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Comparative life cycle assessment of end-of-life options for reverse osmosis membranes

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HIGHLIGHTS

- Life cycle assessment model for RO membrane manufacturing and end-of-life options
- Impact put into the context of total emissions from potable water production
- Membrane reuse over one year is more environmentally favourable than landfill.
- Transportation distance and lifespan play a significant role in reuse viability.
- Provides quantitative information for end-of-life decision making

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ABSTRACT

With continuing growth in the reverse osmosis water treatment industry and the finite lifespan of the membranes, the number of membrane modules requiring disposal is expected to drastically increase over time. This study aimed to provide a quantitative assessment of the environmental impact from membrane manufacturing and its impact on the desalination process, using the tool of life cycle assessment. The results showed no significant difference between the manufacturing of 16″ and 8″ elements, and that module fabrication contributed to less than 1% of the CO_2-e emissions for the production of potable water from seawater. The study also looked at the environmental impact of a number of proposed end-of-life disposal options for membranes within the context of the Australian desalination industry. The results of the study show that membrane reuse over one year is more environmentally favourable to landfill disposal, regardless of the transportation distance required. However, in terms of direct reduction of waste to landfill, incineration provided the greatest benefit, at the expense of increased greenhouse gas emissions. Overall, this study provides detailed quantitative information for membrane users and manufacturers to enhance their decision making process when it comes to end-of-life membrane options.

1. Introduction

Over the last few decades, the use of desalination technologies has dramatically increased and a large proportion of this has been membrane based plants. In Australia, the size and number of these plants have also increased, with large scale plants being located around the country. Australia has six big municipal seawater desalination plants, plus over a hundred commercial plants of varying sizes [1].

An average of one hundred 8″ reverse osmosis (RO) modules, which weigh between 13 and 15 kg and have an average lifespan of 5–8 years [2,3], are needed to produce 1000 m^3/day of product water. It has been estimated that the mass of disposed membranes in Australia alone is expected to reach 800 tonnes/year by 2015 [4]. Currently, once an RO membrane reaches the end of its life, it is disposed in local municipal landfills. Increasing awareness of the environmental impact of products and processes has led to the development of environmental management tools to better understand and manage these effects. Life cycle assessment (LCA) is a systematic tool for assessing potential environmental consequences and has been increasingly applied to the water [5,6], wastewater [7] and membrane industries [8–10].

A number of LCA studies have been conducted on various water treatment processes, including desalination with RO [11]. The majority of these studies focus on the operation phase of the process, including chemical and energy requirements, as they have been shown to have an overwhelming majority of the contribution to environmental impact [12,13]. However, a number of these studies have briefly explored the

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impact of RO membrane production and renewal, showing that it generally contributes less than 5% to the overall environmental impact of the process [14,15]. However, these studies have not adequately assessed the impact of membrane manufacturing or explored possible end-of-life disposal options for used membranes.

This study provides a novel perspective on the specific disposal challenges of the RO industry to help increase its environmental sustainability. Firstly, this study aims to complete the first process based life cycle model of the production and transportation of RO membranes, including all stages of membrane casting and module assembly. This model will be used to assess the impact of membrane manufacturing and transportation in the larger context of seawater desalination, and to compare the impact of using 8″ or 16″ elements. Secondly, it assesses a variety of end-of-life disposal options, addressing the specific challenges in Australia including transportation distances and industry regulations. The effect of variation in membrane reuse lifetime and required transportation distance will be explored through a sensitivity analysis and the mass sent to landfill will be calculated for each end-of-life option.

2. Methodology

This LCA study follows the ISO 14040-44 guidelines [16,17], and comprises of the four major steps of, goal and scope definitions, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. Scenario models were developed for membrane manufacturing and available end-of-life options. These models were generated and assessed using Simapro version 8 software and the Ecoinvent 3 and AusLCI databases.

2.1. Goal and scope definition

This LCA study was undertaken to assist in the decision making process to determine the most preferable disposal options, driving membrane users and manufacturers to more sustainable practices. The intended audience of this study is a combination of policy makers, membrane experts, manufacturers and users. The study aims to answer the question: “Which end-of-life waste treatment option is best for used RO membranes from Australian municipal seawater desalination plants, from an environmental, and resource consumption point of view?”

In addition to the general goal, special consideration is given to:

- The impact and significance of membrane manufacturing,
- The sensitivity to transportation distance and secondary life span,
- Diversion of waste from landfill.

Fig. 1 shows a representation of a standard membrane lifecycle from extraction of raw materials to various end-of-life options. This study is focused on the disposal options, highlighted in green, and the impact of the different options is assessed on a comparative basis. To truly understand the benefits of the various options and to put the waste issue into context, a detailed model of membrane production (highlighted in orange), has also been completed. This model of membrane production includes the extraction of raw materials and manufacturing, packaging and distribution of the module. Therefore, the only component not considered in this study is the “use” phase of the membrane. This is contrary to nearly every previous LCA study on membrane water treatment, as they have mostly focused on the use phase. The use phase is not considered in this study as it is assumed that all membranes are equivalent after reaching the end of their life and that the energy and material consumption during their life span does not affect the impacts from the disposal options.

The LCA boundaries define what is included within the model for all processes considered. The membrane systems under discussion for this study are being used in desalination plants located in Australia's major cities, i.e. Sydney, Melbourne, Adelaide and Perth. The membranes used are assumed to be manufactured in the United States (US) of America, transported to Australia, then used, recycled and disposed of locally. As the membrane construction and use phases occur in different geographical locations, respective local data has been used. For example, values used for membrane production modelling were obtained from US sources, while end-of-life options were based on Australian information. The boundaries of these models include all inputs and emissions associated with the contained processes (processing, manufacturing, transportation etc.), and with the infrastructure required (machinery, buildings, vehicles etc.). Due to the geographically spare nature of the various end-of-life options, a thorough transportation model is also included.

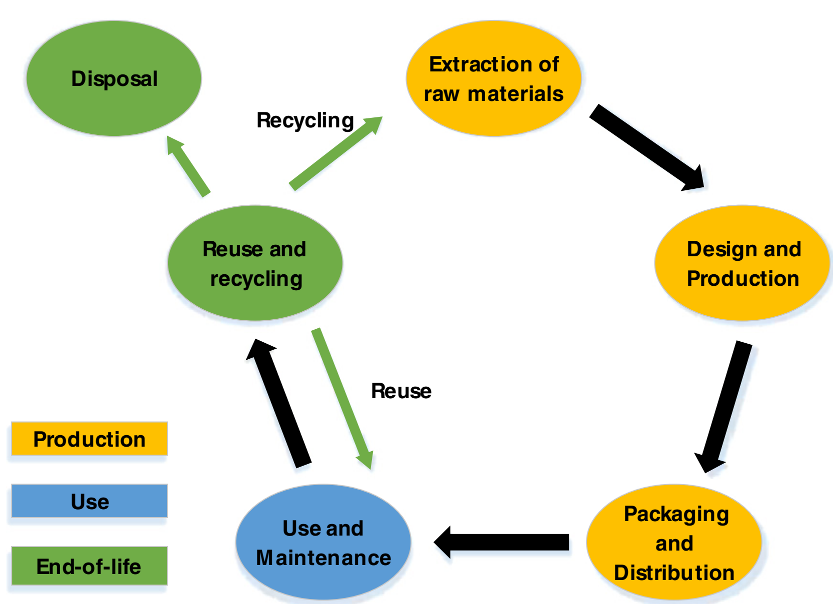

Fig. 1. Membrane life cycle.