**Aquatip offers:**

1. A global collection service for unwanted membranes.
2. Testing protocols, including TDS and energy performance benchmarking prior to reuse.
3. Reuse potential in non-potable or industrial applications (e.g., sacrificial uses, startup testing, or low-spec water treatment).
4. Guidance for determining membrane viability beyond manufacturer warranty periods.

**Waste Transformation Research Hub** in Australia is advancing foundational research on recovering complex polymer materials, including components from spent membranes. Research has focused on chemical depolymerisation, thermal valorisation, and composite separation, all of which are highly relevant to Australia's membrane waste problem.

However, progress remains largely at the R&D stage, with few transitions to commercial-scale trials. The absence of regulatory signals or cost-sharing mechanisms continues to limit industry uptake. Nonetheless, the Hub represents a critical knowledge platform that could underpin future national strategy, particularly if aligned with commercial pilots and utility-driven innovation.

These engagements demonstrate that operational reuse and repurposing is possible, especially when targeting applications with relaxed technical specifications, limited exposure, or humanitarian outcomes.

# International practices identified via stakeholder discussions

While not directly contacted during this research, several international initiatives were repeatedly referenced by stakeholders as emerging examples of membrane reuse, recycling, or repurposing. These were raised in the context of industry knowledge-sharing, anecdotal examples, or as future opportunities for benchmarking. However, it is important to note that no formal evidence or documented data from these projects was collected as part of this study, and their inclusion is based solely on insights offered during discussions.

### MemRE
### Germany

Believed to have explored the mechanical dismantling and material separation of RO membranes, MemRE was referenced as a technically sound initiative, though commercial scalability was reportedly limited. Challenges include high manual labour costs and limited material recovery value

https://www.memre.de/

### NEOM
### Saudi Arabia

NEOM was identified as a potentially valuable case study due to its large-scale reliance on desalination technologies and its stated vision to embed circular economy principles across all infrastructure systems. While specific membrane reuse strategies were not detailed in the conversations, NEOM's commitment to zero-waste and circular water management indicates that it could serve as a critical international comparator—especially given its role as a major user of membrane-based water treatment technologies.

### Israeli Innovation
### Unnamed startup

An Israeli startup was cited for its innovative repurposing of kidney dialysis filters—constructed from materials such as polysulfone—into small-scale water purification systems deployed in developing countries. While not directly equivalent to municipal RO membranes, this example demonstrates the adaptability of high-spec filtration technologies in cross-sector reuse applications, including community-scale potable water access.

While these international cases were not directly examined, they point to the growing global interest in membrane circularity and underscore the need for Australia to proactively monitor, evaluate, and, where appropriate, adapt global models to local conditions. Of particular note is NEOM, which warrants further exploration due to its system-level commitment to circularity and its dependence on desalination, making it a relevant and potentially strategic comparator for Australia’s water sector.

# FINDINGS & DISCUSSION

# FINDINGS AND DISCUSSION

This section consolidates the insights derived from literature review, stakeholder engagement, international benchmarking, and industry consultation. It presents key findings under four thematic areas:

(i) opportunities for reuse and recycling,

(ii) international case studies,

(iii) sector-specific recommendations, and

(iv) a strategic roadmap for implementation

## Opportunities for membrane reuse and recycling in the Australian context

Australia's water industry is increasingly being called upon to align with national circular economy goals and to reduce the environmental impacts of its infrastructure systems. Despite this, end-of-life RO and UF membranes are predominantly treated as residual waste, disposed of via landfill or, in some cases, incineration. The project identified several untapped opportunities to transition from a linear to a more circular membrane management system:

# Opportunities for membrane reuse and recycling in the Australian context

## Second-life applications

Used membranes may retain residual filtration capacity and can be repurposed for non-potable or lower-specification uses, including greywater treatment, irrigation, and environmental remediation. Preliminary evidence from industry stakeholders and international examples supports this pathway as both technically viable and potentially scalable.

## Mechanical and chemical recycling

While component-level recycling is technically feasible, e.g., polypropylene spacers or fibreglass housings, these approaches have yet to gain traction due to lack of commercial pathways. Universities and specialised recyclers represent important partners for pilot testing and validation of recycling methods.

## Membrane conversion

Physical or chemical modification of used RO membranes can convert them into UF or nanofiltration membranes, extending their usable life. This is particularly promising for decentralised applications and low-resource settings.

## Design for disassembly

Some membrane suppliers are beginning to explore modular designs that facilitate dismantling and selective material recovery. This upstream innovation is critical for enabling future circular flows.

## Industry collaboration

There is increasing interest among utilities, manufacturers, and recyclers to engage in joint feasibility studies, pilot trials, and product stewardship schemes.

Despite these emerging opportunities, several key challenges emerged.

## KEY CHALLENGES

### Lack of market demand and economic erivers

Without clear end-markets for repurposed or recycled membranes, and in the absence of financial incentives, uptake remains limited.

### No crisis or regulatory imperative

Compared to other waste streams (e.g. PFAS-contaminated materials), membrane disposal has not yet triggered a regulatory or public response. This reduces the perceived urgency for industry action.

### Fragmented knowledge and communication gaps

Many stakeholders are unaware of reuse or recycling opportunities, resulting in missed synergies and duplication of effort.

## Integrating circular economy principles: Reuse and recycling hierarchy

A critical framework for assessing end-of-life strategies in the membrane sector is the waste management hierarchy, widely adopted across environmental management domains. The conventional hierarchy: Avoid → Reduce → Reuse → Recycle → Recover → Treat → Dispose, is designed to guide decision-making toward increasingly sustainable material outcomes.

Figure 4 compares this traditional waste hierarchy with a membrane-specific model that reflects the technical and operational realities of membrane systems. A membrane-specific model places circular design, focusing on durability, repairability, reuse, and recyclable materials at the top. It then prioritises extending membrane lifespan, optimising maintenance, reusing or repurposing membranes for second-life, recycling components where possible, and energy recovery if recycling isn't feasible. Disposal is the last resort due to the irreversible loss of materials and energy.

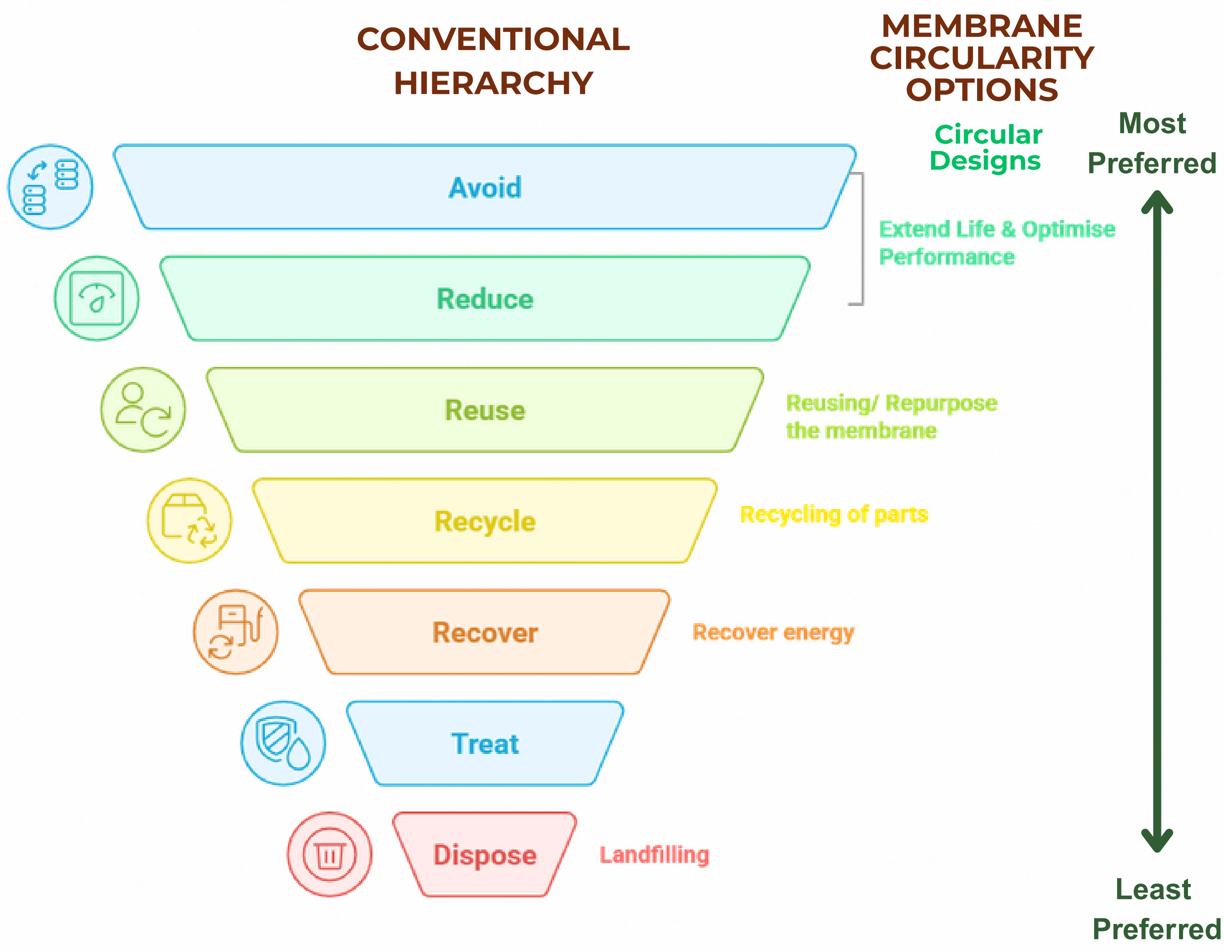


*Figure 4: Presents a comparison between the traditional waste hierarchy and a proposed membrane circularity options*

Given the composite structure, functional degradation pathways, and limited recyclability of RO membranes, this report advances an enhanced hierarchy tailored to membrane circularity, shown alongside the conventional model in the above Figure 4. The proposed hierarchy prioritises practical interventions that can extend membrane life, recover residual functionality, and minimise environmental burden:

*Extend life*
through rigorous cleaning protocols, predictive maintenance, performance monitoring, and integration into hybrid system designs.

*Optimise performance*
by relocating aged membranes within a filtration train or system to tasks with less stringent performance requirements.

*Reuse/Repurpose*
in secondary or non-potable applications such as irrigation, greywater reuse, or industrial process water

*Recycle*
via mechanical or chemical recovery of discrete components, such as endcaps, housings, and spacers.

*Recover (Energy)*
through controlled thermal processes (e.g., gasification or incineration with energy recovery) to extract residual energy from polymeric materials.

*Dispose*
in landfill, as a final option where other pathways are technically or economically infeasible.

This proposed hierarchy emphasises maximising functional value before committing to material recovery or disposal. It recognises that in the case of membranes, traditional recycling routes are often constrained by technical and economic limitations. Therefore, reuse, repurposing, and performance optimisation are critical transitional strategies toward a more circular membrane economy.

By adopting this adapted hierarchy, water utilities, manufacturers, and policymakers can align membrane lifecycle management with broader sustainability and circular economy objectives, while simultaneously identifying practical, near-term interventions.

# International case studies and comparative analysis

This section reflects on selected international initiatives that demonstrate how circular economy principles have been operationalised in membrane management. While Section 3 summarised broader global examples identified through stakeholder discussions, the focus here is on extracting cross-cutting insights from mature initiatives to inform Australia's strategic direction.

## REMEMBRANE (Spain): Large-scale demonstration of circular membrane recovery

The REMEMBRANE project (2012–2015), funded under the EU LIFE programme and led by Spanish water utility AQUALIA, was one of the most advanced demonstrations of RO membrane recovery globally [13]. In response to the disposal of over 100,000 RO modules annually from Spain's 900+ desalination plants, the project developed a mobile pilot plant to mechanically and chemically treat end-of-life membranes.

### Results

- **80%** Membranes successfully recovered for continued or downgraded use.
- **20%** Repurposed for lower-spec applications (e.g., non-potable reuse)

### Environmental & economic benefits

🌿 Life-cycle analysis confirmed significant environmental advantages.

💶 Recovery cost: €45–100/unit vs €350–400 for new membranes.

♻️ Estimated 6,700 tonnes of membrane waste diverted annually.

### Barriers to scale-up

- Logistical barriers in transporting and matching reused membranes.
- Absence of national collection infrastructure.
- Lack of regulatory drivers such as Extended Producer Responsibility (EPR).

Link to the project

REMEMBRANE was a pilot project in which membranes were either redeployed to other plants or regenerated within the same facility, depending on the type of fouling or clogging detected. However, post-project experience highlighted logistical constraints, particularly the limited availability of suitable sites capable of reusing these membranes for applications such as wastewater reuse. Despite these challenges, REMEMBRANE remains a model of what can be achieved through the combination of technical innovation, targeted funding and policy alignment. It also offers valuable lessons for Australia in designing pilots, mobilising regional reuse networks, and aligning regulatory levers.

## Comparative Learnings from International Practice

Beyond REMEMBRANE, a growing number of international efforts, some summarised in the above section '*Stakeholder insights and findings*', reveal common patterns, enabling conditions, and barriers that are highly relevant to the Australian context.

Key observations include:

**Technical feasibility is established**

Multiple initiatives have demonstrated that RO membranes can be physically dismantled, chemically processed, or repurposed into secondary uses. The challenge lies less in technical viability than in systemic integration.

**Economics and regulation are critical enablers**

Projects such as REMEMBRANE succeeded due to dedicated funding, clear recovery incentives, and alignment with EU policy frameworks. In contrast, technically sound efforts like MemRE stalled due to poor scalability and low material value recovery in the absence of policy drivers.

**Cross-sector innovation is gaining ground**

Innovative repurposing efforts (e.g., Israeli startups) show that membranes and similar filtration media can serve humanitarian, industrial, or community-scale applications, particularly when material integrity remains high after primary use.

**Circularity requires systemic design**

Large-scale urban developments like NEOM illustrate how circular water strategies are most effective when embedded upstream into infrastructure planning—not bolted on at end-of-life.

# Recommendations

Based on literature review, industry consultation, and international benchmarking, this project outlines targeted recommendations for advancing circular membrane practices in Australia. These actions are tailored to three key stakeholder groups, industry, government, and research institutions, and aim to shift the current linear disposal model toward a future-proof, resource-efficient system. The recommendations emphasise collaboration, innovation, and regulatory alignment as critical enablers for scaling reuse, repurposing, and recycling of membranes across the water sector

## For Industry

- Initiate small-scale trials to test second-life membrane applications in non-potable or industrial systems.
- Partner with academic and commercial innovators to co-develop membrane recycling or conversion technologies.
- Set internal end-of-life diversion targets and adopt circular procurement principles for new membrane systems.

## For Government

- Introduce extended producer responsibility or landfill bans for membrane materials, similar to evolving PFAS policies.
- Fund feasibility studies and demonstration projects, especially in regional areas where disposal challenges are heightened.
- Support regulatory frameworks that classify membranes as a target waste stream under circular economy strategies.

## For Research Institutions

- Advance technology development in polymer recovery and composite material separation.
- Build an open-access database of membrane types, materials, and possible reuse pathways.
- Host cross-sector workshops to share learnings from international projects and stimulate Australian innovation.

## Proposed roadmap for implementing circular economy principles

The shift from linear membrane disposal practices toward a circular economy approach will require coordinated, multi-phase intervention across sectors. This roadmap presents a staged implementation strategy, from initial awareness-building to full-scale deployment of reuse, repurposing, and recycling solutions. Each phase builds on the previous, recognising that progress hinges on both technological readiness and systemic change.

The roadmap identifies the key phases and lead stakeholders best positioned to drive action, while acknowledging that success depends on cross-sector collaboration. Early steps focus on transparency, data collection, and engagement; mid-term priorities centre on innovation, piloting, and enabling regulation; and long-term efforts aim to embed commercial-scale circular practices within Australia's water and waste management ecosystems. Figure 5 outlines these phases and associated actions to guide strategy and investment across utilities, manufacturers, regulators, and the research community.

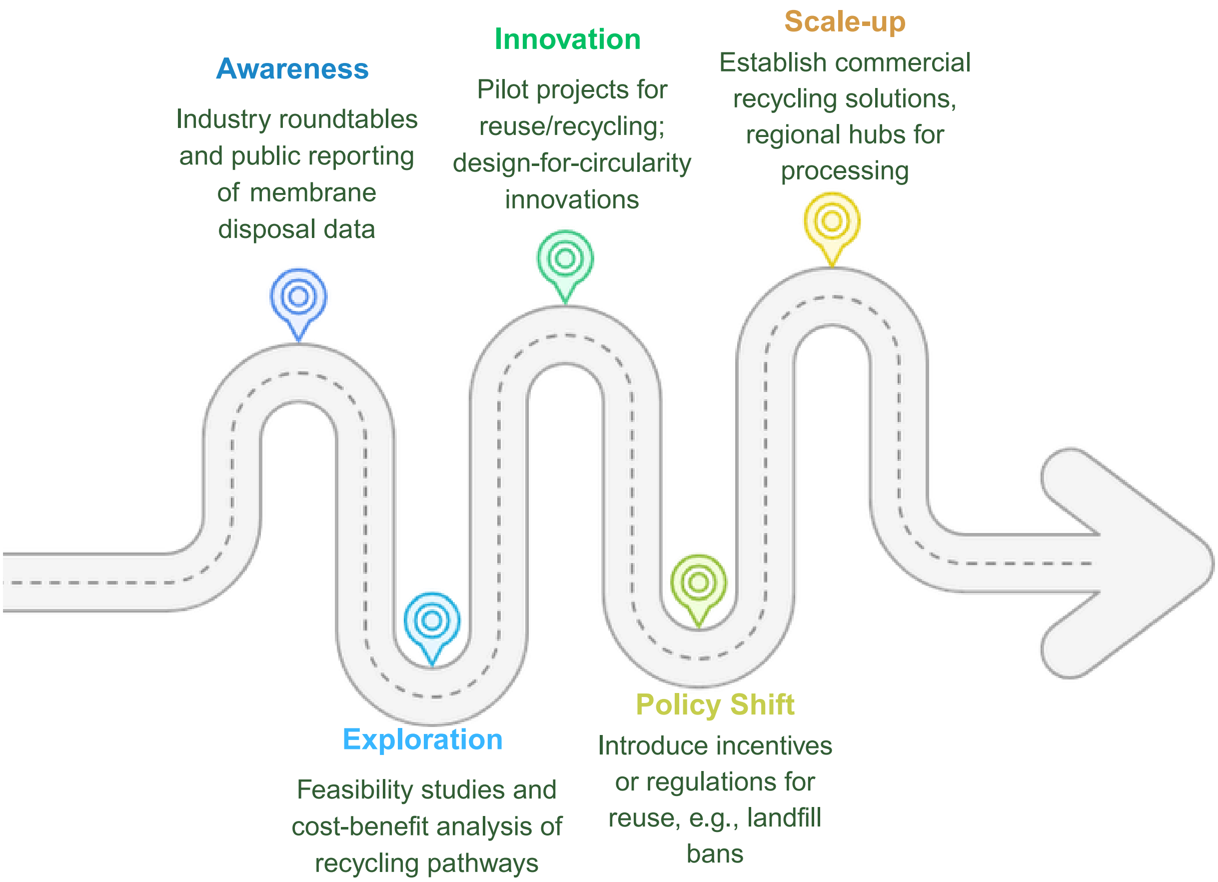


*Figure 5: Propose roadmap for achieving Circularity in RO Membrane Management*

These findings and strategic steps create a clear path forward for transforming membrane waste into a resource stream and embedding circular economy practices in Australia's water sector.

# CONCLUSION

# CONCLUSION

The increasing use of membrane technologies, particularly RO in water treatment and desalination, is generating a growing volume and under-recognised end-of-life waste. This report has synthesised global literature, stakeholder perspectives, and emerging international models to highlight both the challenges and practical opportunities in managing used membranes more sustainably. The findings demonstrate that reuse and repurposing for second-life, lower-specification applications are technically viable and represent the most practical near-term circular options, whereas material recycling remains constrained by the composite nature of membranes and is not yet commercially viable at scale. Consistent with practices observed in other Australian jurisdictions, RO membranes in South Australia are predominantly treated as general waste and disposed of to landfills.

By aligning with circular economy principles and adopting proactive strategies, South Australia has the potential to lead in this emerging space. Lessons from initiatives such as REMEMBRANE (Spain), SkyJuice Foundation (Australia), and and early-stage pilot and innovation efforts by utilities and technology providers demonstrate that membrane circularity is achievable when supported by enabling policy frameworks, coordinated logistics, inter-sector collaboration and targeted innovation ecosystems.

This study sets the groundwork for such a transformation. The roadmap presented outlines practical steps to move from awareness to commercial-scale implementation. If adopted, these pathways could significantly reduce landfill dependency, extend the usable life of valuable membrane assets, and foster a more sustainable water industry.

The following outcomes are anticipated as a result of this work:

- **Actionable recommendations** for South Australian water utilities and recycling firms, with a clear emphasis on feasible reuse and repurposing pathways.
- **Enhanced understanding** of international best practices, recovery technologies, and circular design strategies applicable to membrane systems.
- **A collaborative foundation** for innovation, enabling partnerships between utilities, manufacturers, researchers, and recyclers.
- **Alignment with Green Industries SA's strategic goals**, contributing to long-term sustainability, innovation, and resource efficiency across South Australia's circular economy framework.

Ultimately, realising these outcomes will depend on the collective commitment of industry, government, and research institutions to prioritise life extension and reuse, invest selectively in innovation, and design membrane systems with long-term value recovery in mind.

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# ABBREVIATIONS

| | |
|---|---|
| **ERP** | Extended Producer Responsibility |
| **EU** | European Union |
| **GISA** | Green Industries South Australia |
| **MF** | Microfiltration |
| **MLD** | Megalitre per Day |
| **NF** | Nanofiltration |
| **PET** | Polyethylene |
| **PFAS** | Per- and polyfluoroalkyl substances |
| **PVDF** | Polyvinylidene Fluoride |
| **RO** | Reverse Osmosis |
| **SA** | South Australia |
| **SME** | Subject Matter Expert |
| **TDS** | Total Dissolved Solids |
| **UF** | Ultrafiltration |
| **UV** | Ultraviolet |

# STAKEHOLDERS

The following stakeholders were interviewed and/or provided information to in support of this project:

| Category | Name and Organsiation |
|---|---|
| Industry | A/Prof Rhett Butler, Chairman<br>**SkyJuice Foundation Inc., NSW** |
| | 1. Julien Anese, Senior Manager Innovation, Research & Development<br>2. Neil Palmer, Chief Technical Officer<br>**Osmoflo, SA** |
| | Mitchell Bacon, Manager, Environmental Development<br>**Resource Co, SA** |
| | Steve, Director<br>**Aquatip, Worldwide** |
| Research | Dominic Bui Viet, Lead Technical Team<br>**Waste Transformation Research Hub, University of Syndey** |
| SME | Steven Morton, Executive Director,<br>**WasteWater Education** 501(c)3; SA |
| | Karen Clode, Market Leader – Industry<br>**Isle Utilities, Australia** |
| Utility | Bradley Edwards, Senior Technical Advisor<br>Advanced Water Recycling<br>**Water Corporation, WA** |
| | David Daminato, Circular Economy Specialist,<br>**SA Water** |
| | Jodi Kerrigan, Environment Manager<br>**Production & Treatment Alliance, SA Water** |
| | 1. ONG Key Wee; Chief Specialist (Potable Water Treatment), Technology & Engineering Dept<br>2. Lei LIU<br>**PUB Singapore** |
| | Rongtao Liu, Site Engineer,<br>**Desalination Plant, Adelaide Aqua** |