Environment and Natural Resources Trust Fund
2016 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **043-B**

Membrane-Based Process for Decentralized Drinking Water Production

Category: B. Water Resources

Total Project Budget: $ 191,304

Proposed Project Time Period for the Funding Requested: 2 years, July 2016 to June 2018

Summary:

We will develop a low-energy, membrane-based process to produce drinking water from untreated surface waters polluted with contaminants of emerging concern (e.g., pesticides and pharmaceuticals), and heavy metals.

Name: Santiago Romero-Vargas Castrillón

Sponsoring Organization: U of MN

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

A membrane-based process is proposed to treat surface waters (from lakes, rivers, etc.) contaminated with pollutants of emerging concern (e.g., pharmaceuticals, pesticides, personal care products, heavy metals) to produce drinking water. The process combines two mature membrane technologies (forward osmosis and membrane distillation) to effect the purification of water.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

I. PROJECT STATEMENT

Water scarcity is one of the central problems of our time, even in water-rich regions such as Minnesota. Processes for water treatment based on membranes (a thin sheet of porous material that rejects contaminants while allowing the passage of clean water) offer the possibility of increasing the water inventory. However, current membrane processes for water purification deployed in Minnesota can only remove large molecules and dispersed particles from the feed, falling short for the case of smaller harmful contaminants such as **small organic molecules (e.g., pharmaceuticals and personal care products) and heavy metals**. Even reverse osmosis, a process in which high pressure is used to drive the water feed across the membrane, shows incomplete rejection of these contaminants. Moreover, implementation of reverse osmosis, particularly as a decentralized water treatment process, has been hindered by its high capital (pressure vessels) and energy requirements (high pressure). Therefore, research should be devoted towards **membrane materials and low-energy water treatment processes engineered for the removal of toxic heavy metals and organic contaminants of emerging concern (e.g., pharmaceuticals, personal care products, and pesticides)**. In this project we will combine two ***proven*** **membrane technologies**, forward osmosis and membrane distillation, towards advancing **a low-cost, on-site water treatment technology for the production of drinking water from untreated surface waters**.

In forward osmosis, water permeation is driven by osmosis, i.e., the natural tendency of water to migrate from a low-salt (e.g., river water) to a synthetic high-salt solution (known as the draw solution) across a water-selective membrane. The second stage of the process uses membrane distillation to extract clean water and reconcentrate the draw solution. Using membrane distillation, the draw solution is heated to favor the transport of water vapor across a membrane that rejects liquid water and draw solutes. Because temperatures around 60 °C (140 °F) suffice to drive water vapor through the distillation membrane, the proposed process **has a lower energy demand compared to RO** and may operate using waste heat as the energy source. A further advantage of the low energy and low capital requirements (ambient pressure operation) of the combined forward osmosis-membrane distillation process is the possibility of deploying this system as a decentralized water treatment unit to generate water for on-site use (e.g., in a mining community or a farm).
The project is structured along the following objectives:

- *Materials development:* To develop forward osmosis and distillation membrane materials capable of removing **>90% heavy metals and contaminants of emerging concern** from **untreated surface water.**
- *Process integration:* To combine forward osmosis and membrane distillation into a single pilot-scale unit capable of **producing >100 gallons/day of drinking water from untreated surface water**.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Development of membranes for filtration by forward osmosis and membrane distillation showing >90% rejection of heavy metals and organics. **Budget: $92,915**

- Forward osmosis membranes: We will fabricate forward osmosis membranes showing high rejection of heavy metals and emerging contaminants (e.g., pharmaceuticals, pesticides, and personal care products) from raw (i.e., untreated) surface waters, such as Mississippi River, lake and ground waters. The materials developed should withstand the adsorption on the membrane surface and pores of large biomolecules, designated as natural organic matter (NOM), that are present in significant concentrations in most waters and which may clog the membrane. In previous studies, we have successfully prepared forward osmosis membranes capable of producing ~5 gallons of water per m^2 of membrane per hour at high sodium chloride rejection. Given that the mechanisms of removal of heavy metals and small organics are similar to those by which sodium chloride is rejected, we are well positioned to develop highly selective membranes. To address the clogging of the membrane, we will develop membrane surface coatings to resist the adsorption of natural organic matter. Strategies to accomplish this goal include the binding of water-soluble chain-like polymer molecules to the membrane surface; these molecules have a high affinity for water, and create a "protective brush" structure that prevents NOM molecules from reaching the membrane surface.

- Membrane distillation filter: The second milestone of Activity 1 pertains to the development of a distillation membrane to re-concentrate the diluted draw solution and produce clean water. The membrane must be water-repellent and have a low thermal conductivity. The combination of these two properties induces the transport of pure water vapor across the membrane, while draw solutes are rejected. Low conductivity and water repellency are properties commonly found in plastics such as Teflon (PTFE), which can be used to prepare microporous films for membrane distillation applications.

Both the forward osmosis and membrane distillation materials will be characterized in terms of their water flux (volume of water processed per unit area of membrane per unit time, with a target value of >5 gal/m^{2}h). Osmotic flow of water across the forward osmosis membrane will be induced by an inexpensive sodium chloride draw solution at a concentration of ~1 mol/L. We will demonstrate forward osmosis and distillation membranes with high rejection (>90%) of contaminants of emerging concern (e.g., personal care products such as triclosan, pharmaceuticals such as primidone and pesticides such as atrazine) as well as heavy metals (e.g., cadmium and mercury).

Outcome	Completion Date
1. Forward osmosis (FO) and membrane distillation (MD) membranes developed	6/30/2017
2. Membrane characterization shows >90% contaminant rejection with minimal membrane surface clogging. Membranes operate at >5 gal per $m^2_{membrane}$ per hour	6/30/2017

Activity 2: Construction of a 100 gal/day pilot-scale drinking water purification unit. Budget: $98,389

The membranes developed in activity 1 will be integrated into a forward osmosis-membrane distillation pilot-scale unit (membrane area ~1 m^2) that will produce drinking water from untreated surface water sources at a rate of >100 gallons per day. The water production rate increases with membrane area, so we anticipate that the developed system will be scalable to meet the drinking water requirements of the average American family of four. The dual membrane barrier for contaminant removal will result in high rejection (>90%) of heavy metals and small organic contaminants, such as pharmaceuticals, personal care products and pesticides, which are incompletely rejected by other membrane processes such as reverse osmosis.

Outcome	Completion Date
1. Pilot-scale drinking water unit designed and built	12/31/2017
2. Filtration experiments performed, showing production of >100 gallons of drinking water per day from untreated surface water (e.g., Mississippi River water)	6/30/2018

III. PROJECT STRATEGY

A. Project Team/Partners

The project manager will be Professor Santiago Romero-Vargas Castrillón (U. of Minnesota), who will supervise a graduate student in the execution of the proposed work. Romero-Vargas has expertise in the development, characterization, and testing of membrane materials for water purification, and membrane-based processes for water production.

B. Project Impact and Long-Term Strategy

The proposed work will result in membrane materials and low-energy processes for the removal of heavy metals and organic contaminants of emerging concern from untreated surface waters in Minnesota. We expect this project to lead to further applications in municipal wastewater treatment (e.g., the direct, decentralized treatment of sewage) and, also, to patentable technology.

C. Timeline Requirements

The proposed investigations will be completed in the allotted two-year period.

2016 Detailed Project Budget

Project Title: Membrane-based process for decentralized drinking water production.

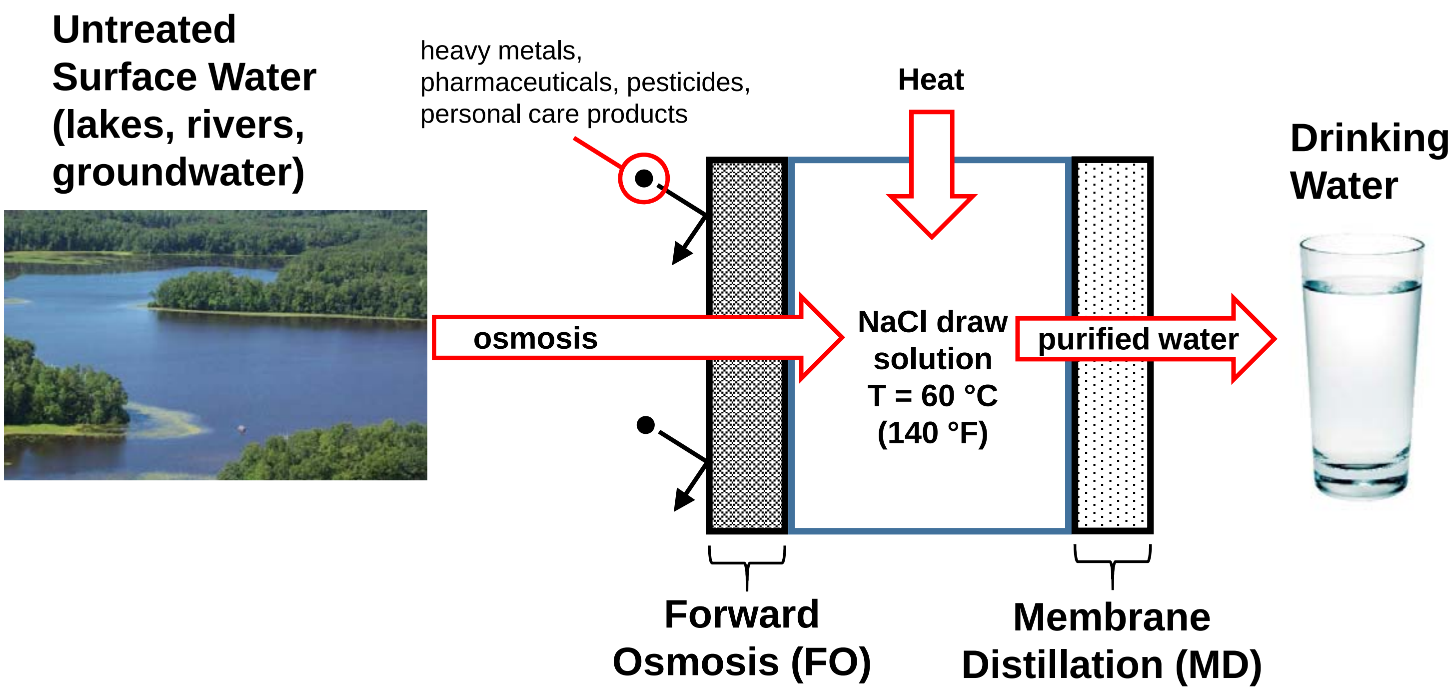
IV. TOTAL ENRTF REQUEST BUDGET 2 years

BUDGET ITEM	AMOUNT
Personnel: Romero-Vargas Castrillón (PI), two weeks of summer salary year + 5% AY	$ 25,376
Support for a 50% appointment for 1 graduate student for two years	$ 89,459
Equipment/Tools/Supplies: Polymers for membrane fabrication (polysulfone, ptfe, polyethylene glycol, total: 850 grams, $387), organic solvents for membrane fabrication (dimethylformamide, n-methyl-pyrrolidinone, total: 36 liters, $2130), other reagents for membrane synthesis (chemicals needed for membrane distillation and forward osmosis membrane synthesis, including m-phenylenediamine, trimesoyl chloride, silica, dopamine, ethylenediamine, n-hydroxisuccinimide, etc., total 5910 grams, $1361), membrane casting equipment (casting blade, non-woven fabric, glass plates, total $2775), chemicals to simulate natural organic matter (humic substances, sugars, proteins, total: 1150 grams, $764), supplies for membrane characterization (microscopy sample holders and cantilevers for force spectroscopy, total: 100 units, $1457), characterization facility user fees (for use of spectrometers and microscopes in the characterization facility at U. Minnesota, total: 80 hours, $2800)	$ 11,674
Travel: To collect water samples within Minnesota. Mileage and lodging per university plan.	$ 1,000
Additional Budget Items. Components for the construction of 1 lab-scale forward osmosis and 1 membrane distillation system: Gear pumps, heads and water heater/chiller (8 pumps, 2 heaters/chillers, total: $16,748), custom-made flow cells for forward osmosis and membrane distillation (2 cells, total: $3,300), unit instrumentation (2 computers, 2 conductivity meters, 4 stirring plates, 8 flowmeters, 8 3-way valves, 2 10-packs of fittings, 4 water reservoirs, total: $10,250). Components for the construction of a forward osmosis-membrane distillation pilot-scale water purification unit: Custom-made fluid cells and associated instrumentation (2 cells, total: $20,000), gear pumps, heater for membrane distillation unit (4 pumps, 1 water heater/chiller: $8373), unit instrumentation (total: $5,124)	$ 63,795
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 191,304

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	$ -	*N/A*
Other State $ To Be Applied To Project During Project Period:	$ -	*N/A*
In-kind Services To Be Applied To Project During Project Period:	$ -	*N/A*
Funding History: United States Geological Survey (Ultrafiltration membranes for drinking water treatment)	$ 30,000	awarded
Remaining $ From Current ENRTF Appropriation:	$ -	*N/A*

Membrane-based process
for decentralized drinking water production.



Investigator's qualifications

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Education:

2012 Ph.D. Princeton University, Princeton, NJ (Chemical Engineering)
2007 Diploma of the Imperial College, Imperial College, U. K. (Chemical Engineering)
2005 M. Eng. Sci., University of Western Ontario, London, ON (Chemical Engineering)
2002 B. Eng. (Distinction), McGill University, Montreal, QC (Chemical Engineering)

Professional Experience:

October 2014 – Assistant Professor, CEGE Department, University of Minnesota
2012 – 2014 Postdoctoral Associate, Yale University (Environmental Engineering)
2006 – 2011 Research Assistant, Department of Chemical Engineering, Princeton University
2005 – 2006 Research Engineer, RECAT Technologies, London, Canada
2003 – 2005 Research Assistant, Department of Chemical and Biochemical Engineering, UWO
2002 – 2003 Research Assistant, Department of Chemical Engineering, Imperial College

Selected Publications (of 15 total):

X. Lu, L. H. Arias Chavez, S. Romero-Vargas Castrillón, J. Ma, M. Elimelech, Influence of active layer and support layer surface structures on organic fouling propensity of thin-film composite forward osmosis membranes, *Environ. Sci. Technol.* **2015**, *49*, 1436-1444

S. Romero-Vargas Castrillón, X. Lu, D. L. Shaffer, M. Elimelech, Amine enrichment and poly(ethylene glycol) (PEG) surface modification of thin-film composite forward osmosis membranes for organic fouling control, *J. Membr. Sci.* **2014**, *450*, 331-339

X. Lu, S. Romero-Vargas Castrillón, D. L. Shaffer, M. Elimelech, In situ surface chemical modification of thin-film composite forward osmosis membranes for enhanced organic fouling resistance, *Environ. Sci. Technol.* **2013**, *47*, 12219-12228

S. Romero-Vargas Castrillón, S. R. Matysiak, F. H. Stillinger, P. J. Rossky, P. G. Debenedetti, Phase behavior of a lattice hydrophobic oligomer in explicit water, *J. Phys. Chem. B* **2012**, *116*, 9540-9548

S. Romero-Vargas Castrillón, N. Giovambattista, I. A. Aksay, P. G. Debenedetti, Structure and energetics of thin film water, *J. Phys. Chem. C* **2011**, *115*, 4624-4635

Organization description. The University of Minnesota is a public, land-grant, sea-grant, and space-grant research university located in Minneapolis and Saint Paul, Minnesota.