"Nanotechnology-Enabled Water Treatment (NEWT) Engineering Research Center"

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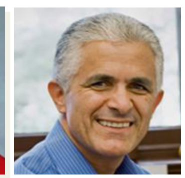
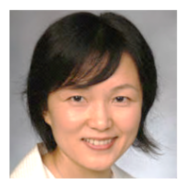
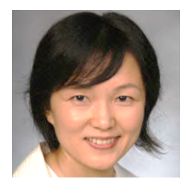
Sugar Land, TX
November 17, 2015

NEWT Leadership Team

Director		Pedro Alvarez	Environmental Nanotechnology & Biotechnology
Management		Paul Westerhoff	Water Systems
Diversity		Roland Smith	Sociology
Thrust 1		Mike Wong	Nano-Catalysis
Thrust 2		Naomi Halas	Nano-Photonics
Thrust 3		Meny Elimelech	Membrane Processes
Testbeds		Paul W.	Advanced Treatment
Sustainability and safety		Julie Zimmerman	Green Engineering
Education		Rebecca Richards-K	Beyond Traditional Borders
Innovation		Brad Burke	Managing Director

Thrust 1	Co-Lead		Dino Villagran	Physical & Inorganic Chemistry
Thrust 2	Co-Lead		Mary Laura Lind	Eng. Matter, Transport & Energy
Thrust 3	Co-Lead		Qilin Li	Advanced Treatment
Testbeds	Co-Leads		Qilin Li	Advanced Treatment
Sustainability and safety	Co-Leads		Jorge Gardea-T	Environ. Chemistry
Education	Co-Lead		Carolyn Nichol	K-12 Education

What is a NSF/ERC?

- ERCs operate at the **interface between** the **discovery**-driven culture of science and the **innovation**-driven culture of engineering.

- They provide a **venue where industry can work with faculty and students on resolving long-range challenges**, producing the knowledge needed for steady advances in technology and their **speedy transition to the marketplace**.

Why We Need a National Research Center

- Attract the brightest minds/ students to focus on systems-level solutions to water security
- Engage and synergize industry and other partners to accelerate commercialization of nano-enabled solutions

http://www.ngobox.org/wp-content/uploads/2013/08/water-security.jpg

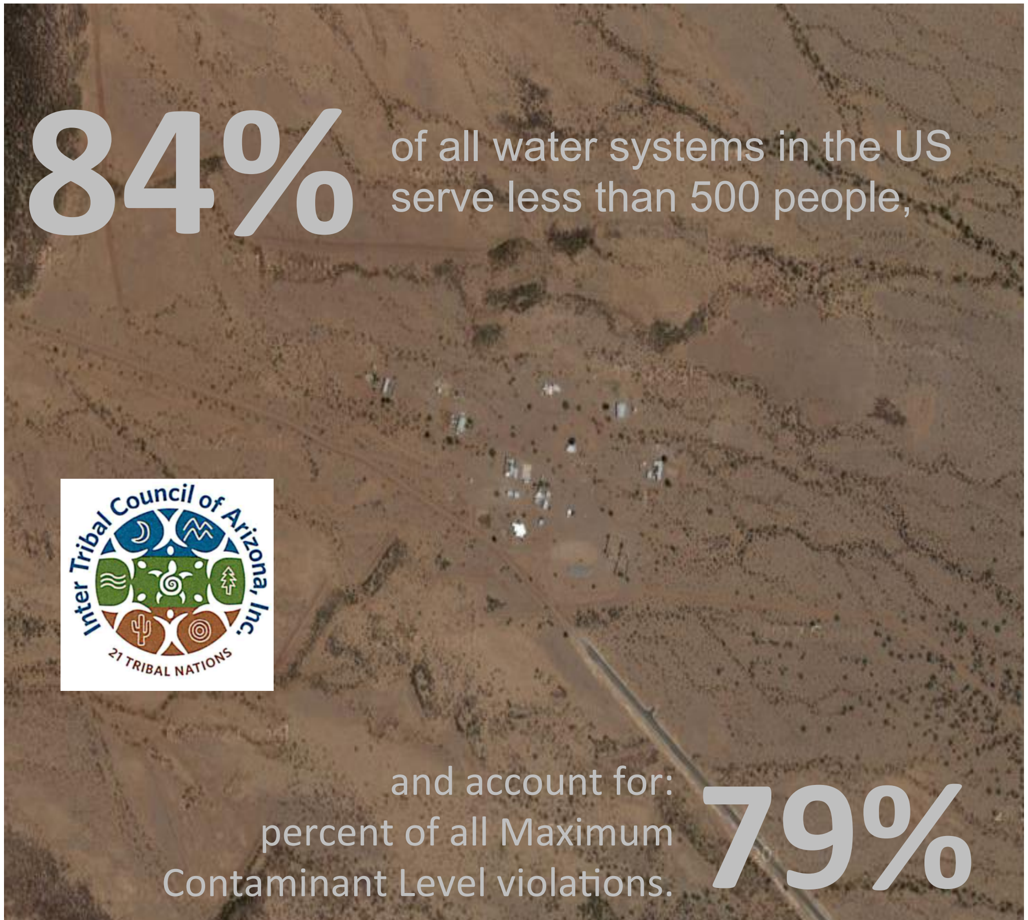
- Collaborate with other NSF centers, hubs, and related investments (sustainability, advanced materials, solar energy, water-energy-food nexus)

4 NanoSystems ERCs (17 active ERCs)

- Translational Applications of Nanoscale Multiferroic Systems (TANMS)
- Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT)
- Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)
- **Nanotechnology Enabled Water Treatment Systems (NEWT)**

NEWT VISION

Enable access to treated water almost anywhere in the world, by developing transformative and off-grid modular treatment systems empowered by nanotechnology that protect human lives and support sustainable development.



3-5 million gallons of water needed to develop each well

Credit: Alfred Eustes, Colorado School of Mines & CU NSF/SRN on AirWaterGas

>40 million US Residents are not connected to community water systems

Point-of-use Treatment Systems are a multi-billion $ market

Humanitarian Engineering and Solving Water-Energy Challenges is a MAJOR draw for top science and engineering students

Focus on Two Applications

- Off-grid humanitarian, emergency-response and rural **drinking water** treatment systems

https://www.globalgiving.co.uk/projects/clean-water-for-peru/updates/

- Industrial **wastewater reuse** in remote sites (e.g., oil and gas fields, offshore platforms)

http://switchboard.nrdc.org/blogs/rhammer/fracking-2.jpg

State-of-the-Art

- Current POU drinking water supply systems are limited to fresh water and few target contaminants; RO has low water recovery; require frequent replacement
- Current energy ww treatment systems use diesel generators, are highly energy intensive, produce large brine stream, and often over treat.
- Scarce nano-based technologies

www.crystalclearsuppy.com

www.visbegroup.com

Overarching Goals

1. Conduct high-risk/high-reward research that expands fundamental knowledge and the limits of water technologies

2. Deploy transformative, decentralized water treatment systems

3. Create centralized testbed and training facilities

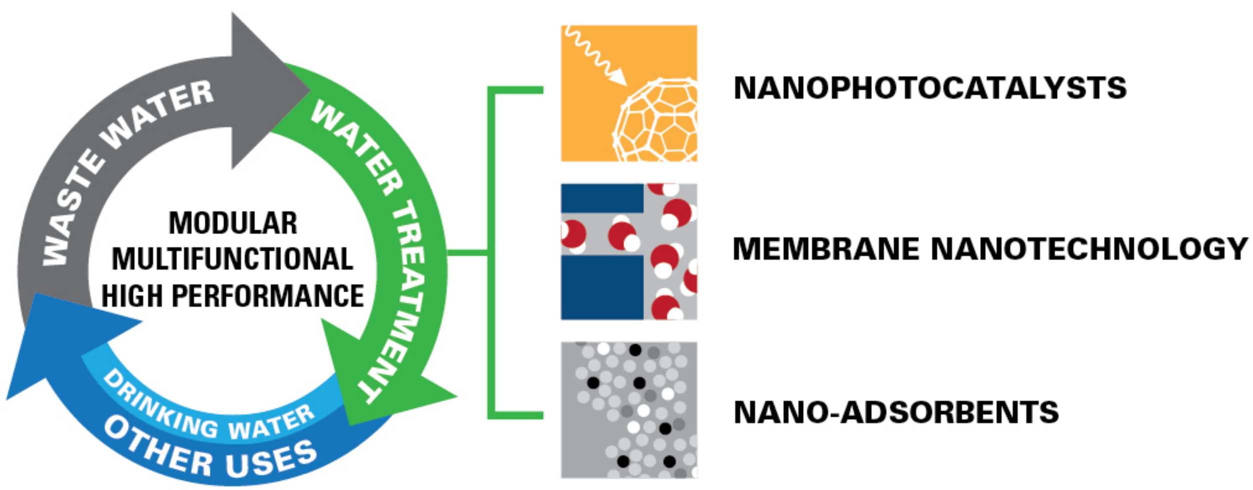
4. Inspire and train the next-generation, diverse, globally-competitive workforce that enables sustainable development

Why Nano?

Leap-frogging opportunities to:

- Develop small, high-performance multifunctional materials & systems that are easy to deploy, can tap unconventional water sources, and reduce the cost of remote water treatment

- Transform predominantly chemical treatment processes into modular and more efficient catalytic and physical processes that exploit the solar spectrum and generate less waste



Many People Doing Nano-For-Water.... So - why do we need an Engineering Research Center?

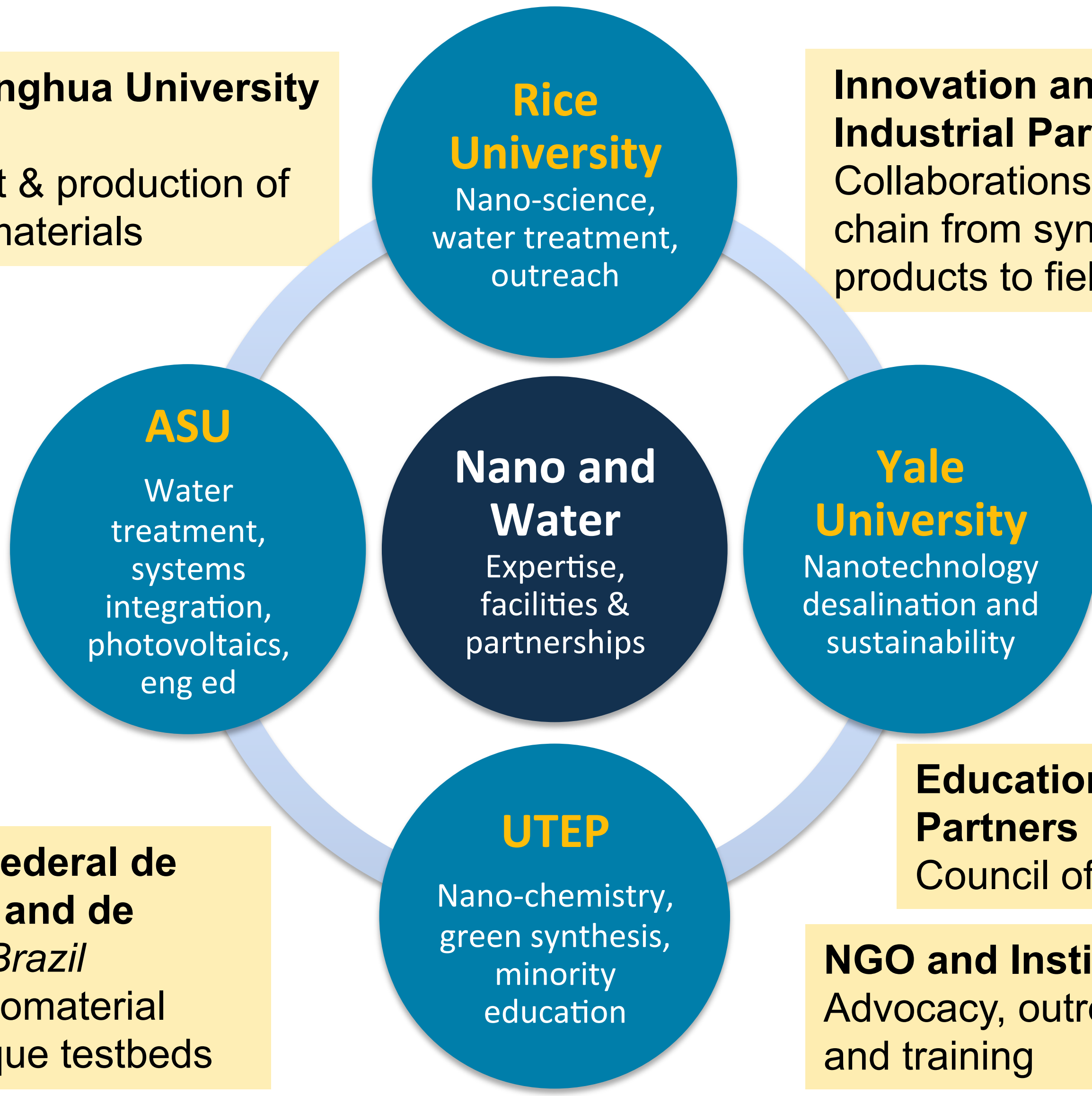
Help recognize contributions everyone is making
Provide some national organization & leadership
Facilitate National Sanitation Foundation standards
Facilitate safety standards
Organize workshops
Develop platforms for scale-up of nano-systems
REU/RET/REV increases pipeline & awareness
Organize & show possibilities to industry
Developing integrated "systems"
Considering nano-manufacturing of water systems

Institutional Configuration

A Collaboration for Success

Nankai and Tsinghua University
China
Co-development & production of multifunctional materials

Innovation and Industrial Partners
Collaborations across the value chain from synthesis and products to field operations

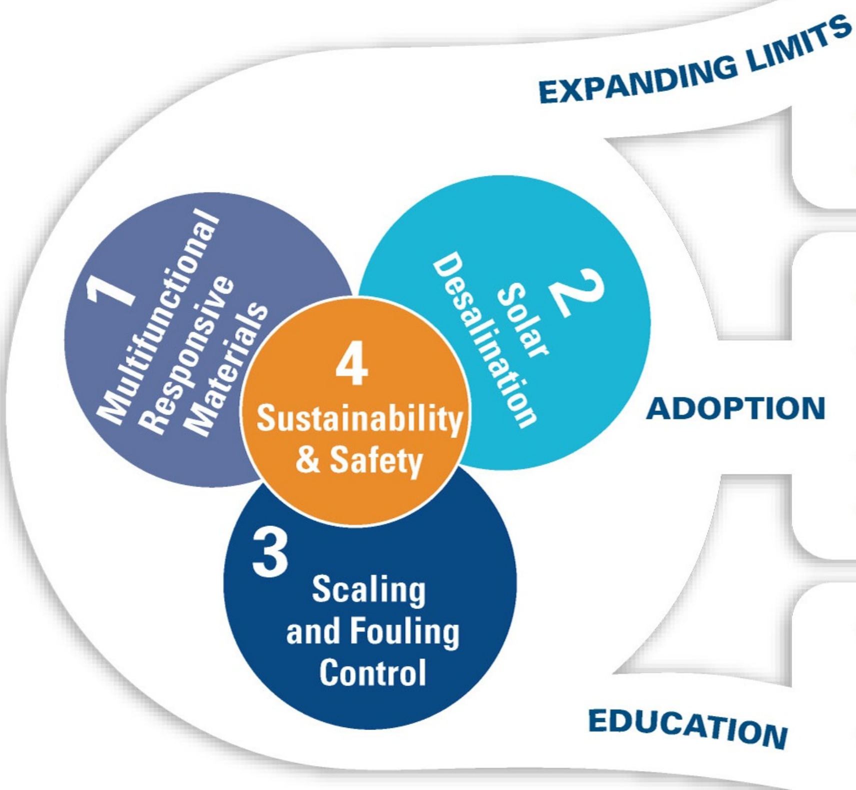


Educational and Outreach Partners RETs, Inter-Tribal Council of AZ

Universidade Federal de Santa Catarina and de Minas Gerais *Brazil*
Large-scale nanomaterial synthesis & unique testbeds

NGO and Institutional Partners
Advocacy, outreach, operations and training

Operational Vision & Outcomes



APPLICATIONS AND OUTCOMES

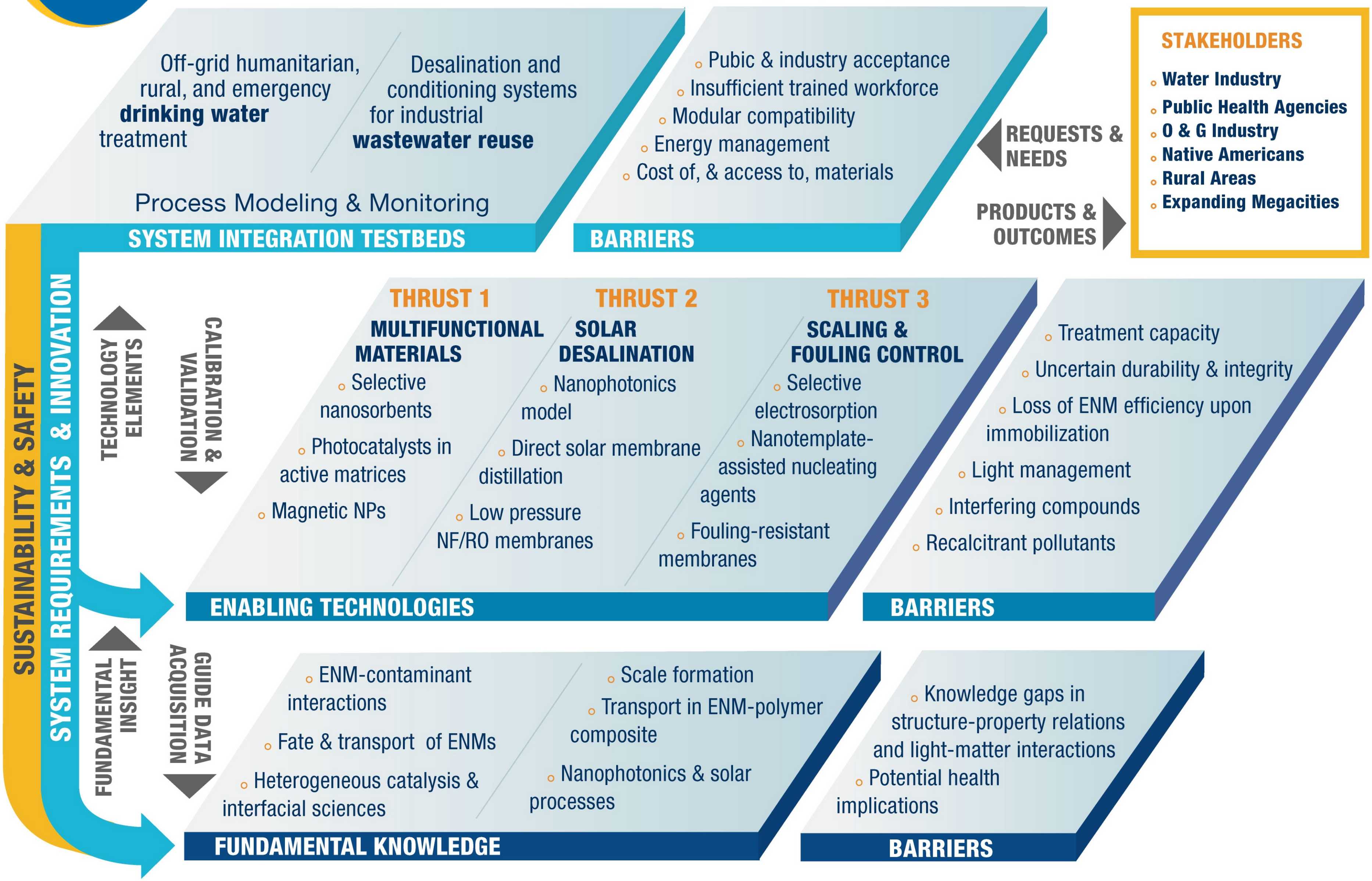
- Simple operation, low cost, humanitaran water supply (higher efficiency, lower energy requirements)
- Emergency water supply for disaster recovery
- Tailored water treatment in O&G fields

- Global health through safer water
- Renewable energy for water treatment and desalination
- Revitalization of water infrastructure
- O&G recovery with lower environmental impacts

- Globally competitive technology innovators and entrepreneurs
- Enhanced competitiveness of U.S. industries in the emerging markets of global health and water-energy nexus management and treatment

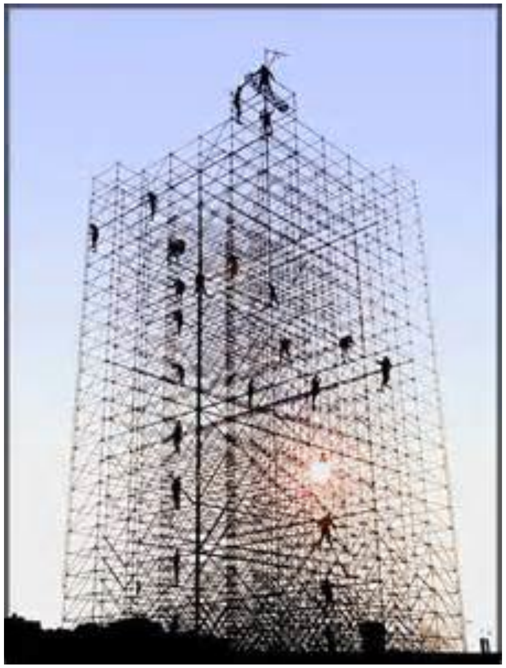
BASIC SCIENCE AND DISCOVERY ▶ **TECHNOLOGICAL INNOVATION** ▶ **COMMERCIALIZATION AND ECONOMIC DEVELOPMENT**

Top-Down Strategic Plan



Over Arching Science Questions

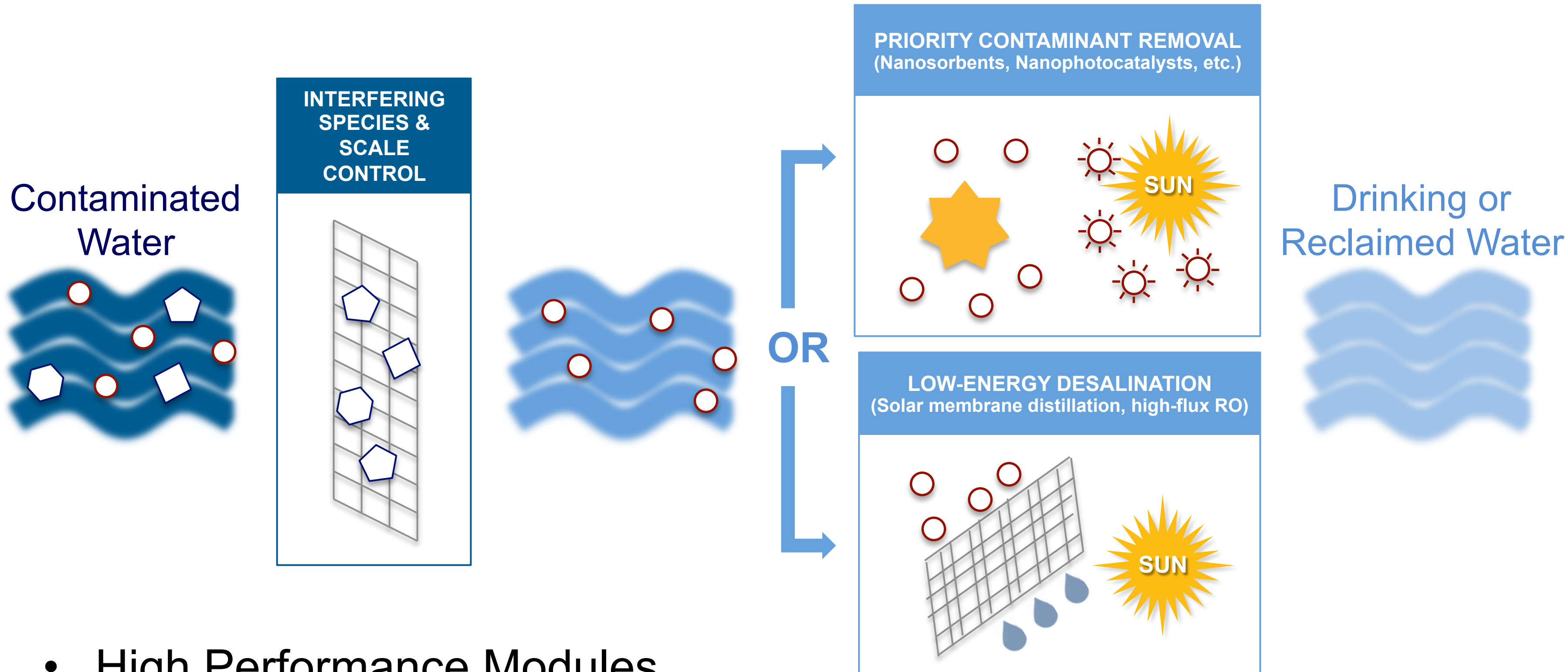
- How can we use novel nano-properties for water purification?
- How can nano-materials be embedded into scaffolding without loosing their functionality?



- What safety concerns exist around nano-enabled water technologies?

Modular Treatment Systems

Match treated water quality to intended use



- High Performance Modules
- Lower Chemical Consumption
- Lower Electrical Energy Requirements
- Less Waste Residuals
- Flexible and Adaptive to Varying Source Waters

Research Challenges & *Opportunities*

Thrust 1: Multifunctional ENMs

- **Selectivity**
- **Scalability**
- *Superior nanosorbents with option for magnetic separation*
- *Advanced, selective (photo)catalysts*

Thrust 2: Solar-Thermal Processes

- **Light penetration and heat transfer**
- **Nanoparticle immobilization without loss of efficiency**
- *Low-energy desalination*
- *High-flux, low-pressure RO membranes*

Thrust 3: Scaling and Fouling Control

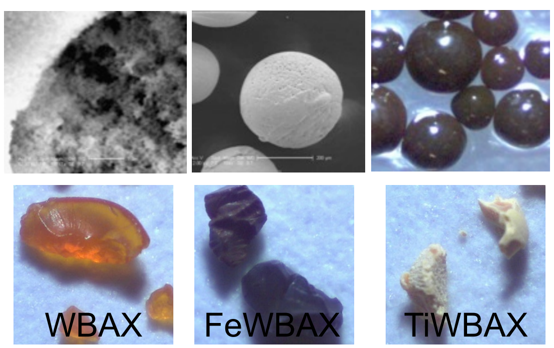
- **Control of nucleation of scaling elements**
- **Membrane functionalization without adverse effects**
- *Effective pre-treatment to prevent scaling and fouling*
- *Multifunctional membranes*

Unique NM Properties Being Employed

- Plasmonic Resonance – Thermal
- Photonic – ROS Production
- High, Selective & Mutlifunctional Sorption
- Magnetic
- Electrically Conductive
- Controlled size separation

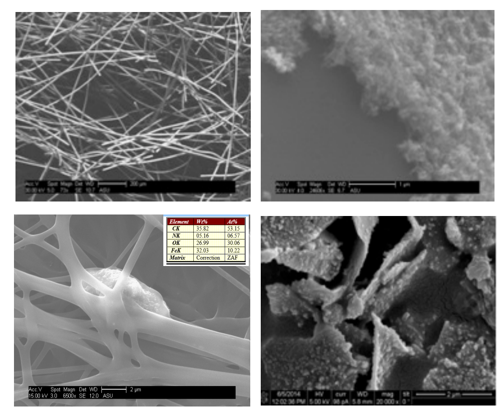
1.1. Multifunctional ENM Sorbents

Develop methods to incorporate nanosized adsorbent materials into macroscopic structures like fibers, carbon blocks, and ion-exchange beads



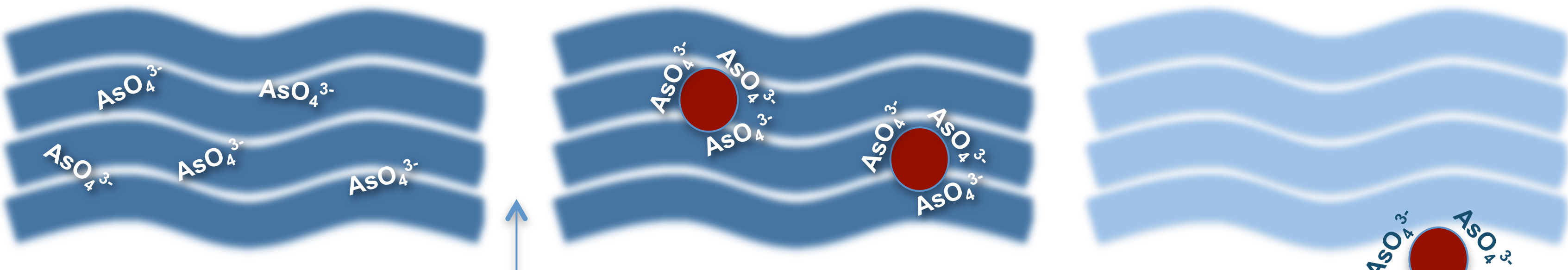
eSpring® POU system by Amway: example of how nanotechnology will be integrated into macroscale device

Design nanoparticles, nanofibers, and nanosheets that selectively adsorb oxoanions



1.2. Multifunctional Magnetic ENMs

Example: Arsenic removal under flow | **Contaminant specific interaction** | **Magnetic capture**



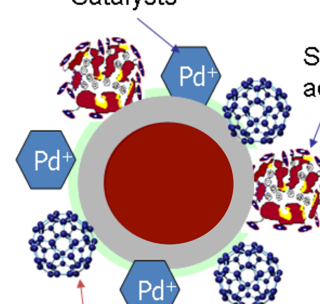
Superparamagnetic ENMs

Arsenate binds to Fe_3O_4 nanoparticles

Low-field magnet traps nanoparticles

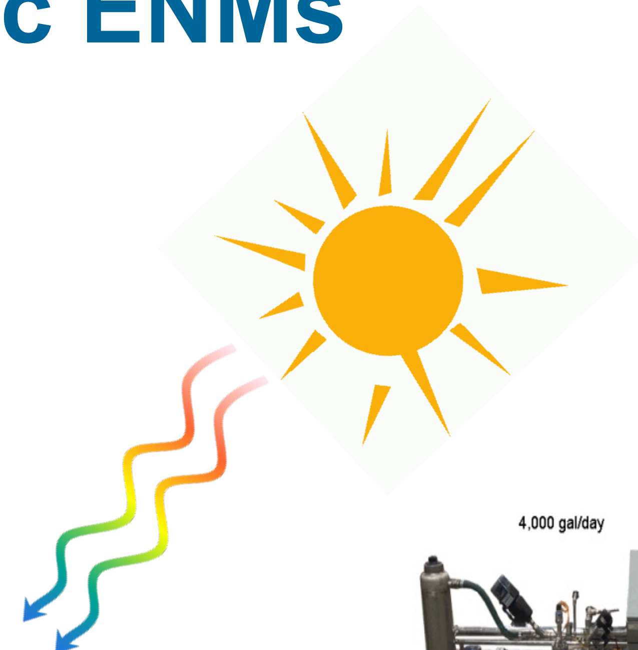
New reactor design, operational approach

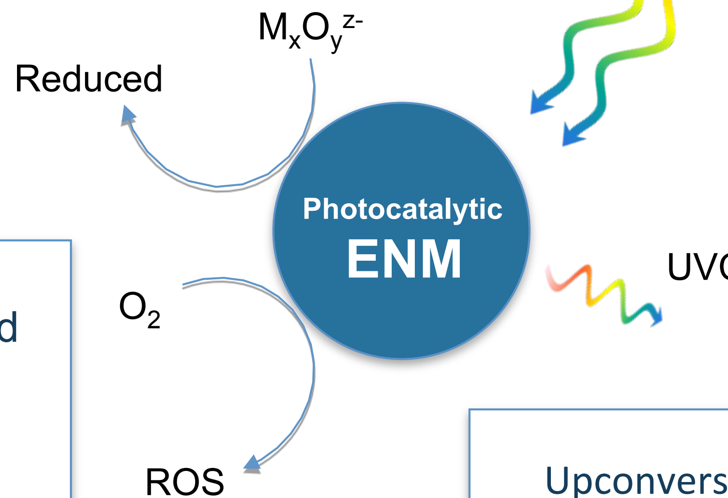
Can be used to support photocatalytic ENMs, adsorbent ENMs



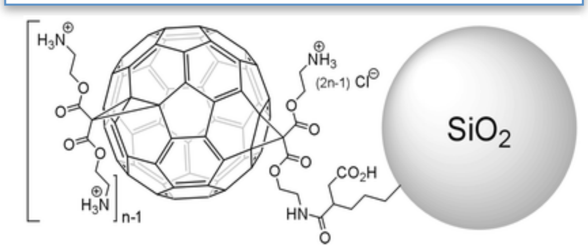
1.3. Photocatalytic ENMs

New classes of semiconductor-metal composite photocatalysts that reduce oxo-anions





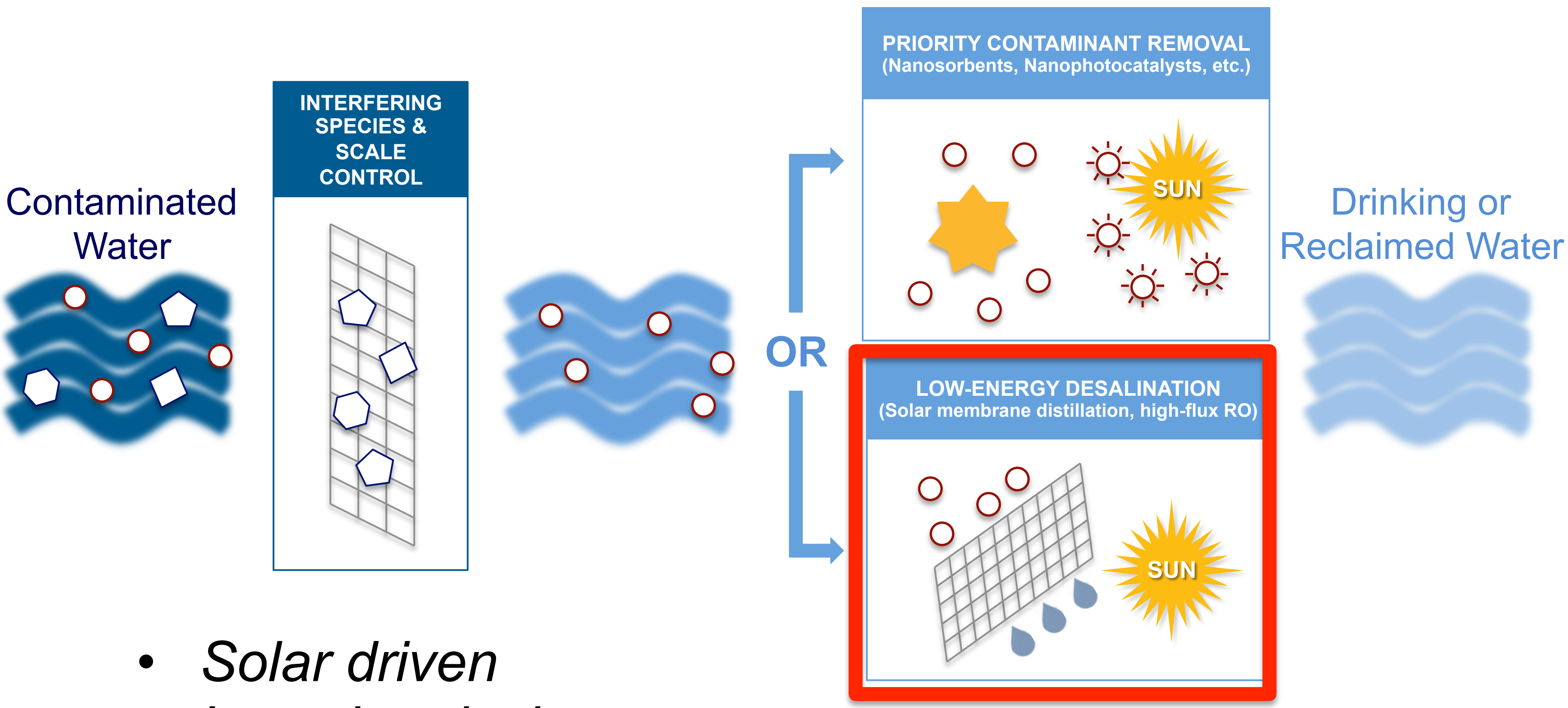
Organic (fullerene)-based photocatalysts for organics oxidation and pathogen inactivation



Upconversion photoluminescence ENMs that absorb lower-energy photons and emit higher-energy photons to effect disinfection

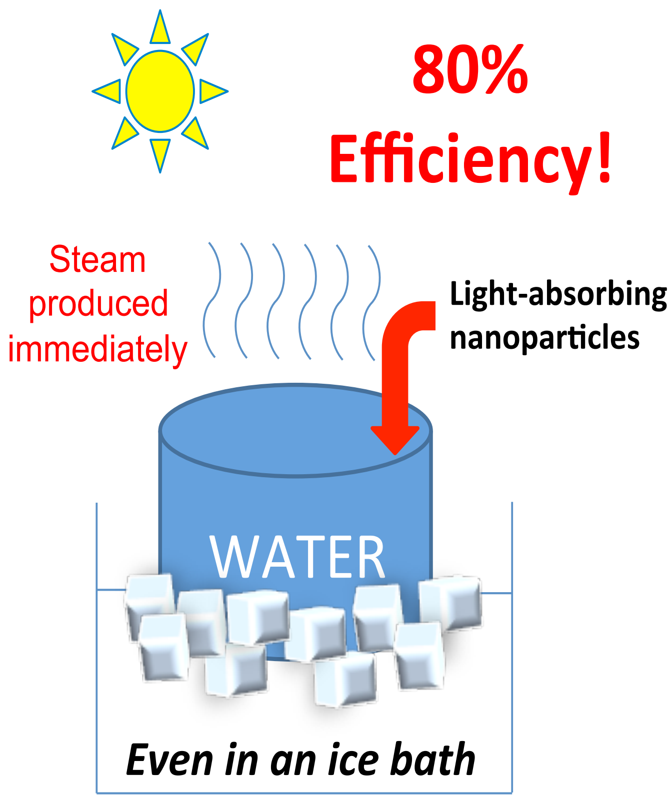
Objectives of ERC and Thrust 2:

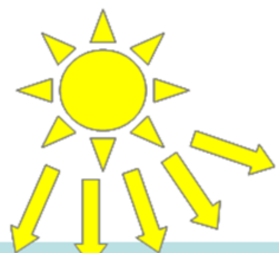
Solar Desalination by Nanophotonics-Enhanced Membrane Distillation and Low-Pressure Reverse Osmosis



- *Solar driven*
- *Low chemical usage*
- *Low maintenance*
- *Low brine volume*
- *Low capital cost*

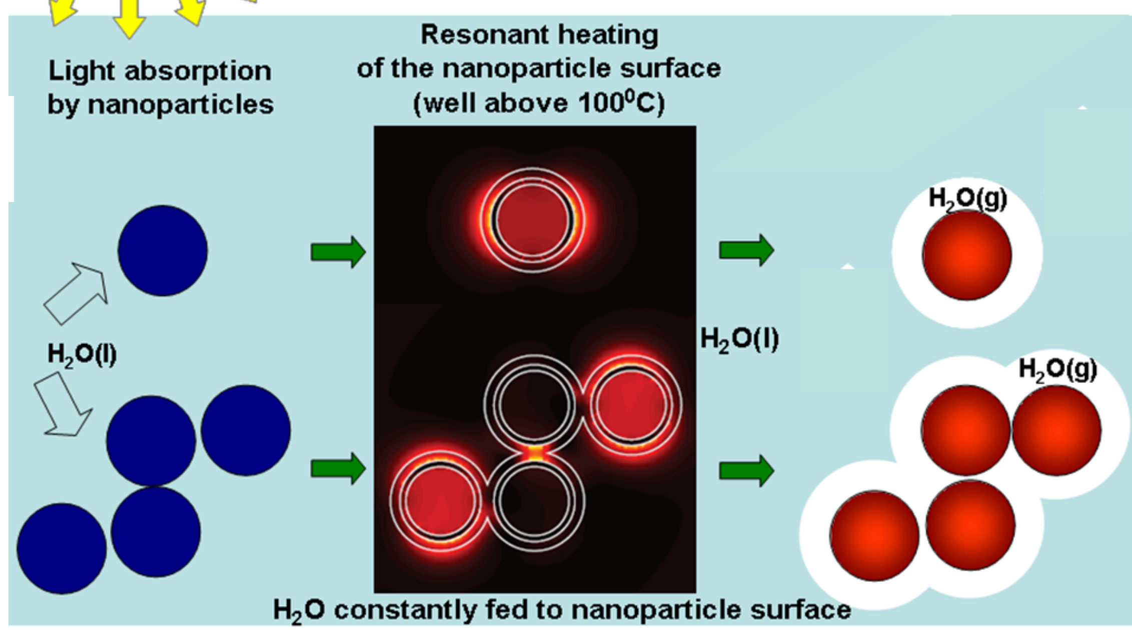
2.1 Photonics of Nanoparticles for Solar-Thermal Applications





Solar Steam Generation
enabled by submicron particles

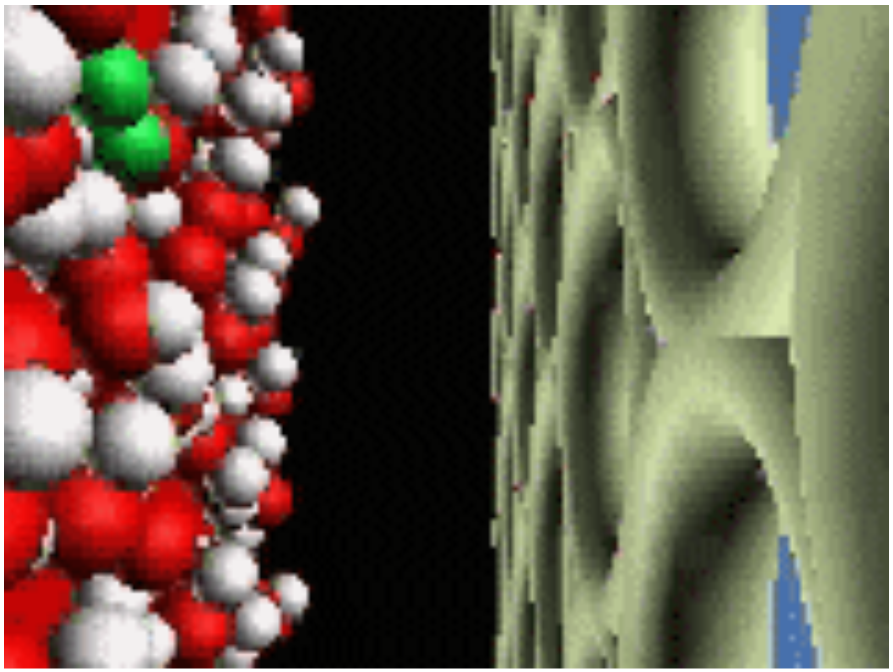
Oara Neumann, A. S. Urban, J. Day, S. Lal, P. Nordlander, and NJH, "Solar Vapor Generation enabled by nanoparticles", *ACS Nano* 7, 42-49 (2013).

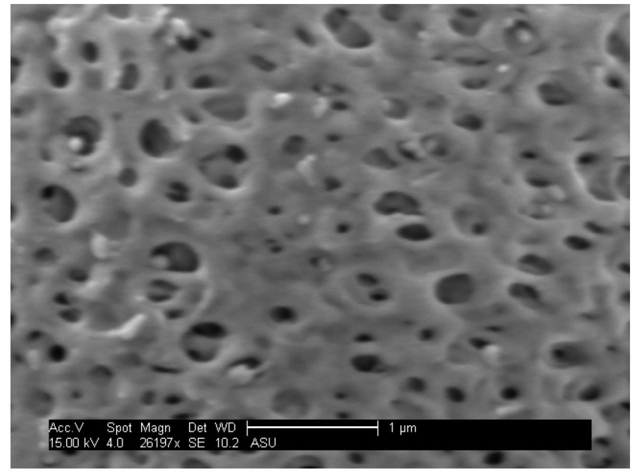


Light localization by multiple scattering confines solar energy, enabling high efficiency heat transfe (Hogan et al., *Nano Lett.* **2014**, *14*, 4640-4645)

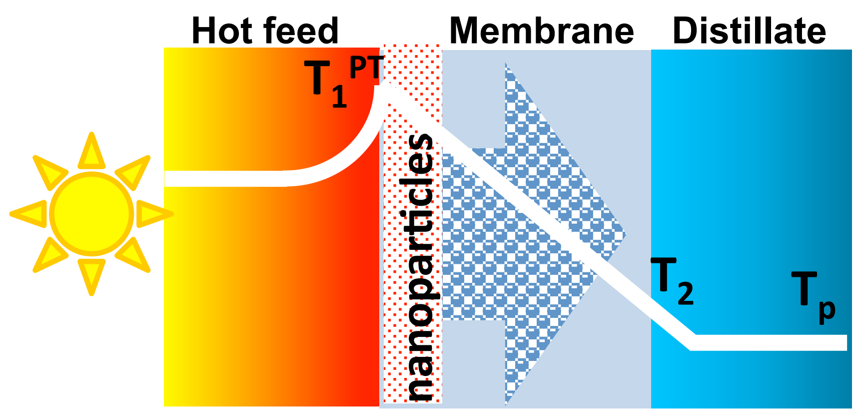
2.2 Reactors for Enhancing Membrane Distillation

www.desalination.biz





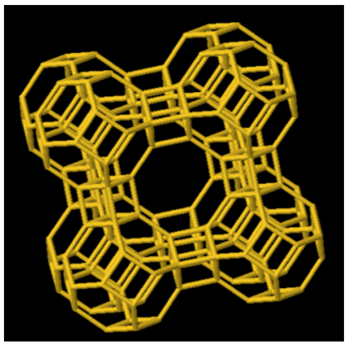
Photothermal MD



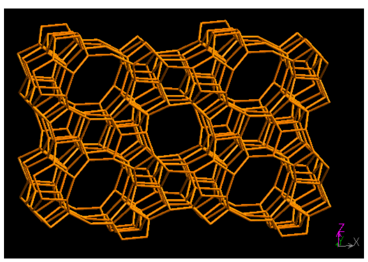
Higher ΔT→ increased efficiencies!

2.3 Mixed Matrix Membranes with Molecular Sieves for Low Pressure RO

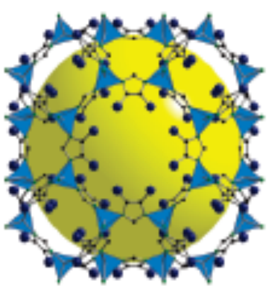
Molecular sieve nanoparticles



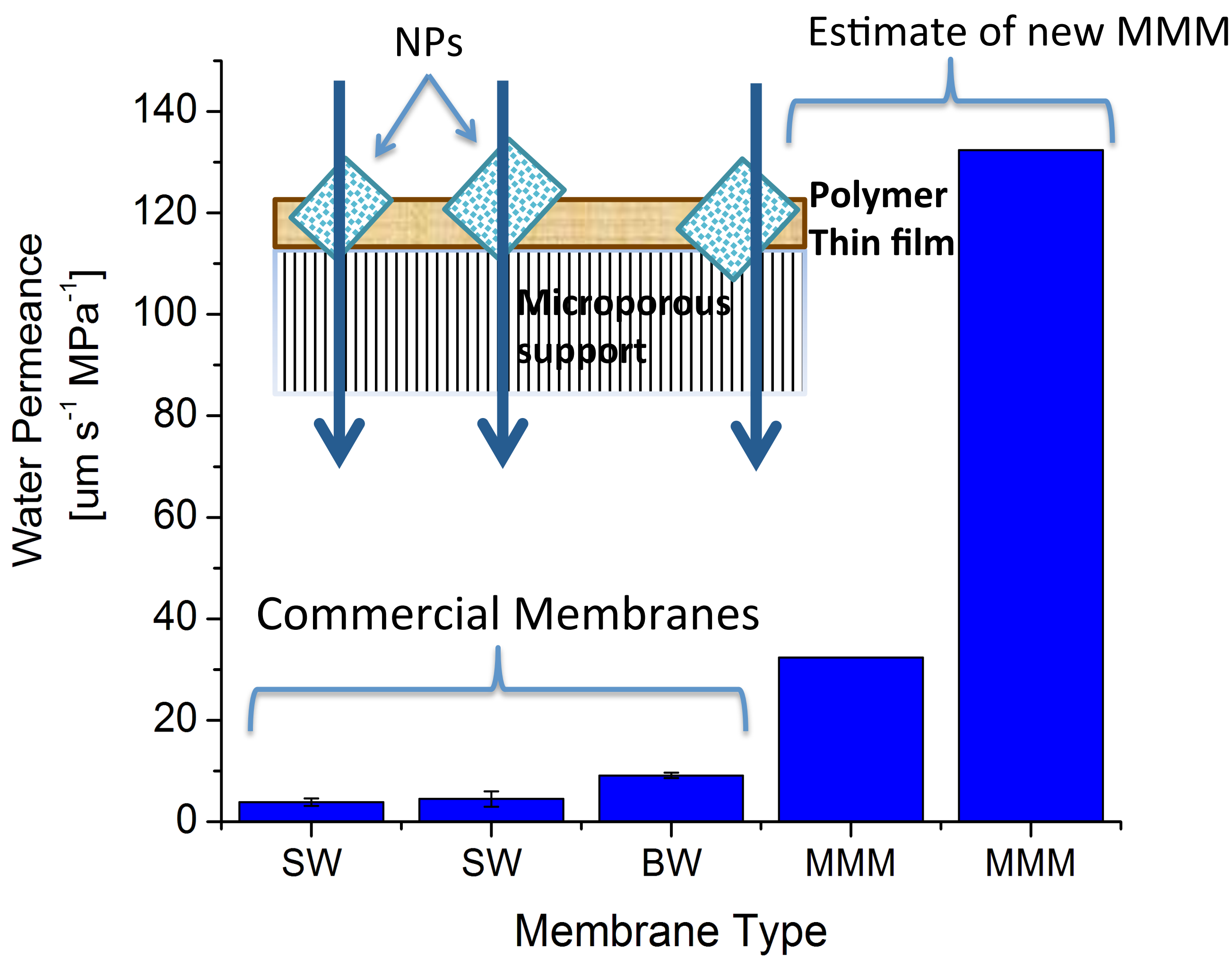
LTA zeolite



ZSM-5 zeolite

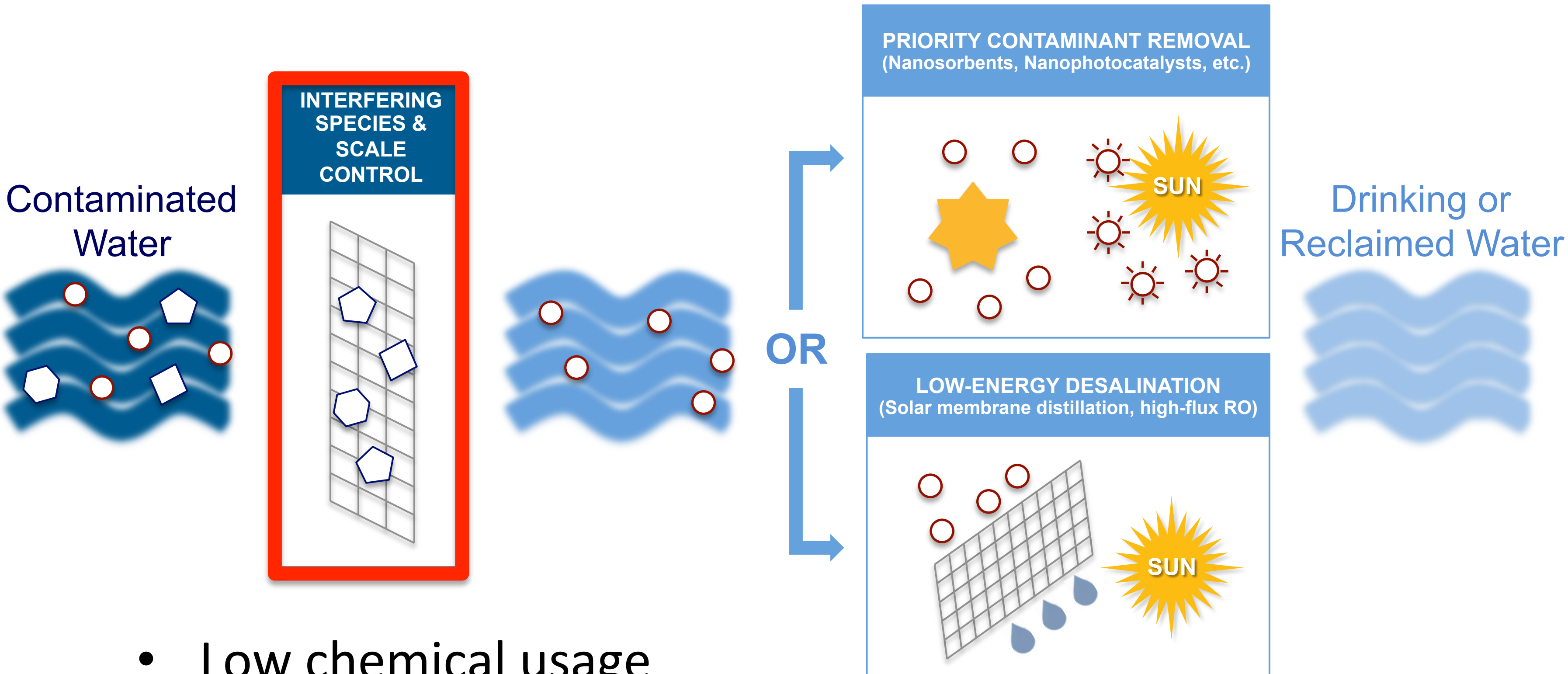


ZIF-71



Objectives of ERC and Thrust 3:

To develop scaling and fouling control methods to ensure stable and reliable operation of NEWT's mobile water treatment systems

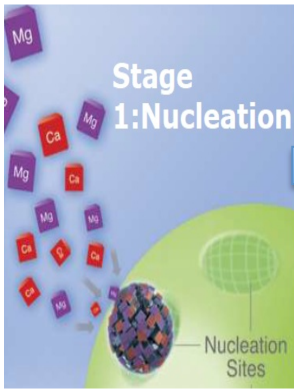


- Low chemical usage
- Low cost
- Wide TDS range
- Safe and durable

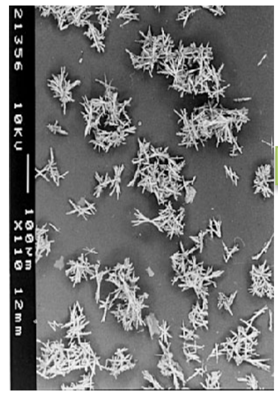
3.1 Nanotemplate for Mineral Nucleation

Water containing scale forming minerals, Ca, Mg, Si

Template assisted nucleation

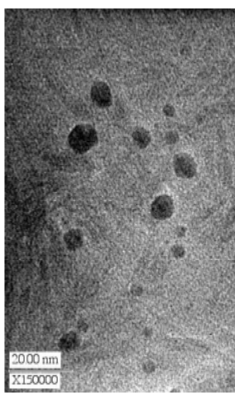


Nanocrystal formation

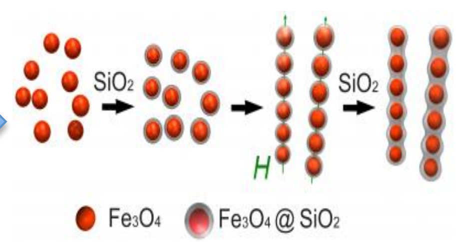


Crystals growth in solution, not on surfaces

Crystals exiting system



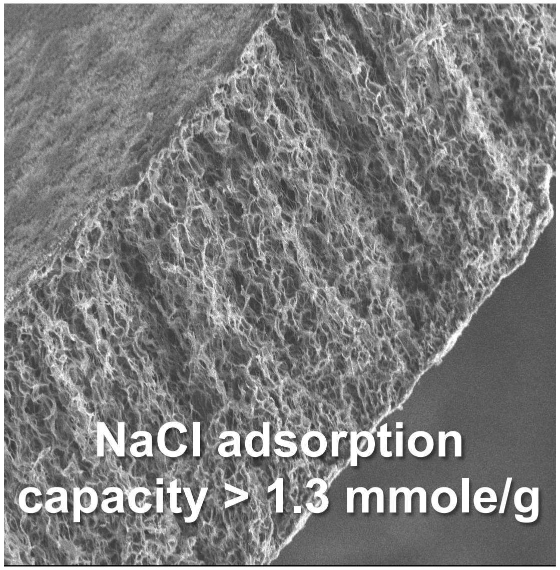
Fe-oxide nanoparticle

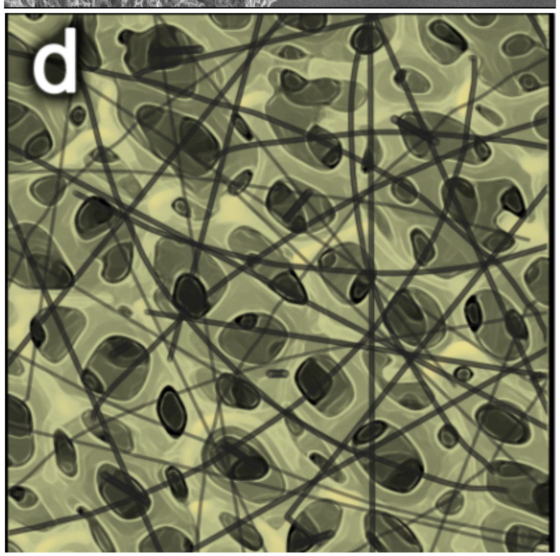


Si adsorption and magnetic separation

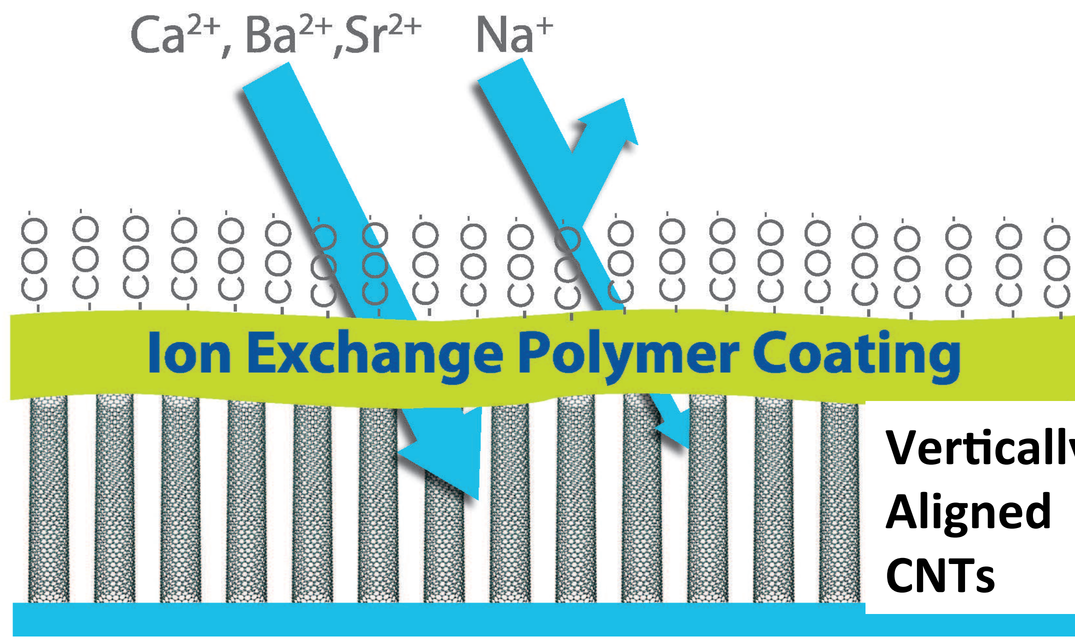
Reduced silica – no silica fouling

3.2 Electrosorption for Scaling Control





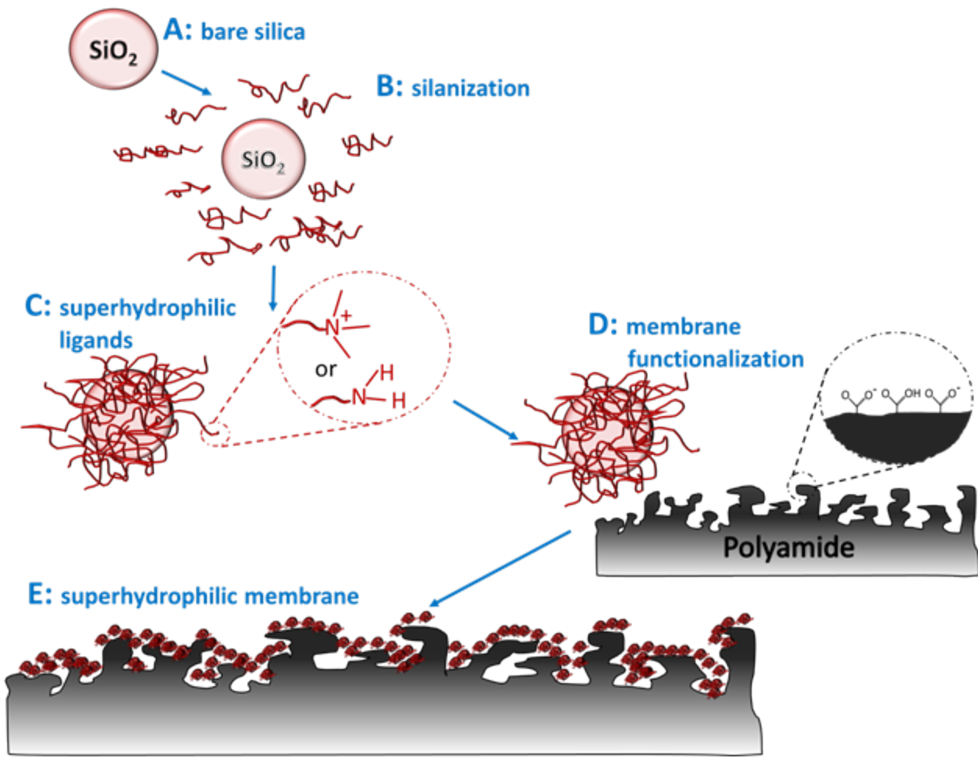
Nanocomposite electrodes to remove multivalent ions from brines, and generate smaller waste streams



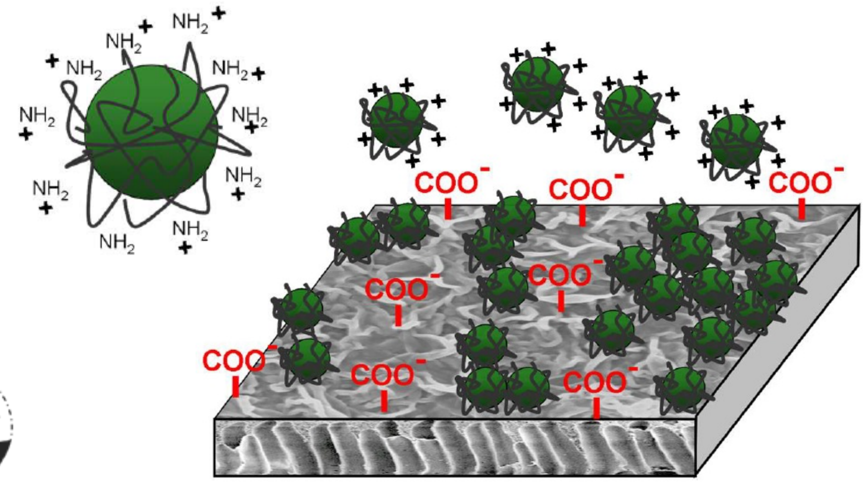
CNTs/graphene enhance sorption capacity, kinetics, mechanical strength and electrical conductivity.

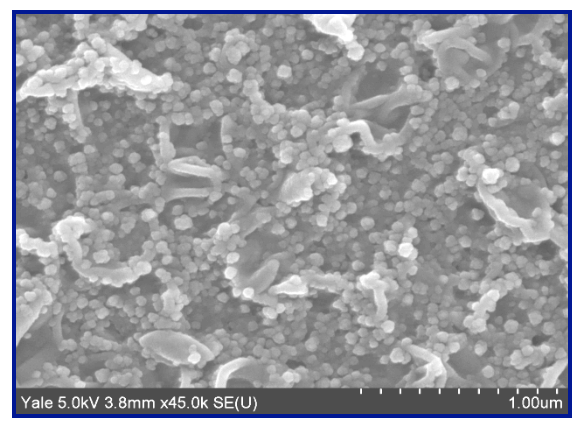
3.3 ENM Coatings for Fouling/Scaling Control

Superhydrophilic TFC Membrane



Biocidal Cu-NP TFC Membrane





Thrust 4: inform nanomaterial selection and design, device development, and technology implementation

4.1 *Market Performance Projection, Lifecycle, Nano-safety and Techno-Economic Analyses*:

Risk = Hazard x Exposure

Hazard

- Prioritize use of ENMs of benign, low-cost, and earth-abundant compositions (GRAS); Green Chemistry and Green Engineering
- Experts panel to select ENMs before incorporation into products
- Interface with TSCA in the US and REACH in the EU

Exposure

- Immobilize ENMs to minimize release and exposure and enable reuse (no free NPs)
- Model & monitor treated water for leaching
- Foster safety in manufacturing by iterating with OSHA on best practices
- Independent certification for meeting health & safety stds.

4.2 *Regulatory and Social Acceptance and Risk Analysis*

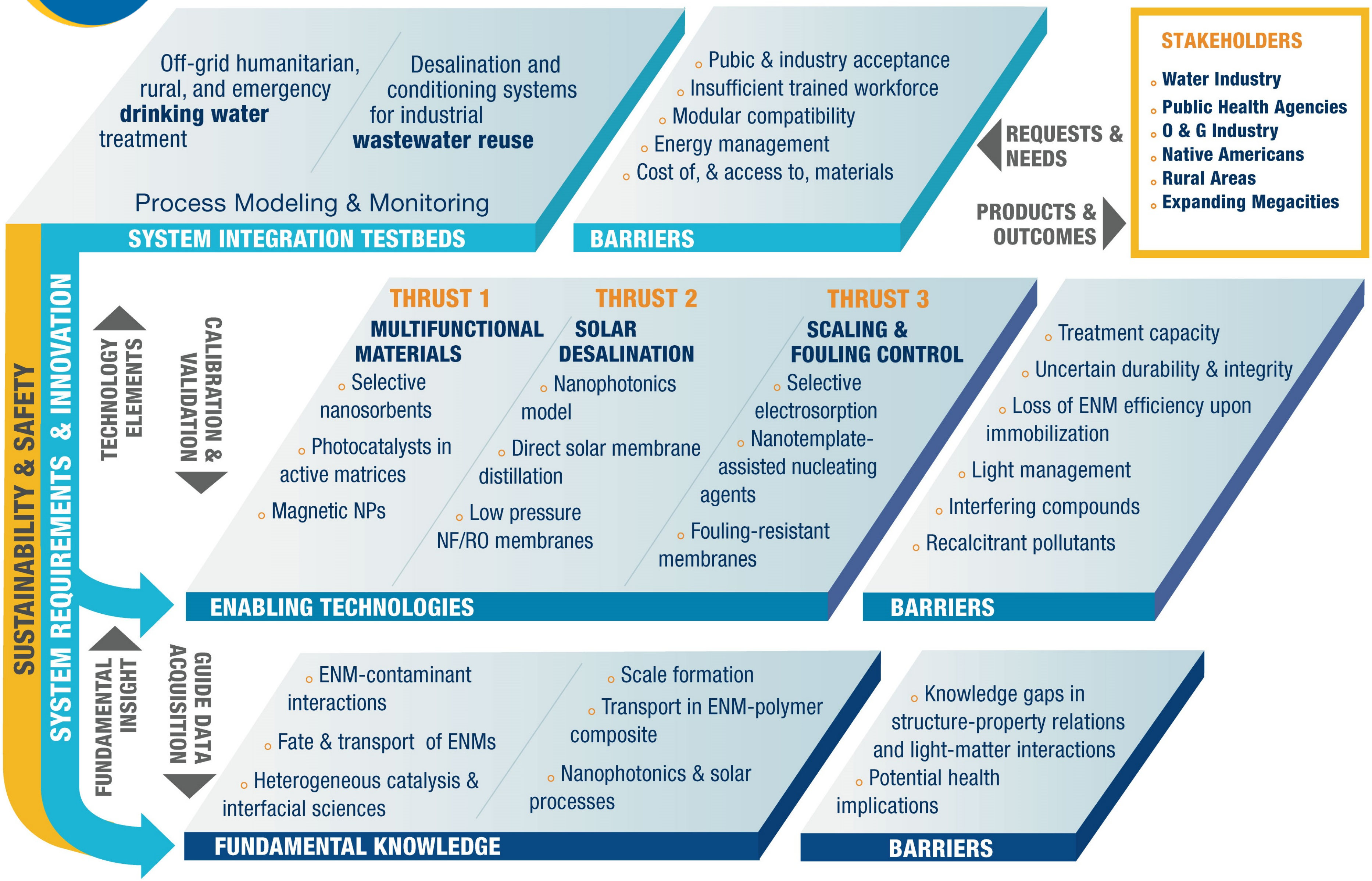
- Understand how the public in both poor (e.g., *Colonias*, unincorporated areas along the U.S./ Mexico border) and more affluent communities uses POU devices
- Conduct policy analysis to assess the viability of treated industrial wastewaters for non-potable uses
- Work with water treatment operators to understand their concerns regarding operational issues around module treatment (efficiency, maintenance, safety, monitoring, etc.).
- Identify and develop solutions to address barriers (e.g., public perception, regulatory frameworks, device certification, etc.) for accepting nano-enabled water devices for potable water at residential to community scale

Safe Nano Leadership

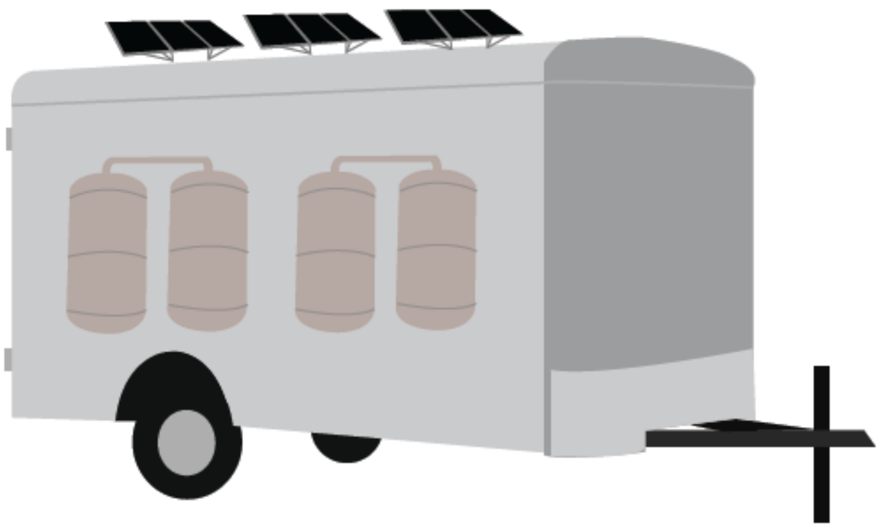
- Instill culture across NEWT team
- Assure NEWT IPAB, SAB and public stakeholders that nano-enabled water systems are safe
- Lead effort to get nano-enabled water devices tested and approved by NSF International

http://galleryhip.com/boy-drinking.html

Testbeds


Off-grid humanitarian, rural, and emergency **drinking water** treatment
Desalination and conditioning systems for industrial **wastewater reuse**
Process Modeling & Monitoring
SYSTEM INTEGRATION TESTBEDS
Pubic & industry acceptance
Insufficient trained workforce
Modular compatibility
Energy management
Cost of, & access to, materials
BARRIERS
REQUESTS & NEEDS
PRODUCTS & OUTCOMES
STAKEHOLDERS
Water Industry
Public Health Agencies
O & G Industry
Native Americans
Rural Areas
Expanding Megacities
SUSTAINABILITY & SAFETY
SYSTEM REQUIREMENTS & INNOVATION
TECHNOLOGY ELEMENTS
CALIBRATION & VALIDATION
THRUST 1
MULTIFUNCTIONAL MATERIALS
Selective nanosorbents
Photocatalysts in active matrices
Magnetic NPs
THRUST 2
SOLAR DESALINATION
Nanophotonics model
Direct solar membrane distillation
Low pressure NF/RO membranes
THRUST 3
SCALING & FOULING CONTROL
Selective electrosorption
Nanotemplate-assisted nucleating agents
Fouling-resistant membranes
ENABLING TECHNOLOGIES
Treatment capacity
Uncertain durability & integrity
Loss of ENM efficiency upon immobilization
Light management
Interfering compounds
Recalcitrant pollutants
BARRIERS
FUNDAMENTAL INSIGHT
GUIDE DATA ACQUISITION
ENM-contaminant interactions
Fate & transport of ENMs
Heterogeneous catalysis & interfacial sciences
Scale formation
Transport in ENM-polymer composite
Nanophotonics & solar processes
FUNDAMENTAL KNOWLEDGE
Knowledge gaps in structure-property relations and light-matter interactions
Potential health implications
BARRIERS

POU/POE - MobileNEWT for Drinking Water



Flowrate ~ 1 gallon per minute

www.crystalclearsuppy.com

Integrated Module Performance

Operator Experience & Outreach

Safety & Residuals Analysis

Point-of-Use Drinking Water Testbed

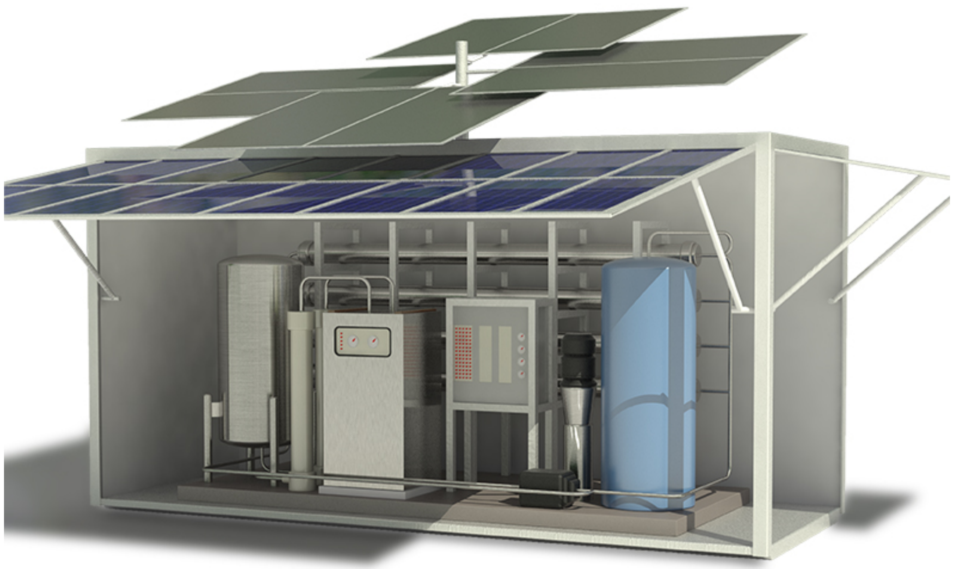
NEWT + QESST =

2nd Location in Mexico Under Development

Metrics:

- Water production rate
- Turbidity, TDS, VOCs, As, Cr, F^-, NO_3^-, TOC, microbial parameters
- Energy efficiency
- ENM in treated water
- Cost and sustainability
- Public acceptance

NEWTSkid for Remote Industrial Reuse



Plug-and-Test Modules for O&G Industry

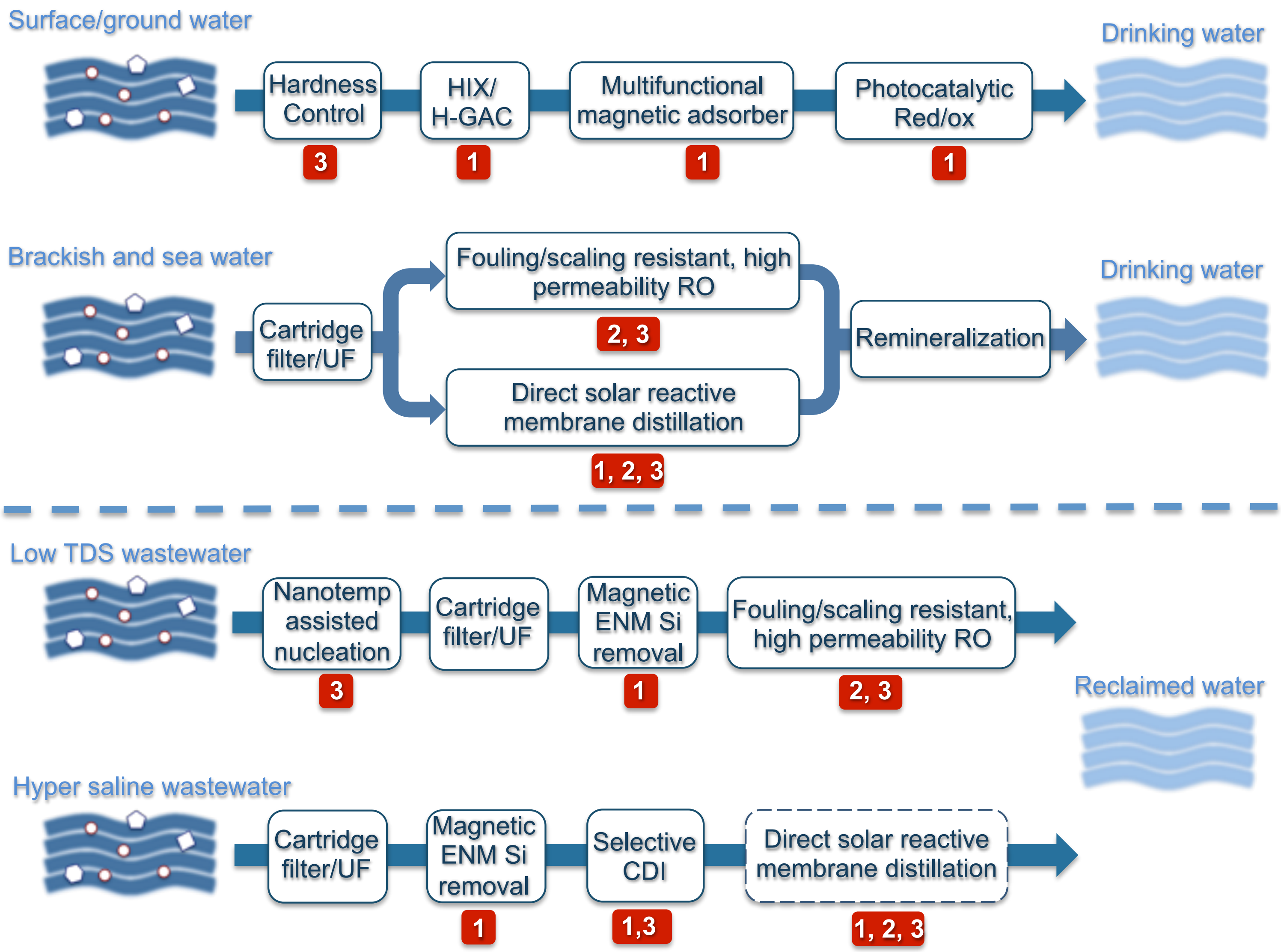
Systems Integration with On-line controls

Capstone design, REU operational experiences

Metrics:

- Water treatment rate/recovery
- Robustness: TDS, Ca, Mg, Ba, St, TOC, heavy metals
- Chemical free treatment capabilities
- Residuals production rate and composition
- Energy: Membrane fouling rate, Solar power options
- Size: 50% smaller than existing technology

Example Systems with combinations of modules



New Education Programs

Graduate
- Sustainable engineering in multidisciplinary and multicultural settings for global technology development

Undergraduate
- Project-based curriculum across NEWT institutions
- National model for inquiry-based learning

Pre-college education
- New professional development course (100 teachers reaching >15,000 students annually)
- Use NEWT's compelling research as "hook" to inspire diverse K-12 students to pursue STEM careers

Innovation Ecosystem to Support Translational Research

- Foster entrepreneurship to accelerate commercialization and facilitate startup ventures
  - Mentoring and validation of business models
  - Market research
  - Legal assistance for IP
  - Incubator space
  - Network of experienced innovation partners and entrepreneurs
- Populate I.E. with partners that fill “missing links” across the value chain

Summarizing....

- Unique nano-properties offer tremendous opportunity
  - We need to demonstrate this now at the systems level
- Niche markets are early adopters of technology
  - then move towards municipal systems
- Industry VERY excited about nano + water
- **How can NEWT help Industry?**

NSF Nanosystems Engineering Research Center for
Nanotechnology Enabled Water Treatment Systems (NEWT)