NAWI National Alliance
for Water Innovation

National Alliance for Water Innovation Overview Presentation

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Tuesday, May 18, 2023

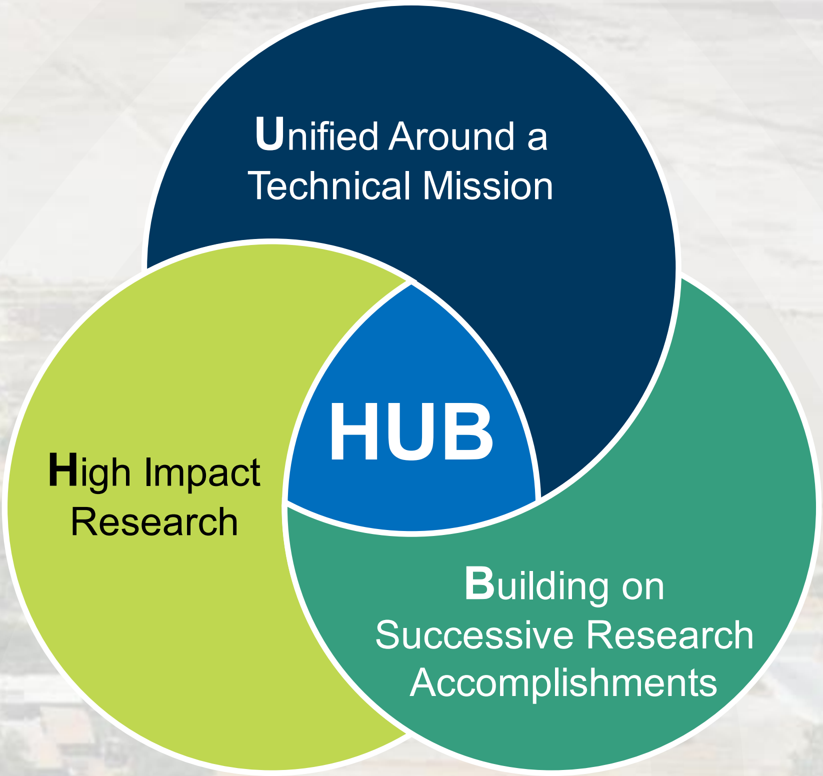
Climate change will be felt through the water cycle

Adaptation: Securing water supplies with non-traditional water sources & reuse

Mitigation: Reducing the cost and carbon intensity of advanced treatment

NAWI is an Energy Water Desalination HUB

- **H**igh impact research on water desalination, an area of critical national need
- **U**nified technical management across diverse teams with national labs, academia, industry
- **B**uilding on successful research, advancing promising technologies to higher TRLs



Unified Around a Technical Mission

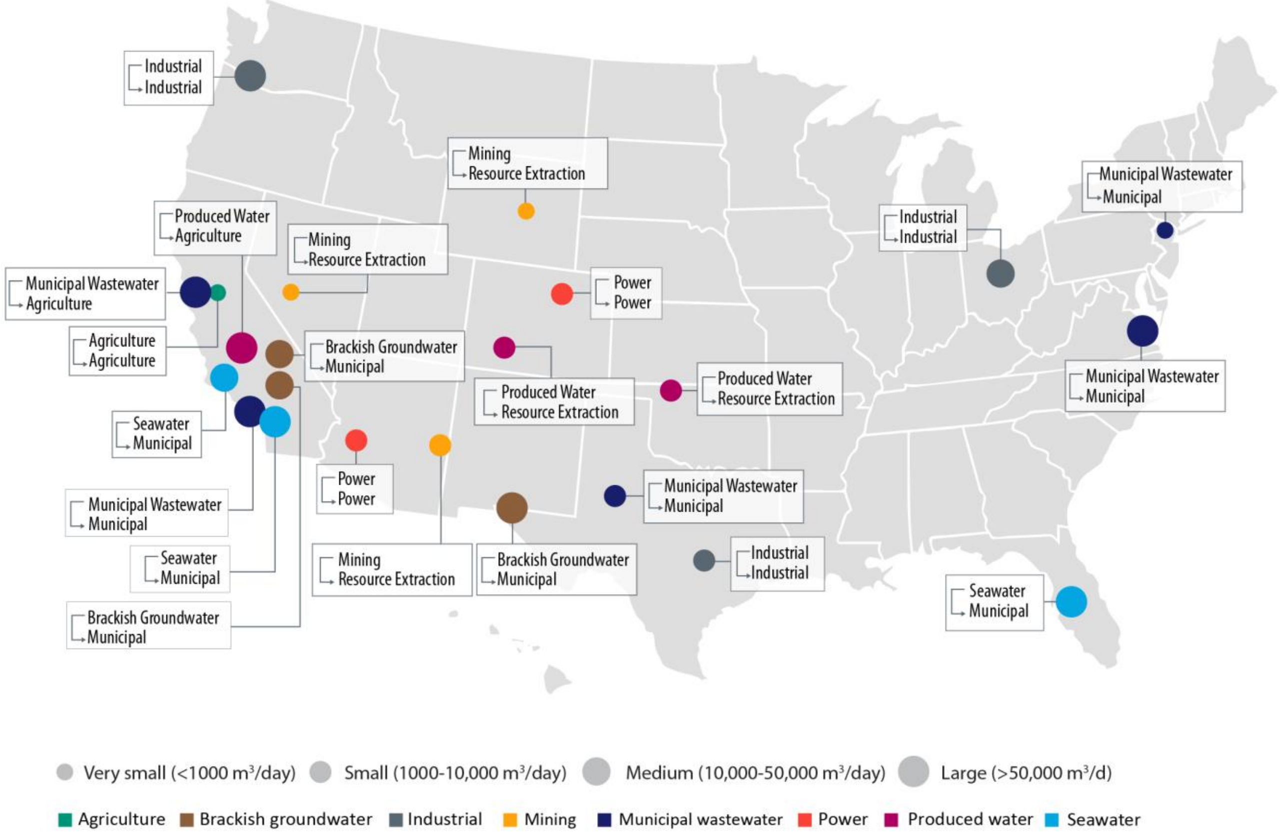
High Impact Research

Building on Successive Research Accomplishments

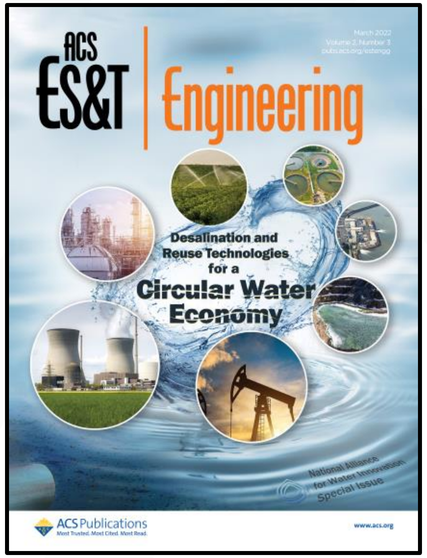
HUB

DE-FOA-0001905 – Energy Water Desalination Hub 2020-2025

High impact mission: Identified research priorities by baselining performance at U.S. facilities



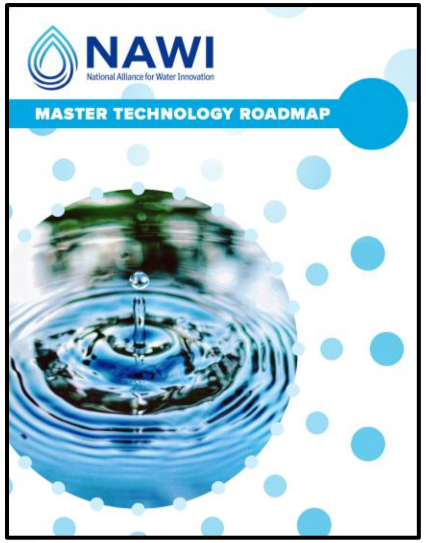
Labels list source water and end use for each case.


ACS ES&T Engineering

Desalination and Reuse Technologies for a Circular Water Economy

National Alliance for Water Innovation Special Issue

ACS Publications


NAWI
National Alliance for Water Innovation

MASTER TECHNOLOGY ROADMAP

8 Baseline Studies

6 Water User Roadmaps

1 Master Roadmap

https://www.nawihub.org/knowledge/roadmap-publication-series/

Secure water supply through energy efficient and cost-effective water desalination

- Desalination is a critical unit proces for tapping a diverse set of natural and wastewater sources non-traditional waters

- APRIME small-scale desalination and water reuse systems
    - Cut carbon/cost of water transpo
    - Enable cost reductions through modular manufactured systems
    - Reduce time to deployment & increase supply resiliency

Desalination for a Circular Water Economy

Non-Traditional Water Sources

Secure & Cost-Effective Water Supply

90% of non-traditional waters achieve ***pipe parity***

Our master roadmap provides a focused vision for the research program

Circular Water Economy	Autonomous Water	Precision Separations	Resilient Treatment	Intensified Brine Management	Modular and Manufacturable Systems	Electrification
C1: Quantifying the benefits of APRIME for distributed and centralized systems	A1: Uniform metadata schema for water treatment facilities	P1: Trace Contaminant Separation or Transformation	R1: Stabilizing process performance to variable feedwaters and operating conditions	I1: Thermodynamics and kinetics of inorganic scaling processes in ultra-high salinity waters	M1: Manufacturing platforms for tailored membranes and modules	E1: Treatment process electrification
	A2: Water treatment data library			I2: Experimentally validated computational models for optimizing heat and mass transfer	M2: Enhancing pretreatment kinetics through modular design	E2: Water and electricity grid coordination
	A3: Predictive algorithms for process control and fault detection			I3: Process and material innovations for concentrating high salinity waters		E3: Passive treatment systems
	A4: Extend capabilities of existing sensors			I4: Bulk constituent transformation or valorization		

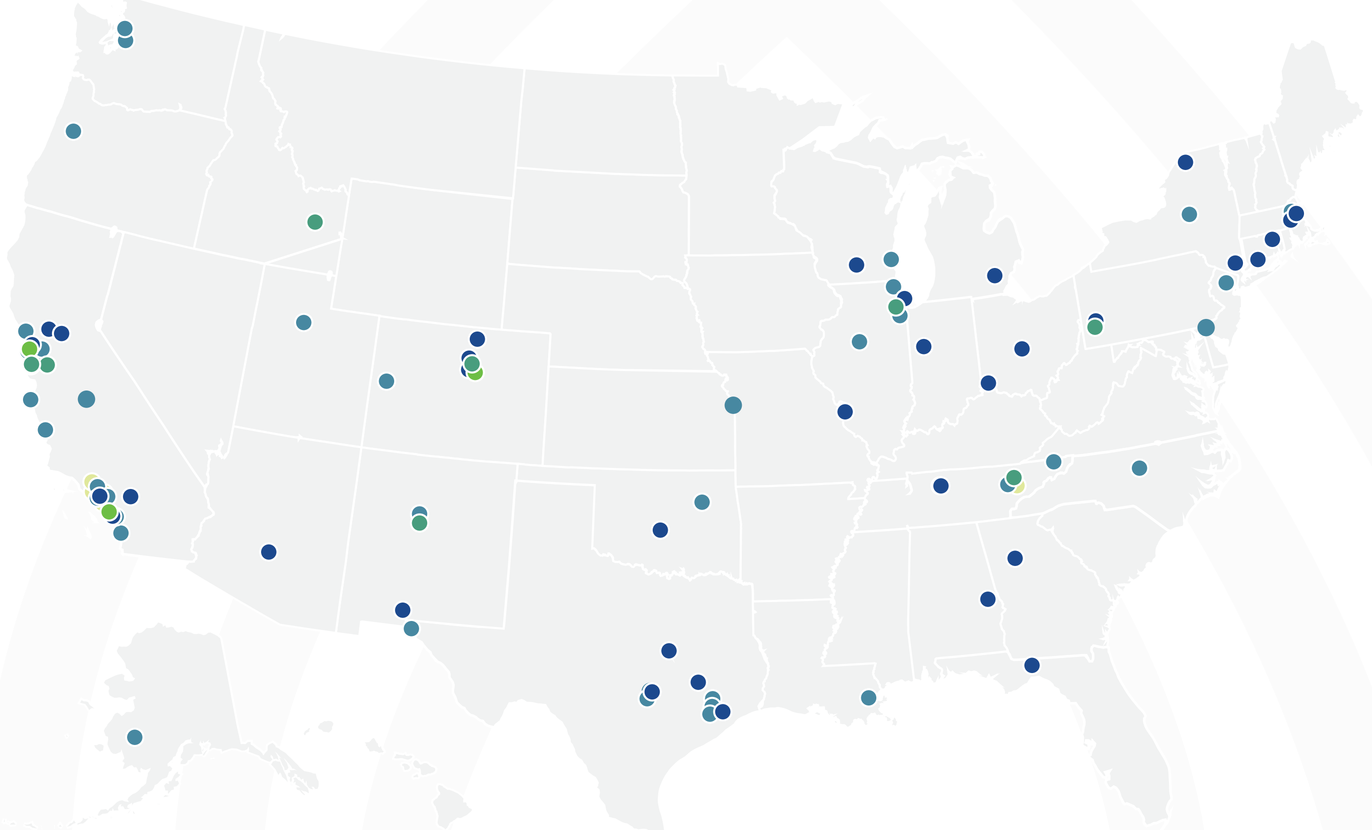
Unified technical management: Inclusive tiered structure


NAWI Research Consortium

11+ Nat Labs
40+ Universities
40+ Industry Partners

Research collaborations involving academic, industry and national lab partners

NAWI Research Consortium Members



University Members

- Arizona State University
- Auburn University
- Baylor University
- California State University, San Bernardino
- Carnegie Mellon University
- Clarkson University
- Colorado School of Mines
- Colorado State University
- Florida State University
- Franklin W. Olin College of Engineering, Inc.
- Georgia Institute of Technology/Georgia Tech Research Corporation
- Massachusetts Institute of Technology (MIT)
- New Mexico State University
- Ohio State University
- Purdue University
- Stanford University
- Texas A&M Engineering Experiment Station (TEES)
- The Board of Regents of the University of Wisconsin System
- The University of Texas at Austin
- University of California, Berkeley
- University of California, Davis
- University of California, Irvine
- University of California, Los Angeles
- University of Cincinnati
- University of Colorado Boulder
- University of Connecticut
- University of Illinois at Chicago
- University of Illinois Urbana-Champaign
- University of Michigan (Regents of the University of Michigan)
- University of Oklahoma (The Board of Regents of the University of Oklahoma)
- University of Southern California
- University of Texas at El Paso
- Vanderbilt University
- Washington University in St. Louis
- West Point
- William Marsh Rice University
- Yale University

Industry Members

- Active Membranes, LLC
- Black & Veatch
- CDM Smith (CDM Federal Programs Corporation)
- IDE Americas Inc.
- ReactWell, L.L.C.
- Rio Tinto Services Inc.
- Aqua Membranes Inc.
- BlueTech Research
- Brown and Caldwell
- CAP Water & Power International, Inc
- Carollo Engineers
- Cascade Technologies, Inc.
- Eastman Chemical Co.
- EPRI - Electric Power Research Institute
- EVUS, Inc.
- Flow-Tech Systems
- Fluid Technology Solutions, Inc.
- Freeport McMoRan - El Paso Refinery
- Glacier Technologies International Inc.
- Global Water Innovations, Inc.
- Greeley & Hansen LLC
- Hazen and Sawyer, D.P.C.
- HydroFLOW USA LLC
- Karl E. Longley
- Kevin Price Consultant
- KIT Professionals, Inc.
- M. Davis & Sons Inc.
- Magna Imperio Systems corp.
- Meridian Institute
- Modelon, Inc.
- NALA Systems
- NGL Energy Partners, LP
- Noria Water Technologies, Inc.
- NTS Innovations Inc
- OLI Systems, Inc.
- Square One Coating Systems, LLC
- Swenson Technology, Inc.
- Tetra Tech, Inc.
- tntAnalysis
- Trevi Systems, Inc.
- Trimeric Corporation
- Trussell Technologies, Inc.
- USG Corporation
- Vortex Engineering
- WaterTectonics
- Yokogawa Corporation of America
- ZwitterCo, Inc.

National Lab Members

- Argonne National Laboratory
- Idaho National Laboratory
- Lawrence Berkeley National Laboratory (LBNL)
- Lawrence Livermore National Laboratory (LLNL)
- National Energy Technology Laboratory (NETL)
- National Renewable Energy Laboratory (NREL)
- Oak Ridge National Laboratory (ORNL)
- Sandia National Laboratories
- SLAC National Accelerator Laboratory

Utility

- Knoxville Utilities Board
- Las Virgenes Municipal Water District
- The Metropolitan Water District of Southern California
- Orange County Water District
- Tennessee Valley Authority (TVA)
- West Basin Municipal Water District

Non-Profit

- Imagine H2O
- National Water Research Institute
- The Water Research Foundation (WRF)

NAWI

thru March 31, 2023

Unified technical management: Inclusive tiered structure

Broad, no-cost membership organization to encourage interaction, and foster collaboration

NAWI Alliance

330+ organizations

- Large Companies
- Small Companies
- Universities
- National Labs
- Federal Agencies
- State Agencies
- Water Utilities
- Non-Profit Orgs

NAWI Research Consortium

11+ Nat Labs
40+ Universities
40+Industry Partners

Research collaborations involving academic, industry and national lab partners

Alliance & Research Consortium Members

NAWI has created a community where researchers, high-impact research problems, and research sponsors can find each other

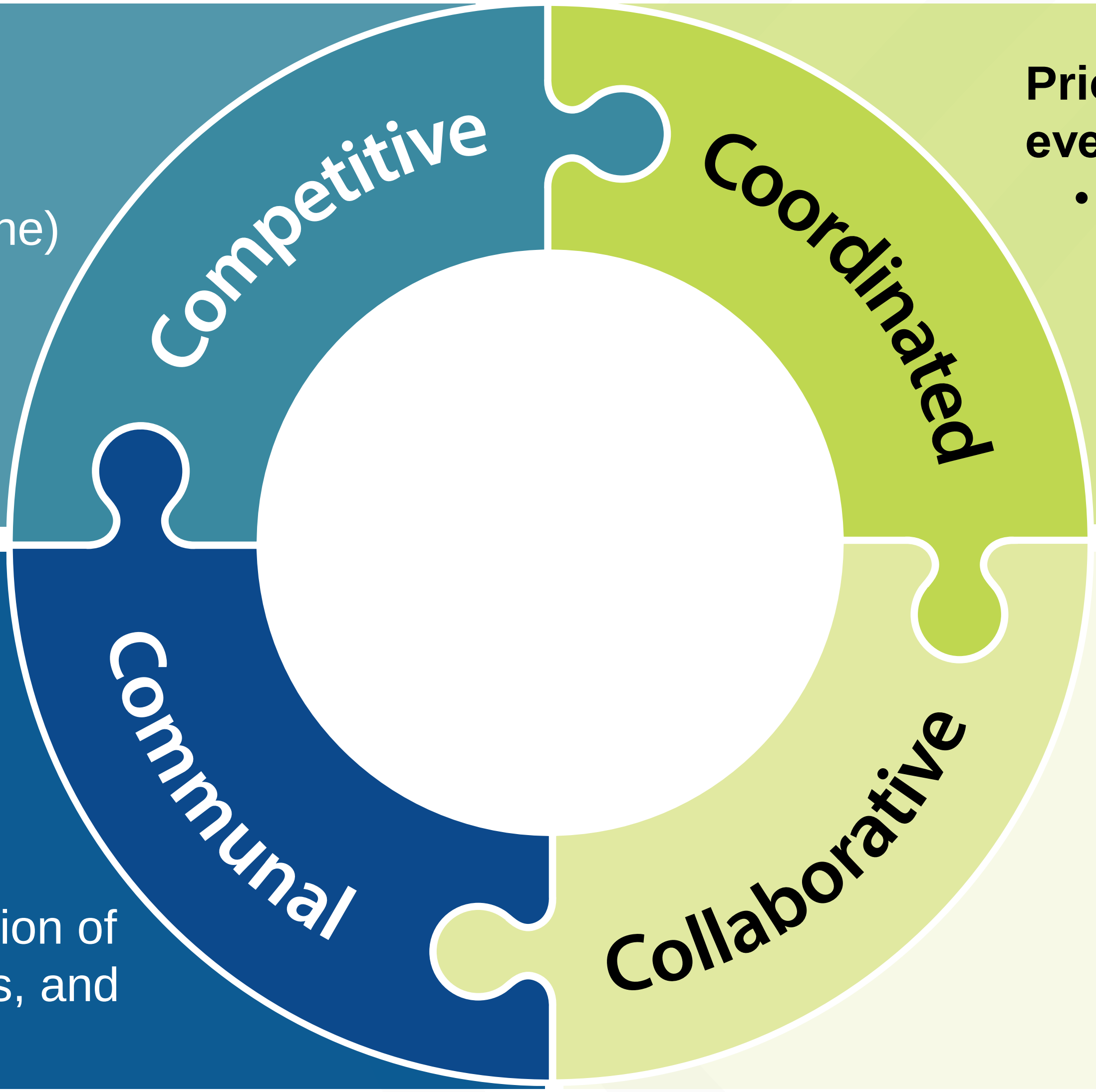
★ Research Consortium Members (102)

● Alliance Members (410)

NAWI

thru March 31, 2023

Building an impactful R&D portfolio: Characteristics of a NAWI research project



Every project is selected by rigorous technical merit review

- External funding opportunities (open to anyone)
- Internal funding opportunities (open to Research Consortium members)

Prior to project kick-off, every project negotiates…

- A detailed Statement of Program Objectives (SOPO) that defines tasks, milestones, Go/No-Go gates

Every project has…

- A Project Support Group
  - Alliance members who love the project and seek to be helpful
- A NAWI One-Pager
  - A public-facing description of the project, the partners, and PI contact info

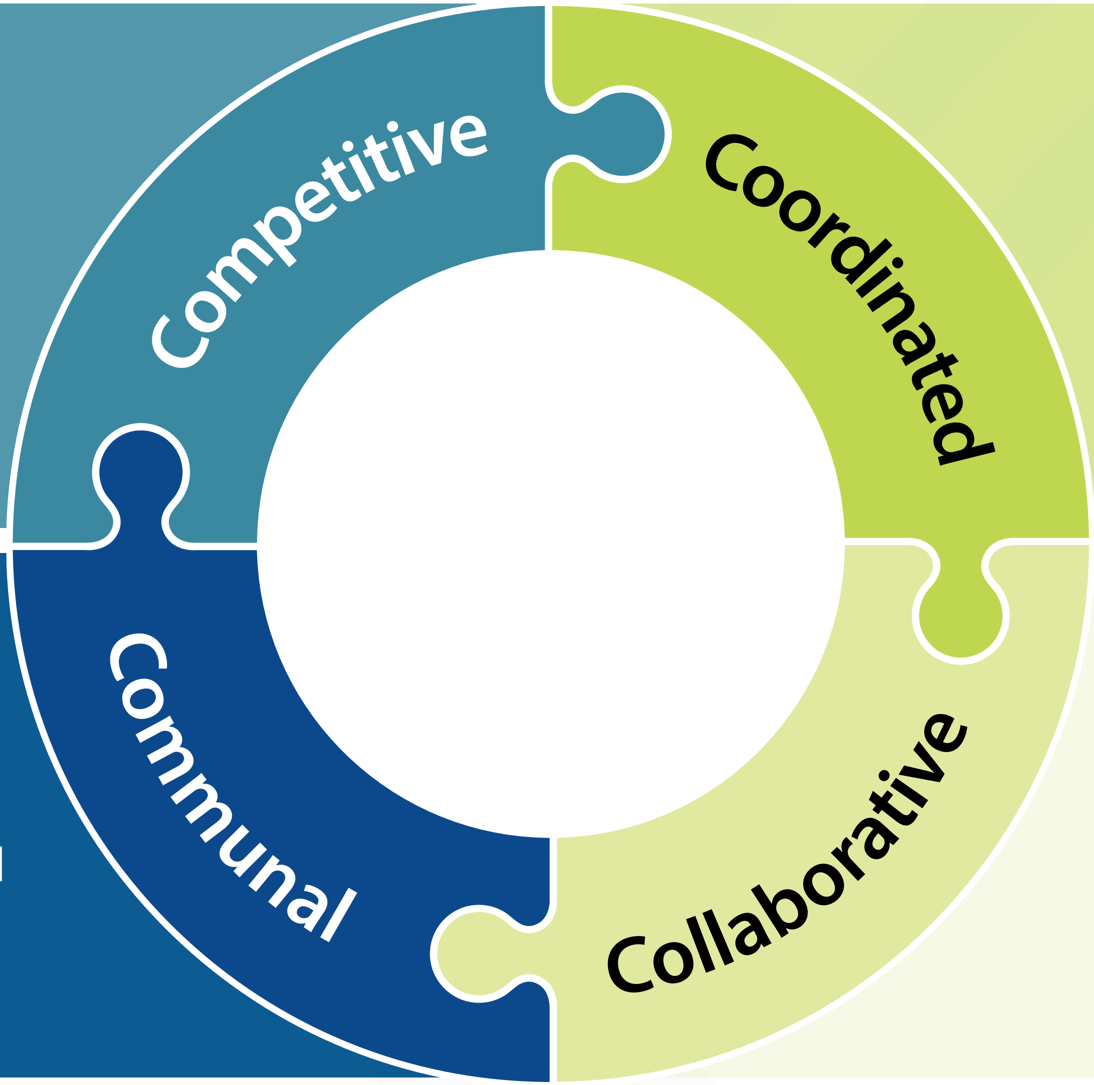
Ideally involving research performers from academia, industry and national labs

NAWI’s Funding Opportunity Track-record

Call Name	Number of Concept Papers	Number of Full Proposal	Number that Entered Negotiations
Year 1 Seedling	189	25	6
Year 1 RFP	157	19	6
Year 2 RFP	96	25	9
Year 2 Internal	43	24	16
Year 3 Pilot	56	14	11
Year 3 Internal	35	17	12
Total	**576**	**124**	**60**

Rigorous, merit-based evaluations, and high selectivity are foundational to NAWI’s project selection process

Characteristics of a NAWI Research Project



67% of projects competitively Selected

~10% funding rate

74% of total project $s

100% of projects address at least 1 Challenge area and at least 1 non-traditional water source

39% of projects have a Project support group

49% have a 1-pager written and posted

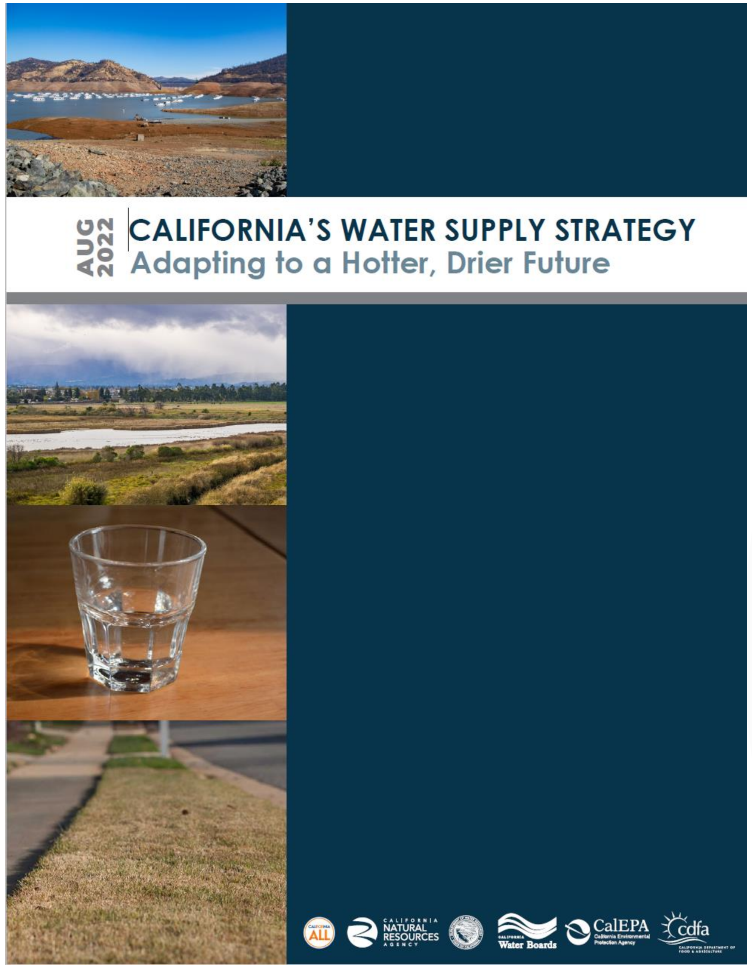
56% of projects involve a national lab, a university and an industry partner

40% involve 2 out of 3

14% involve 1 out of 3

NAWI’s Strategic Impact in the Water Sector

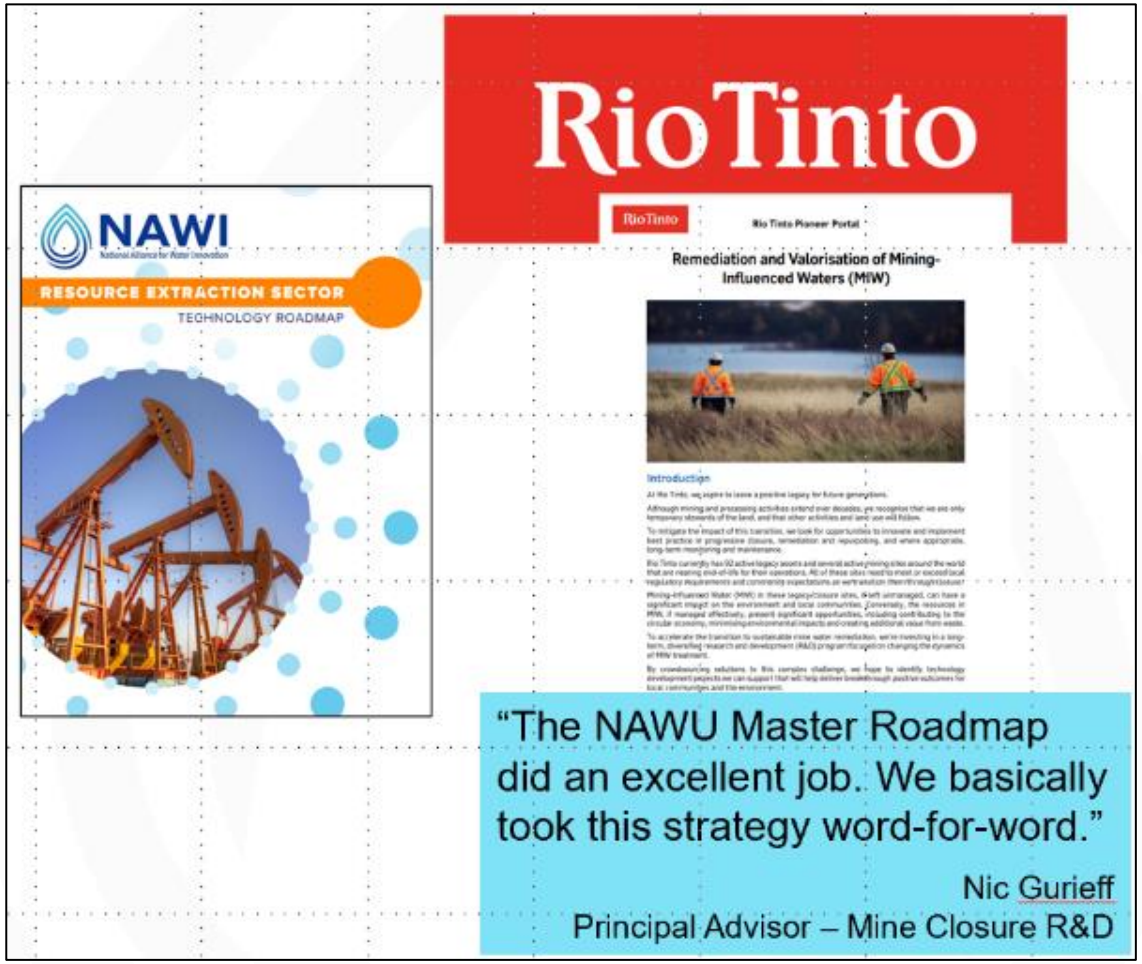
- **We are setting the national agenda for investments in water RD&D**



AUG 2022

CALIFORNIA’S WATER SUPPLY STRATEGY

Adapting to a Hotter, Drier Future



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RESOURCE EXTRACTION SECTOR

TECHNOLOGY ROADMAP

RioTinto

Rio Tinto Pioneer Portal

Remediation and Valorisation of Mining-Influenced Waters (MIW)

Introduction

> “The NAWU Master Roadmap did an excellent job. We basically took this strategy word-for-word.”
>
> Nic Gurieff
> Principal Advisor – Mine Closure R&D

NAWI’s Strategic Impact in the Water Sector

- We are setting the national agenda for investments in water RD&D
- **We are advancing the theory and practice of next generation desalination and reuse technologies**

SCIENCE ADVANCES | RESEARCH ARTICLE

ENGINEERING

Water transport in reverse osmosis membranes is governed by pore flow, not a solution-diffusion mechanism

Li Wang[1], Jinlong He[2], Mohammad Heiranian[1], Hanqing Fan[1], Lianfa Song[3], Ying Li[2], Menachem Elimelech[1]*

We performed nonequilibrium molecular dynamics (NEMD) simulations and solvent permeation experiments to unravel the mechanism of water transport in reverse osmosis (RO) membranes. The NEMD simulations reveal that water transport is driven by a pressure gradient within the membranes, not by a water concentration gradient, in marked contrast to the classic solution-diffusion model. We further show that water molecules travel as clusters through a network of pores that are transiently connected. Permeation experiments with water and organic solvents using polyamide and cellulose triacetate RO membranes showed that solvent permeance depends on the membrane pore size, kinetic diameter of solvent molecules, and solvent viscosity. This observation is not consistent with the solution-diffusion model, where permeance depends on the solvent solubility. Motivated by these observations, we demonstrate that the solution-friction model, in which transport is driven by a pressure gradient, can describe water and solvent transport in RO membranes.

INTRODUCTION

As the need to augment water supply grows in water-scarce regions of the world, desalination of saline waters such as seawater and brackish groundwater has become crucially important. Reverse osmosis (RO) is the dominant desalination technology, mainly due to its high energy efficiency and low operating costs compared to other desalination technologies (*1*, *2*). RO is also a central component in advanced municipal wastewater reuse, a growing technology for alleviating water scarcity in water-stressed regions (*3*, *4*).

Semipermeable desalination membranes—membranes that allow transport of water and reject salt and other solutes—lie at the heart of the RO technology (*1*, *5*). Because of their outstanding water permeability and water-salt selectivity, thin-film composite (TFC) polyamide membranes have been the gold standard for desalination since their invention more than four decades ago (*6*, *7*). TFC RO membranes are formed by interfacial polymerization of *m*-phenylenediamine and trimesoyl chloride on a porous substrate, resulting in a thin (100 to 150 nm) cross-linked selective layer (*8*, *9*).

The transport of water and salt through the active layer of RO membranes governs the membrane desalination performance. The widely accepted theory or mechanism to describe water and salt transport in RO membranes is the solution-diffusion (SD) model, which was proposed over half a century ago (*10*). This model assumes that the membrane active layer is a “dense” polymer phase, where water molecules “dissolve” into the membrane and then diffuse through the membrane down their concentration gradient (*11*, *12*). Another key assumption in the SD model is that the pressure across the membrane is constant (*13*, *14*). In the absence of a pressure gradient, this assumption implies that the chemical potential gradient of water within the membrane is only expressed as a concentration gradient, which is the driving force for water diffusion through the membrane (*11*, *12*). On the basis of this SD mechanism, water permeance (i.e., permeate water flux normalized by the applied pressure) depends on the "solubility" (partitioning) of water into the membrane and diffusivity of water molecules inside the membrane.

Despite the wide acceptance and use of the SD model, recent findings appear to challenge some of its key assumptions. Advances in electron microscopy revealed the presence of interconnected subnanometer cavities and tunnels in fully aromatic polyamide RO membranes (*15*–*19*), in contrast to the assumption in the SD model of dense, nonporous membranes. The average effective pore size or free volume of the polyamide layer of RO membranes has been quantified using positron annihilation lifetime spectroscopy. These studies report a bimodal pore size distribution with peaks around 4 to 5 Å and 7 to 9 Å (*20*, *21*), in general agreement with molecular dynamics (MD) simulations (*22*–*26*). A recent neutron spectroscopy study examined the water dynamics inside a polyamide RO membrane, revealing that water molecules transporting through membrane pores contribute substantially to the overall water flux (*27*). Recent MD simulations further suggest that water molecules transport in chains through connected "pockets" inside the polyamide membrane (*28*, *29*), with a length of continuous water percolation up to 96% of the membrane thickness (*30*). The existence of interconnected pores is also supported by recent experimental studies (*16*, *19*).

Collectively, the experimental and computational studies discussed above may suggest that water molecules transport in chains through interconnected channels inside RO membranes. These studies may therefore imply a pore-flow mechanism for water transport in RO membranes, rather than the widely accepted view of an SD mechanism. Although a recent study suggested that the SD model and the pore-flow model can be mathematically equivalent for swollen polymer membranes (*31*), the two models

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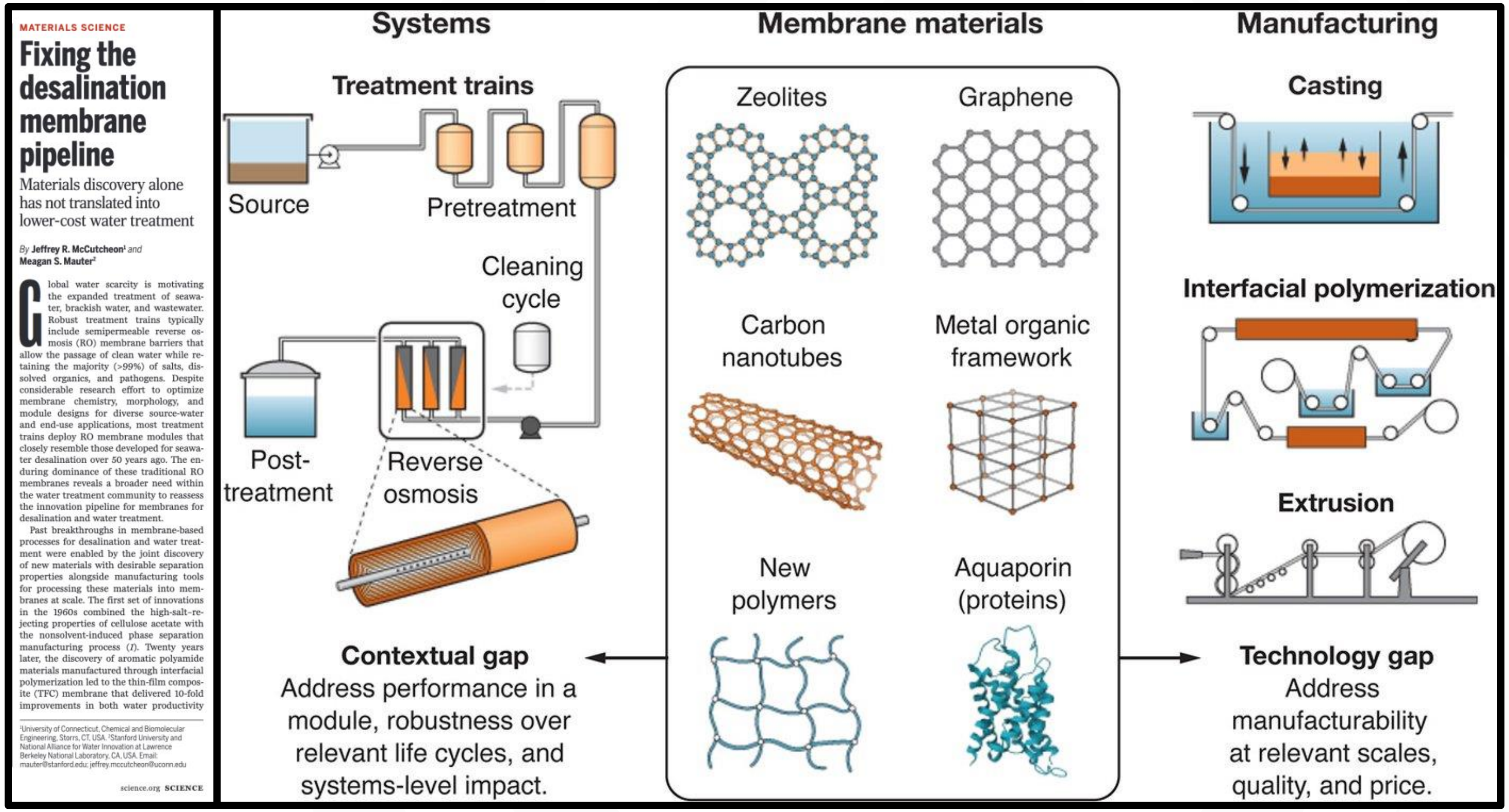
Wang *et al.*, *Sci. Adv.* **9**, eadf8488 (2023) 14 April 2023 **1 of 12**



MATERIALS SCIENCE

Fixing the desalination membrane pipeline

Materials discovery alone has not translated into lower-cost water treatment

By **Jeffrey R. McCutcheon**[1] and **Meagan S. Mauter**[2]

Global water scarcity is motivating the expanded treatment of seawater, brackish water, and wastewater. Robust treatment trains typically include semipermeable reverse osmosis (RO) membrane barriers that allow the passage of clean water while retaining the majority (>99%) of salts, dissolved organics, and pathogens. Despite considerable research effort to optimize membrane chemistry, morphology, and module designs for diverse source-water and end-use applications, most treatment trains deploy RO membrane modules that closely resemble those developed for seawater desalination over 50 years ago. The enduring dominance of these traditional RO membranes reveals a broader need within the water treatment community to reassess the innovation pipeline for membranes for desalination and water treatment.

Past breakthroughs in membrane-based processes for desalination and water treatment were enabled by the joint discovery of new materials with desirable separation properties alongside manufacturing tools for processing these materials into membranes at scale. The first set of innovations in the 1960s combined the high-salt-rejecting properties of cellulose acetate with the nonsolvent-induced phase separation manufacturing process (*1*). Twenty years later, the discovery of aromatic polyamide materials manufactured through interfacial polymerization led to the thin-film composite (TFC) membrane that delivered 10-fold improvements in both water productivity

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Contextual gap
Address performance in a module, robustness over relevant life cycles, and systems-level impact.

Technology gap
Address manufacturability at relevant scales, quality, and price.

NAWI’s Strategic Impact in the Water Sector

- NAWI is setting the national agenda for investments in water RD&D
- NAWI R&D is advancing the theory and practice of next generation desalination and reuse technologies
- **NAWI pilots are addressing place-based challenges with large carbon and cost implications**

For one historically Black California town, a century of water access denied

Now Allensworth is coming up with creative ways to tap sustainable, clean drinking water supplies, creating a potential model for others.

Media partner
The California Report

Scaling from the lab to the field

Questions?