SAND2012-5509P

THE 2012 FLC MID-CONTINENT REGION ANNUAL AWARDS

Nomination Form

Please note the specific criteria for the nominated award.

I nominate the following individual, technology, or organization for the following award (please √):

- ❑ Regional Laboratory Award
- ❑ Regional Partnership Award
- ❑ Representative of the Year Award
- ❑ STEM Mentorship Award
- **X Notable Technology Development Award**
- ❑ Excellence in Technology Transfer
  Criteria is similar to FLC national award – see page 2

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Nominee's Name: Dr. Susan Rempe, Distinguished Member of the Technical Staff
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Biomimetic Membranes
Basis for Nomination—Notable Technology Development
Overview

A pervasive and growing problem afflicting nearly half of the world's population is inadequate access to clean, fresh water. Scarcity of clean water underlies death, disease, and international tension. Furthermore, energy and water are inextricably linked, with the production of one requiring use of the other.

Reverse osmosis (RO) is the technology used for desalination plants. These plants pass saltwater through membranes that reject salts and larger solution components, thus creating drinkable water. However the membrane technology is inefficient, and has advanced only incrementally over the last 30 years.

Inspired by how the human body filters water, biomimetic membrane design and fabrication using self-assembly and atomic layer deposition was recognized with an R&D 100 Award in 2011 as a revolutionary advance in the field of membrane technology for water filtration. Biomimetic membranes are designed for water purification using RO technology, which removes impurities from water with applied pressure powered by electrical energy. A short video gives an overview.

Despite its success and widespread use, water desalination by RO is associated with tremendous energy costs. Even in their initial design, biomimetic membranes achieved a ten-fold improvement in water purification efficiency compared with state-of-the-art RO membranes, reducing energy use. By reducing costs dramatically, biomimetic membranes can increase access to clean water.

Figure 1. Nanoporous biomimetic membrane on a nanostructured support used for water desalination testing.

Description of Technology.

The selective, high-flux desalination biomimetic membranes (Fig. 1) are formed of self-assembled nanopores tuned (with atomic layer deposition) to mimic key structural features found in cell membranes (Fig. 2). Advances in theoretical modeling were essential for deciphering how biological pore structures selectively remove ions, thereby guiding pore design for efficient new membranes. Novel synthetic strategies were instrumental in fabricating highly ordered nanoporous membranes with tailor-made pore geometries and interior surfaces.

By mimicking the nanoscale design features of natural water purification channels in a robust man-made membrane, biomimetic membranes produce an order-of-magnitude improvement in water purification efficiency compared to state-of-the-art RO membranes.

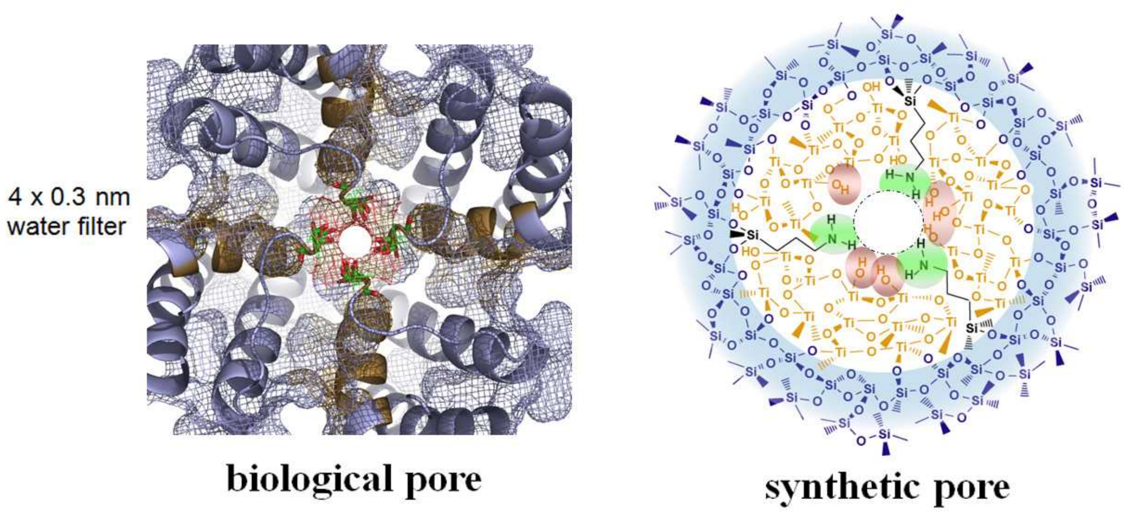

Figure 2. The investigators used multi-scale molecular modeling to assess which key structural features of biological pores that span cellular membranes account for fast, selective flux (left). They translated these features using nanoscale synthetic strategies based on atomic layer deposition (ALD) to achieve a 10-fold gain in water permeability.

Problems it solves and benefits

The need for access to clean water may be the most important issue facing people worldwide because of its critical importance to public health, agriculture, and energy production. Currently, nearly half of the world's population is facing inadequate access to clean, fresh water, and the problem is growing.

Despite its success and widespread use, water desalination by RO is associated with tremendous energy costs since the technology removes impurities from water with applied pressure powered by electrical energy. Expensive electrical energy accounts for the largest component of the operating cost for seawater desalination facilities. The challenge in designing membranes to reduce the cost of desalination comes from the two seemingly contradictory goals: excluding ions while facilitating fast transport of water.

More efficient membranes reduce energy consumption, thus lowering the cost of clean water by desalination. Lowering the cost of water purification will enhance access to clean fresh water, thus improving public health worldwide, easing international tension over water rights, and reducing the cost of energy production.

Thin-film composite membranes first developed in 1977 are still used today in desalination plants. These RO membranes are based on a thin-film composite (TFC) design whose fundamental structure has remained unchanged. While TFC architectures perform well in terms of salt rejection, a breakthrough in materials research was needed to design new membranes that also achieved higher permeability to water, or, equivalently, reduced resistance to flow.

Biological transmembrane channel proteins that demonstrate far more efficient water filtration than commercial membranes provided inspiration. Advances in theoretical modeling enabled new understanding of relationships between molecular structure and function in the biological channels, and informed the nanoporous design of the biomimetic membranes. Recent advances in nanofabrication techniques based on evaporation-induced self-assembly and targeted atomic layer deposition (ALD) were used to fabricate aligned mono-sized pores with tailor-made interiors.

The advantages of the nanoporous biomimetic membrane design include:

- Order-of-magnitude improvement in membrane permeability at low driving pressures, which reflects a 10-fold reduction in membrane resistance to flow (Fig. 3, Table 1).
- High salt rejection maintained independently of driving pressure (Fig. 3).
- Water flux increases linearly with driving pressure (Fig. 3).
- Tunable performance to meet different water flux and salt rejection needs (Fig. 4).
- Separate chemical functionality implementable in internal pore surfaces, to control desalination performance, and membrane surfaces, to avoid biofouling.

Implemented at a large scale, the improvement in water permeability demonstrated by biomimetic membranes is projected to translate to a savings of $1.45 M/yr annually for a single desalination plant. In addition to a huge reduction in electrical energy costs, there will be an associated reduction in greenhouse gas production.

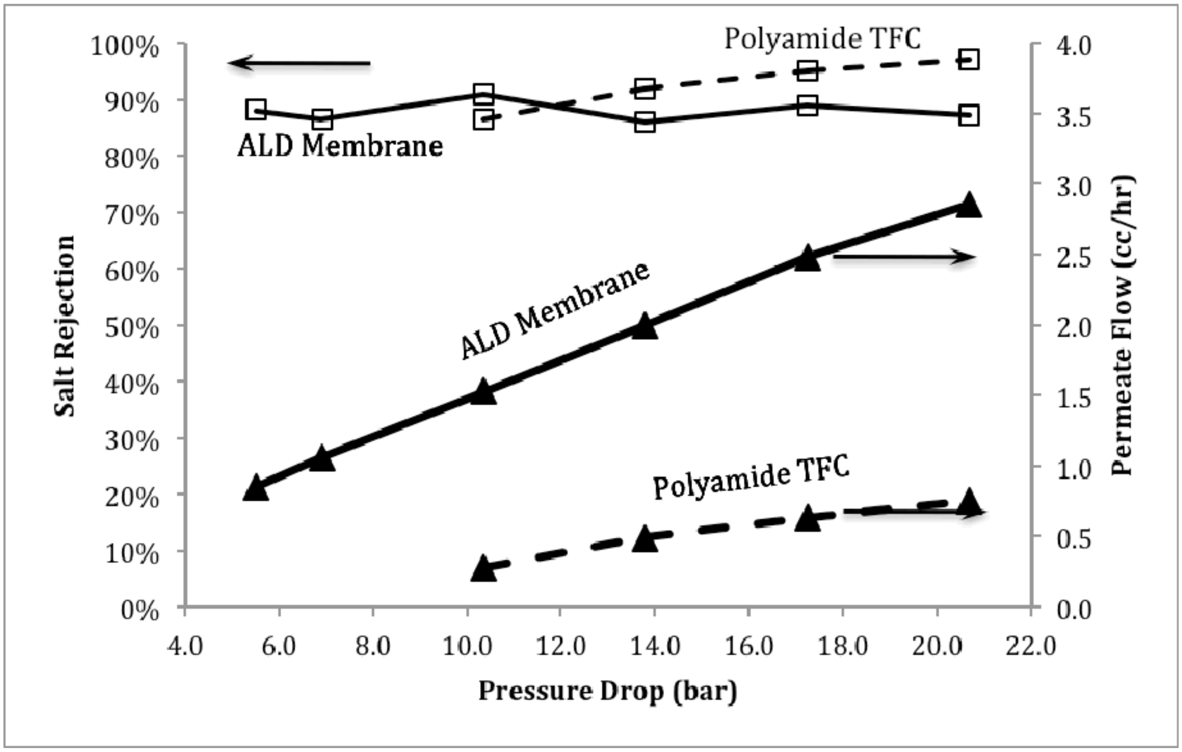

Figure 3. The biomimetic (ALD) membrane demonstrates 4x's faster flow compared to the commercial thin-film composite (TFC) membrane at 21 bar; this ratio increases with decreased driving pressure. Salt rejection for the biomimetic membrane is slightly lower than the commercial membrane at high applied pressures, but stays high independently of pressure. Thus, the biomimetic membrane performs well at pressure drops as low as 5.5 bar, giving rise to a 10-fold improvement in permeability that could translate into a savings of $1.45 M/yr for a single desalination plant.

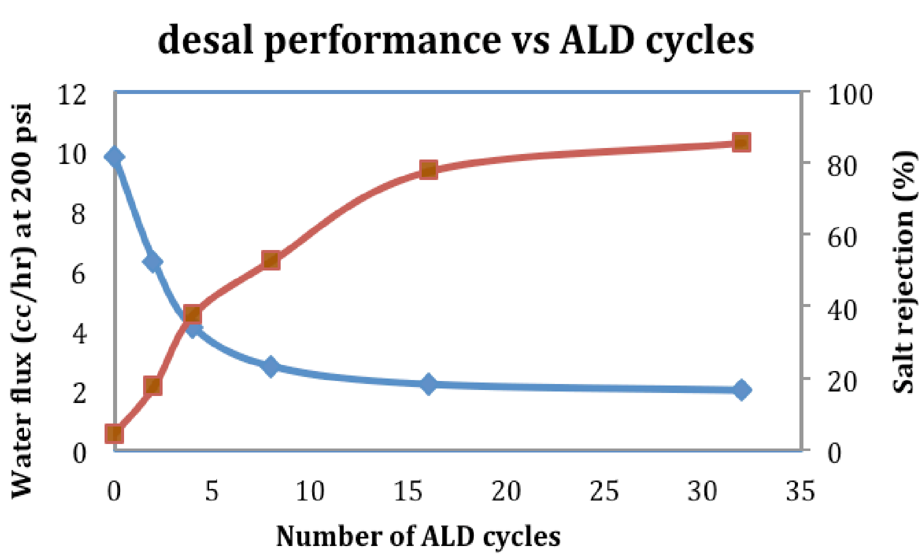

Figure 4. Desalination performance of the biomimetic membrane can be modified depending on the number of atomic layer deposition (ALD) cycles used during fabrication. Thus salt rejection (red line) and water flux (blue line) can be tuned to meet different water purification needs.

Figure 5. Susan Rempe and Sameer Varma of Sandia National Laboratories accept the R&D 100 award for Biomimetic Membranes, October 2011.

Markets and consumers

Biomimetic membrane technology can be applied to develop efficient membranes for a host of separations problems, including toxin removal from water, and electrical energy storage. The biomimetic membrane system is easily scalable to smaller sizes needed for domestic use or use by military in the field. It can be used in electrodialysis membrane technology to separate perchlorates and other dilute contaminants from well-water, in generation of electricity from osmotic pressure gradients between salty and fresh water, or to separate poisons from water to enable algae cultivation with recycled water in biofuels production.

Customers for this technology include membrane development companies, and industries that must purify wastewater, in addition to desalination plants.

Table 1. Biomimetic membranes show more than an order-of-magnitude improvement in water flux per unit of pressure drop and still maintain salt rejection ratios comparable to commercial thin-film composite membranes.

Membrane	Permeability	Salt Rejection
	cm/hr-bar	%
BIOMIMETIC (ALD)	2.42	88
BIOMIMETIC (ALD)*	1.18	91
DOW SW30HRLE**	0.21	87
DOW SW30ULE^	0.17	99.7
TORAY TM800S^	0.14	99.8
NITTO SWC-4014^	0.13	99.4

**Measured at 5.5 bar of applied pressure.*
***Measured at 10.3 bar of applied pressure.*
^Reference data reported on company datasheets for high applied pressure of 55.2 bar needed for high salt rejection

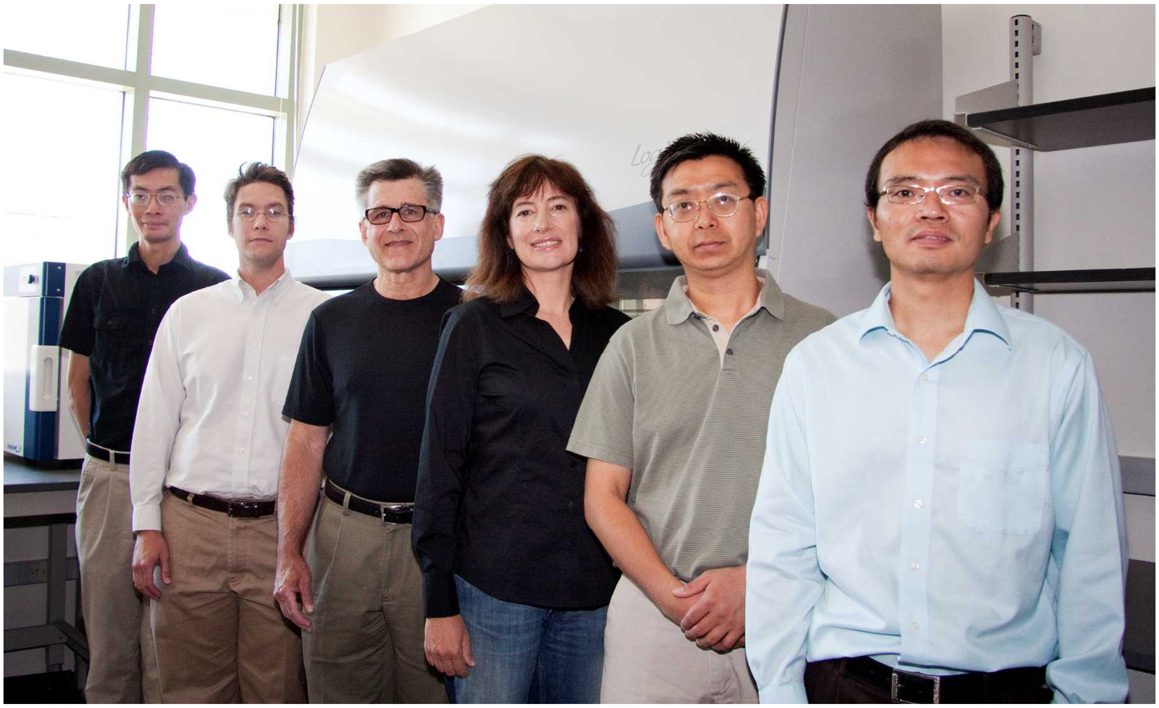

Figure 6. Biomimetic membrane team of researchers from Sandia National Laboratories (SNL) and University of New Mexico (UNM) (left to right): Kevin Leung (SNL), David Rogers (SNL), C. Jeffrey Brinker (SNL, UNM), Susan Rempe (SNL), Ying-Bing Jiang (UNM), Shaorong Yang (UNM), and Sameer Varma (SNL, not pictured).

Partnerships formed

In developing this revolutionary membrane technology, Dr. Rempe teamed (Fig. 6) with scientists from Sandia National Laboratories, who performed theoretical analyses of molecular designs in biological and synthetic membrane pores, and from the University of New Mexico, who constructed the membranes using novel nanofabrication techniques. Partnerships have been formed with Lawrence Livermore National Lab to propose a novel strategy for removing contaminants from well-water, and with electrodialysis experts from the University of Texas, and algae experts from the University of Arizona and Georgia Institute of Technology to propose innovative membrane technologies for sustainable biofuels production from algae. Current collaboration with Corning is aimed at osmotic power generation applications.

Patents filed or awarded

A non-provisional U.S. patent application number SD11775, entitled Biomimetic Membranes and Methods of Making Biomimetic Membranes, was filed October 6, 2011.