# Nanosystems Engineering Research Center for
# Nanotechnology-Enabled Water Treatment

NEWT

## An Overview

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NSF

RICE ASU UTEP Yale

# 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.

# 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)

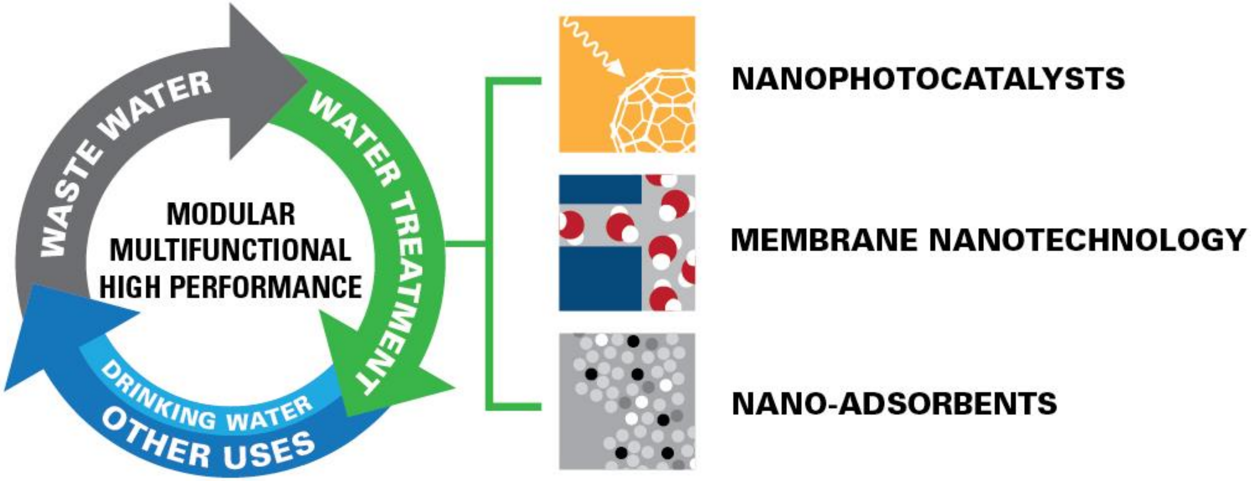
http://switchboard.nrdc.org/blogs/rhammer/fracking-2.jpg

# Why Nano?

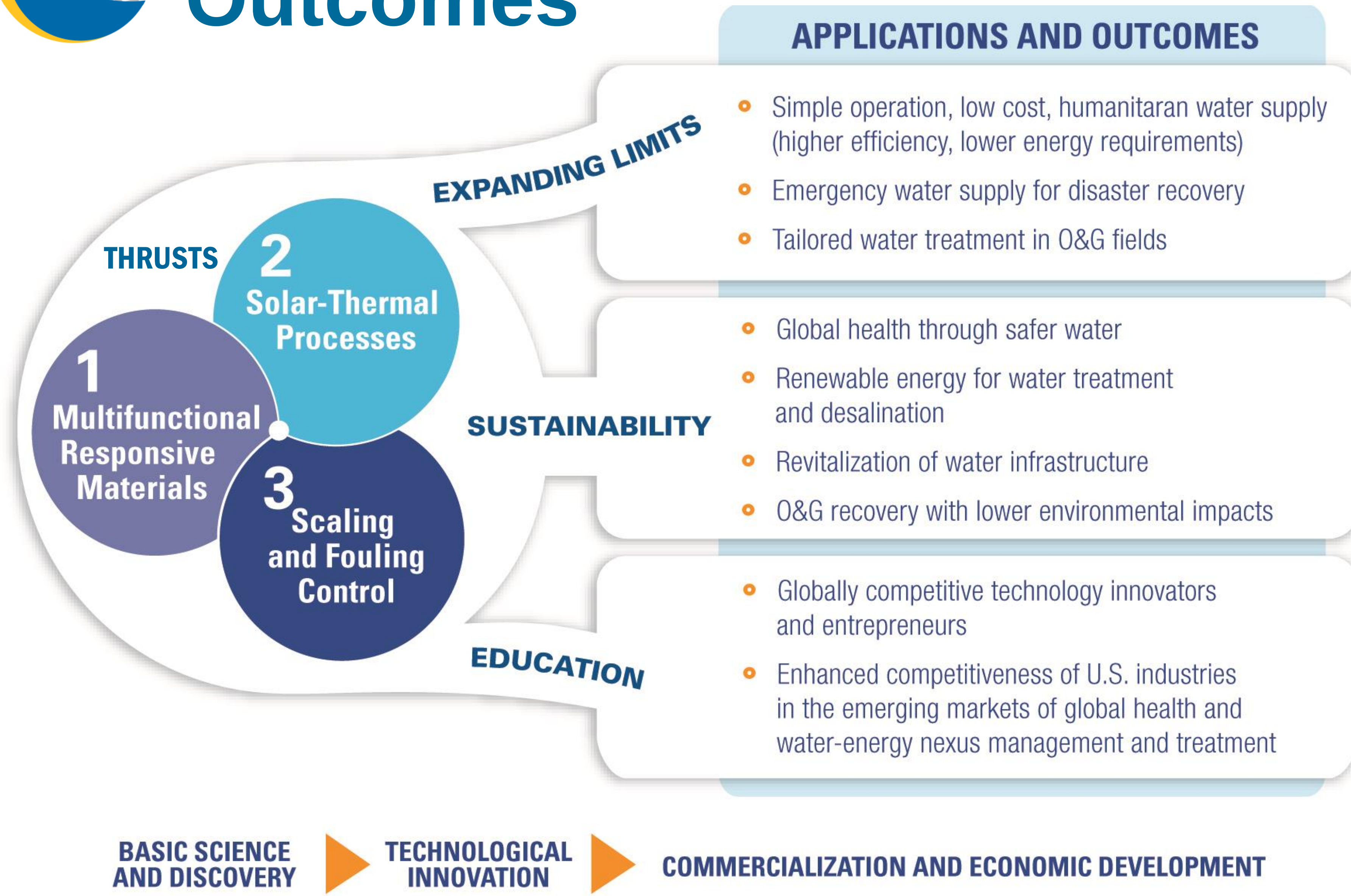
## Leap-frogging opportunities to:

- 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



# Operational Vision and Outcomes



# Safe Use of Nanomaterials

**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.

# Demonstrated Leadership

**Pedro Alvarez**

Microbial Control

**Meny Elimelech**

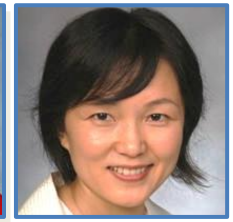
Membrane Processes

**Jorge Gardea-T**

Environ. Chemistry

**Naomi Halas**

Nano-Photonics



**Qilin Li**

Advanced Treatment

**Rebecca Richards-K**

Beyond Traditional Borders

**Paul Westerhoff**

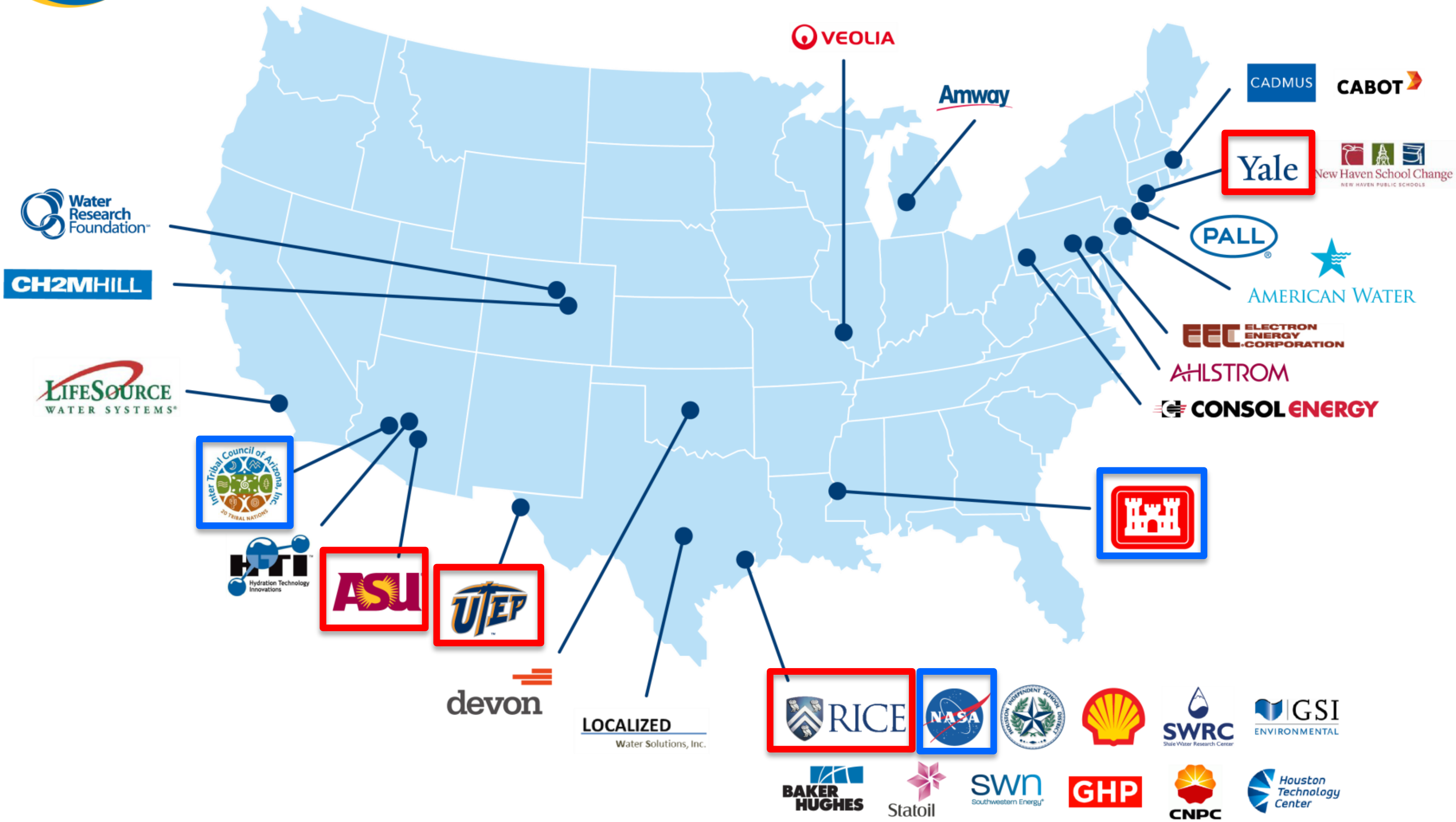
Water Systems

**Mike Wong**

Nano-Catalysis

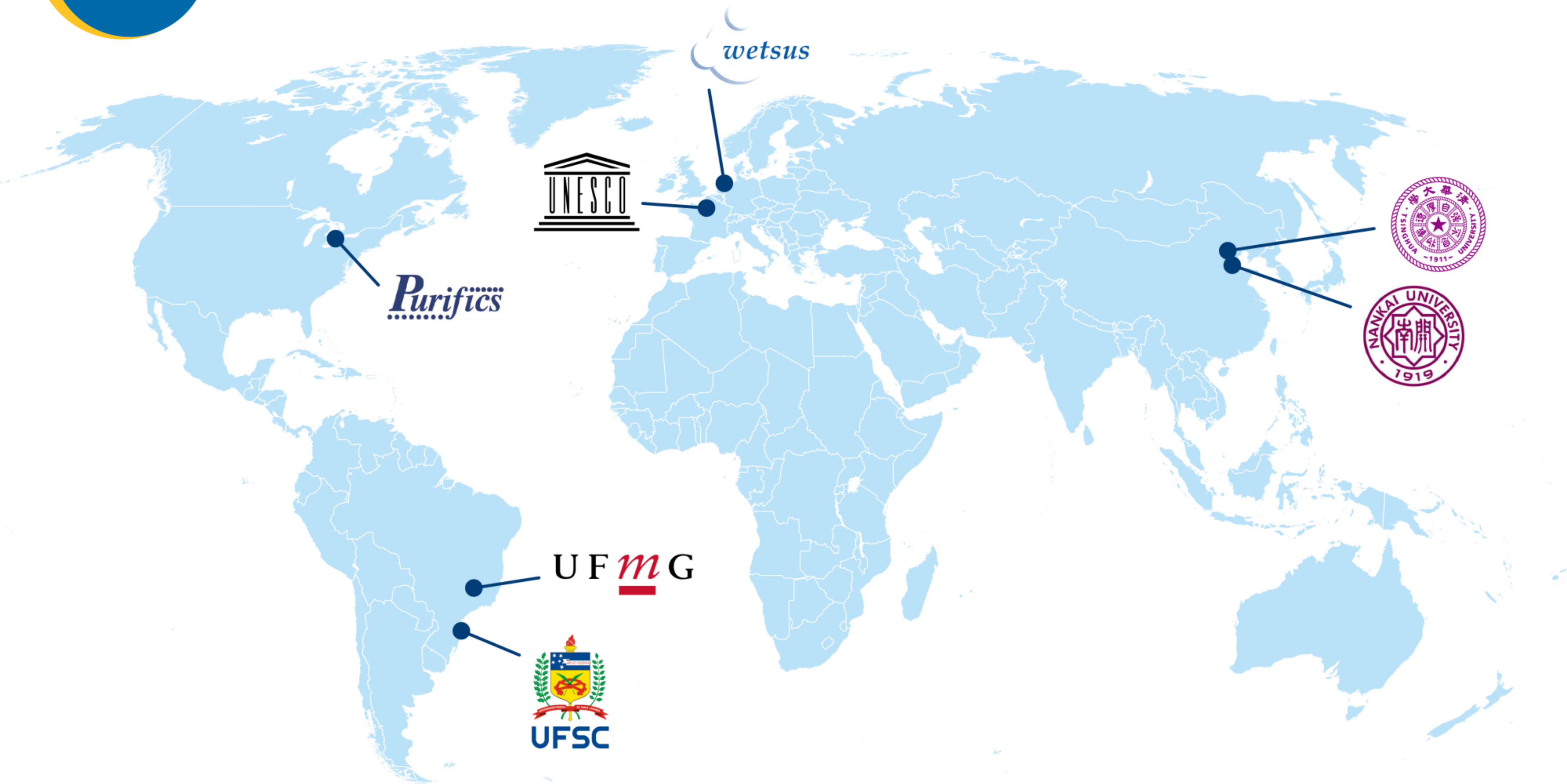
- Three NAE members, two Clarke Prize laureates
- Pioneers in environmental nano and advanced water treatment
  - Photothermal nanoparticles
  - Fouling-resistant membranes
  - Solar-based nano-photocatalysts and upconversion
  - Superparamagnetic nano-sorbents; hypercatalysts; etc.
  - Fate, transport and potential environmental impact of ENMs

# Domestic Partners




- Innovation across value chain (nanomaterial and equipment manufacturers, service providers, R&D and deployment partners, and users)

# International Partners



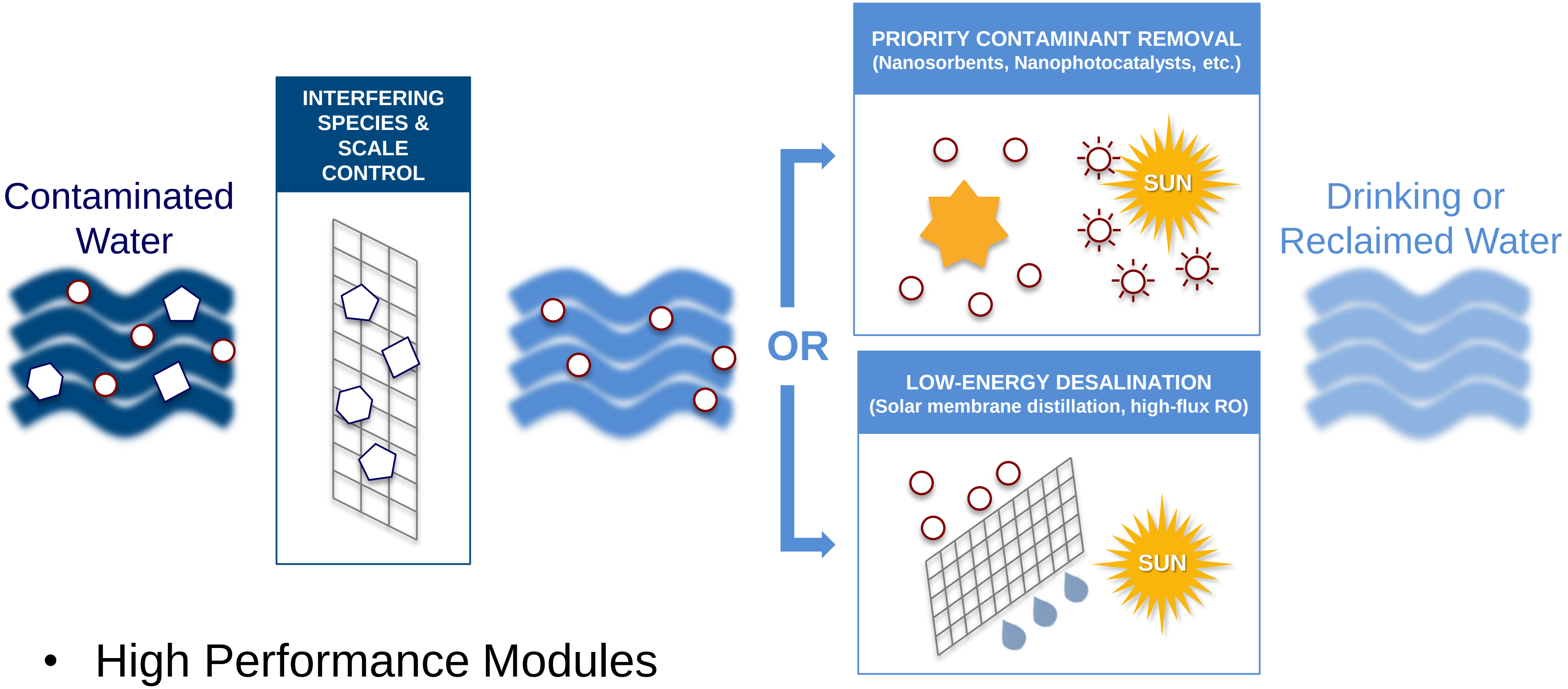

- Co-development and production of advanced multifunctional materials
- Globally-relevant research and education experiences for students
- Testbed sites for applications in fast-growing water markets

# Partners Across the Value Chain

| | |
|---|---|
| Nanomaterial and advanced material manufacturers | EEC Electron Energy Corporation; CABOT; HTI Hydration Technology Innovations; Purifics |
| Equipment manufacturers | AHLSTROM; Amway; LifeSource Water Systems; PALL |
| Research, development and deployment partners | NASA; NSF; CADMUS; GHP; Houston Technology Center; UNESCO; Water Research Foundation; wetsus |
| Service providers | American Water; Baker Hughes; CH2MHILL; GSI Environmental; Localized Water Solutions, Inc.; SWRC; VEOLIA |
| End users | CNPC; CONSOL ENERGY; devon; swn Southwestern Energy; Statoil; Inter Tribal Council of Arizona, Inc. |

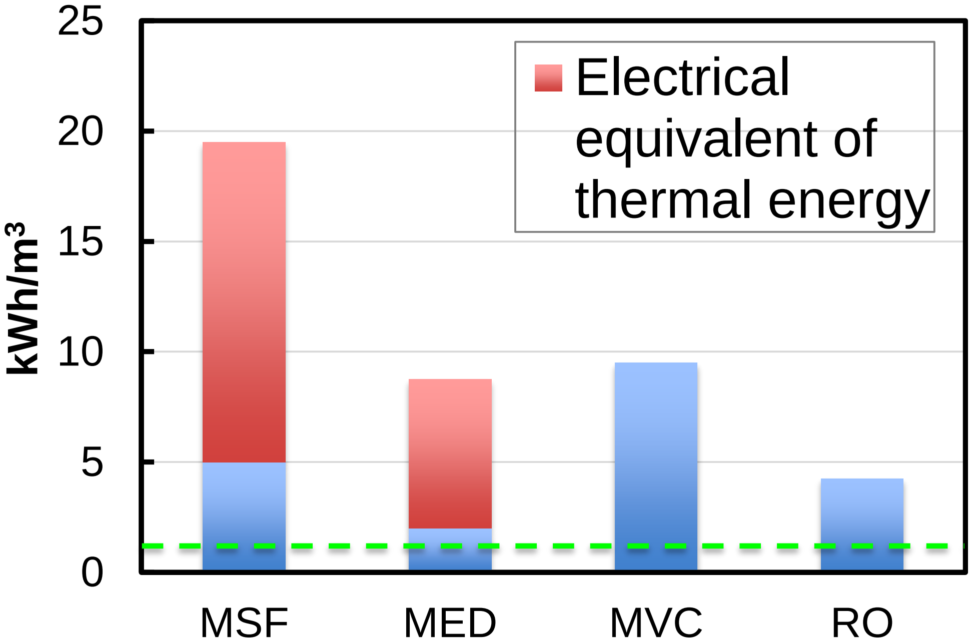
# Modular Treatment Systems

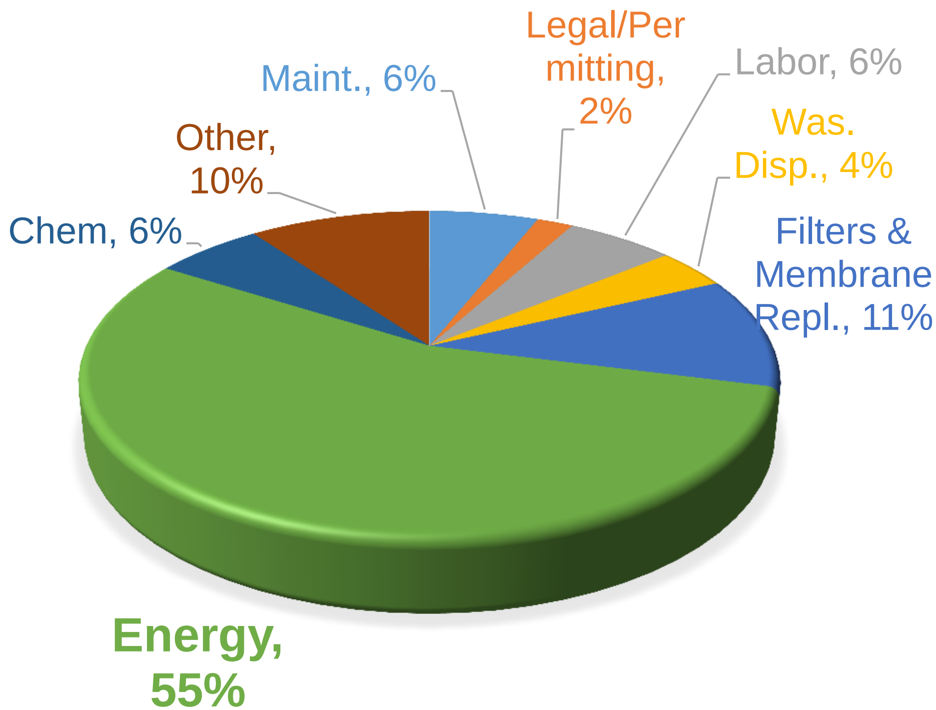
## Match treated water quality to intended use




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

# The Energy Challenge




<u>Theoretical minimum</u>:

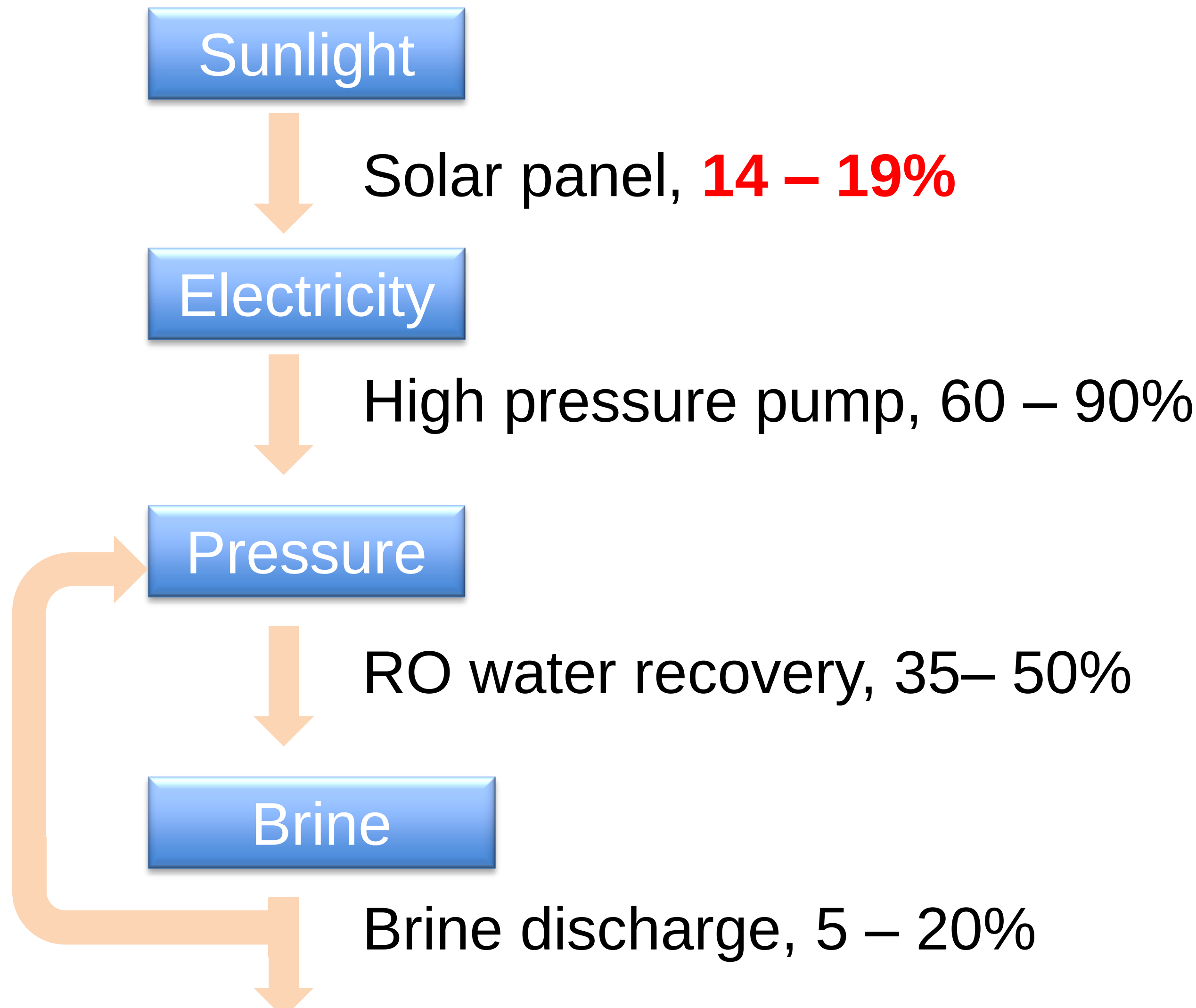
1.06 kWh/m$^3$ (35 g/L, R = 50%)

*Source*: 1) Water Reuse Association, *Seawater desalination cost*, January 2012

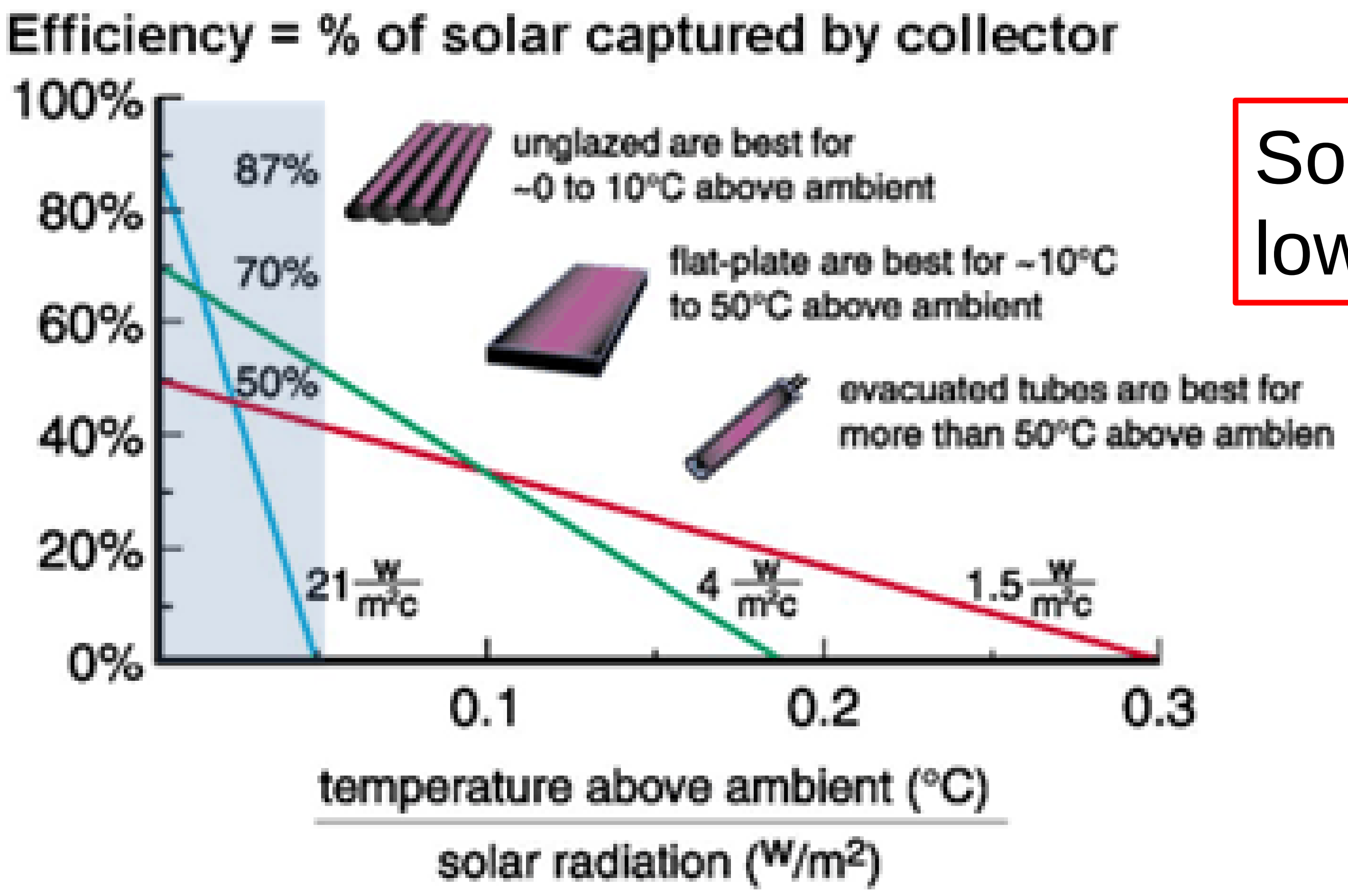
2) Elimelech and Phillip, *Science* 2011

# Current Solar Desalination: Solar PV

**Overall energy efficiency:**



# Solarthermal Energy



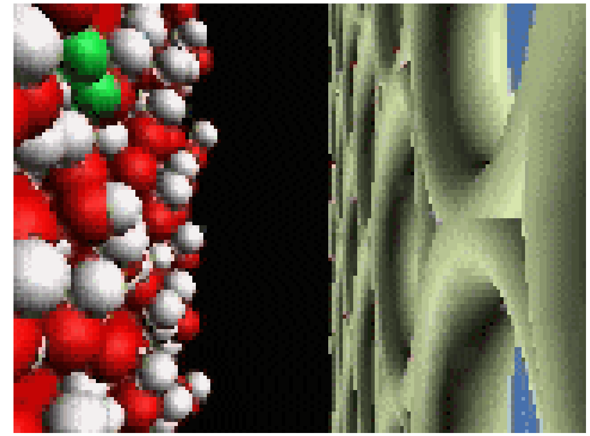

Solarthermal low T desal?

http://www.wbdg.org/resources/swheating.php

# Enabling Technology
## Desalination

Direct solar (membrane) distillation

- Uses nanophotonics
- Converts sunlight to heat efficiently

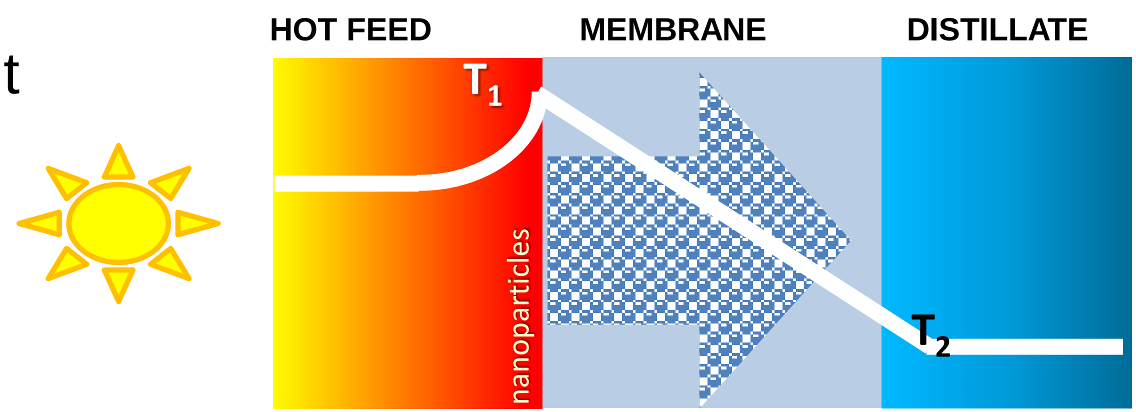


www.desalination.biz

Multifunctional membranes

- Fouling-resistant
- High-flux
- Self-cleaning

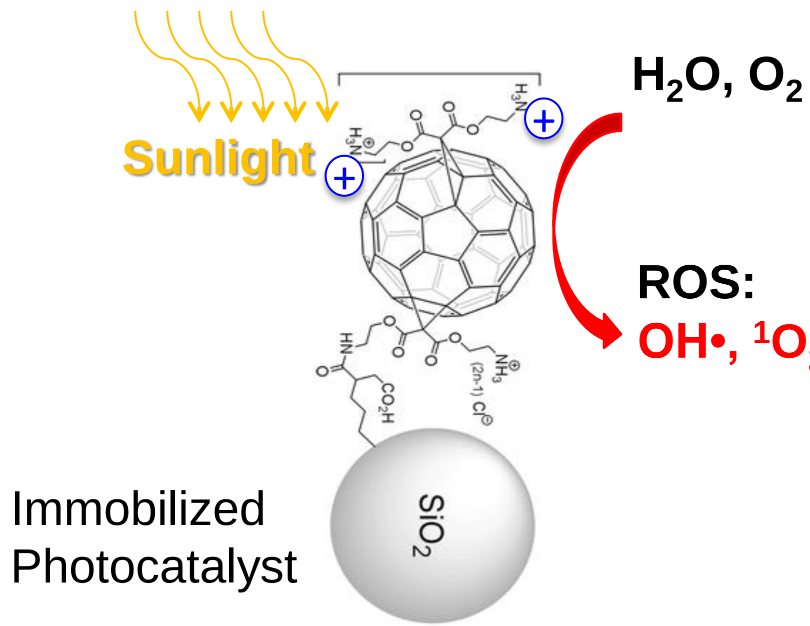
**Solar-enhanced MD**



# Enabling Technology

## (Photo)Disinfection and Advanced Oxidation

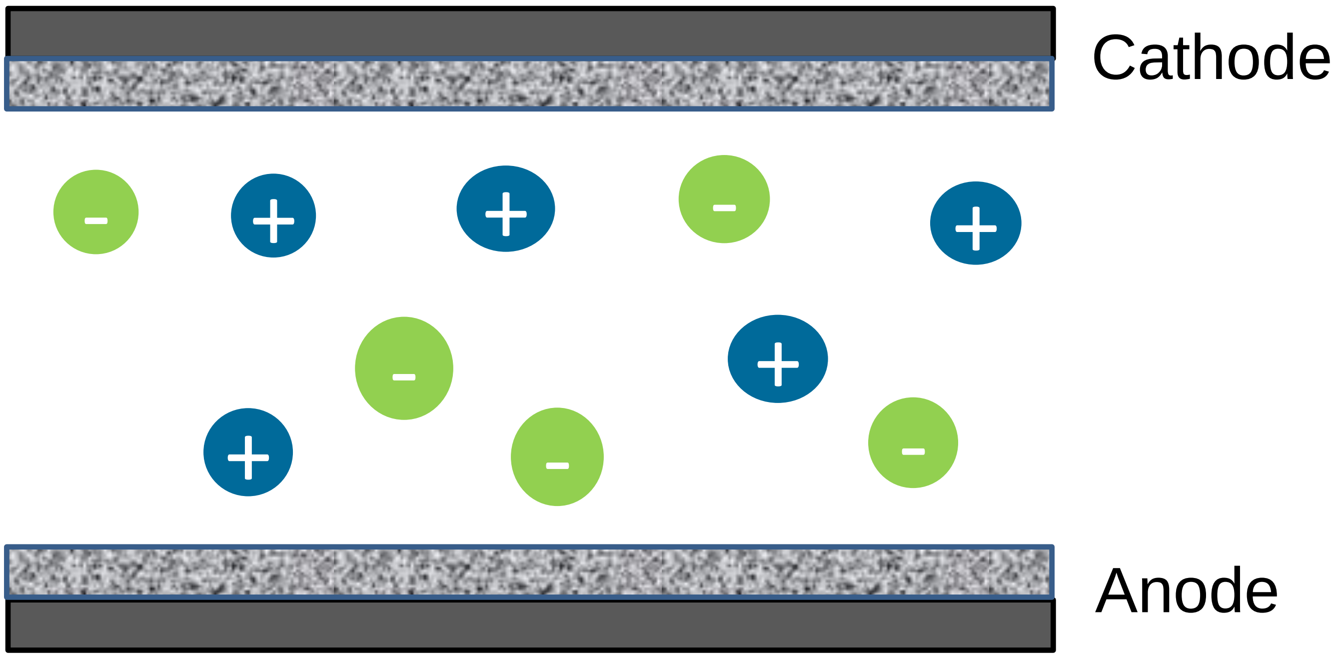
Nano(photo)catalysts that use solar radiation to generate ROS that destroy resistant microbes and recalcitrant pollutants without generating harmful disinfection byproducts



# Enabling Technology

## Electrosorption for Scaling Control

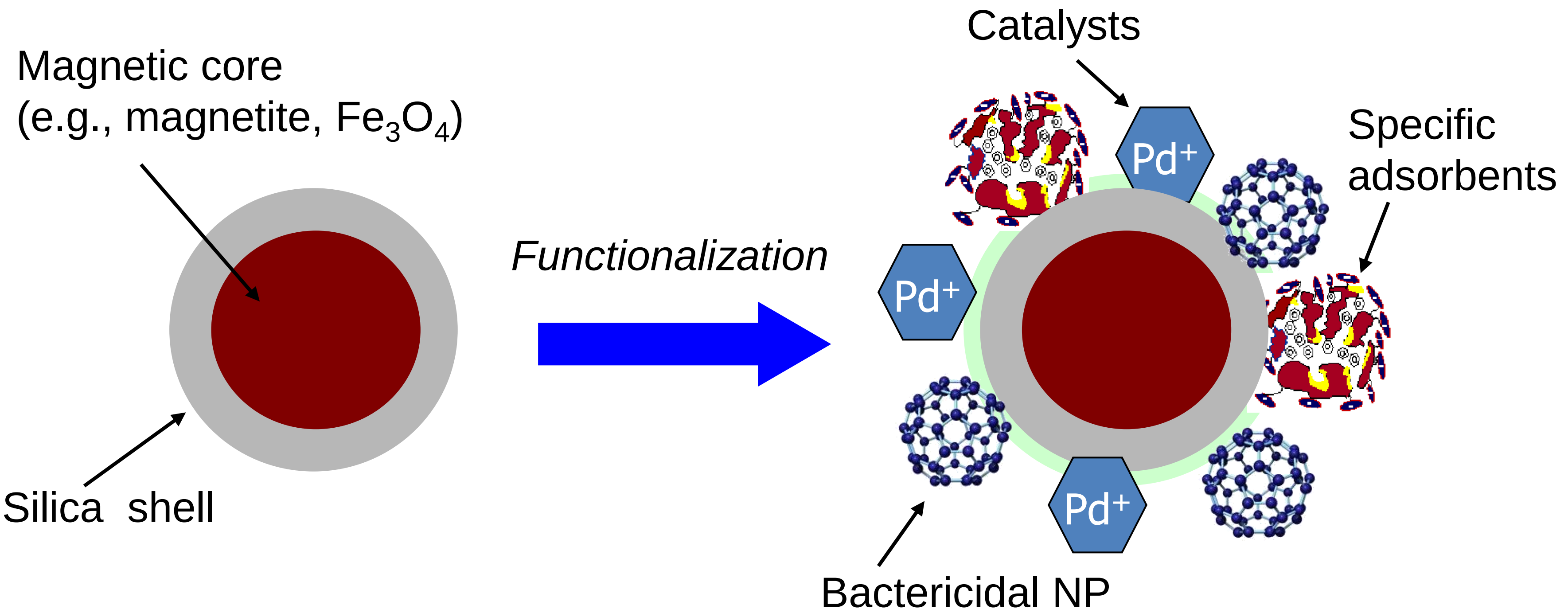
Nanocomposite electrodes to remove multivalent ions from brines, and generate smaller waste streams



# Enabling Technology

## Multifunctional nanosorbents

Selective removal of target contaminants by functionalized nanoparticles supported in macroscale structures or subject to magnetic separation for enhanced removal kinetics and easier reuse



# What We Will See in 10 Years

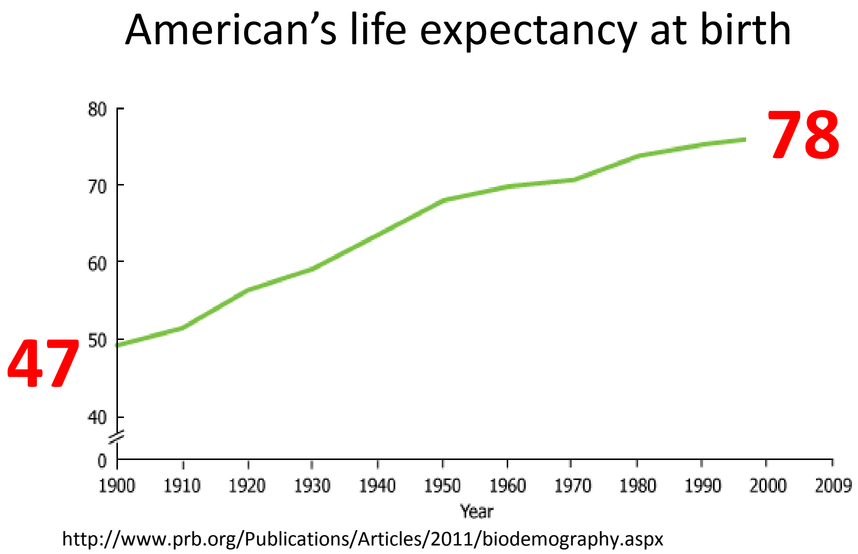
Compact, solar-harvesting, high-performance, flexible water treatment systems that meet the growing industrial and societal needs for decentralized water supply and reuse

# Welcome to Join NEWT

## NEWT kickoff meeting

Oct. 21-22, 2015
Rice University
Houston TX

# NEWT Serves National Interests




- Public health
- Energy production
- Food security
- Economic development

- 43 million Americans lack access to municipal water; 800 million worldwide lack access to safe water
- Global market for drinking water ~ $700 billion
- Larger market for industrial wastewater reuse

# 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

# Water Treatment Landmarks

**144 B.C.**
Rome builds its third aqueduct. Unlike other aqueducts built to carry water for bathing and flushing, this one was erected primarily to transport drinking water.

**1804**
Paisley, Scotland, becomes the world's first municipality to provide drinking water filtration for its entire city, installing sand filters to produce potable water.

**1854**
John Snow's investigation into a cholera outbreak in London links its spread to drinking water. This led to awareness that drinking water could carry disease, and in turn, to improvements in drinking and wastewater treatment systems.

**1974**
The Safe Drinking Water Act passes to protect public health by regulating the nation's drinking water supply.

**2009**
The EPA updates the list of drinking water contaminants it regulates, bringing the number of monitored contaminants to 90.

**2015**
A collaborative effort involving universities, industry partners, and NSF begins to apply nanotechnology to develop *decentralized water treatment systems* that tap a broad range of source waters, are easy to deploy, and utilize solar processes for off-grid humanitarian water supply and industrial wastewater reuse.

**Growing need for decentralized water treatment for humanitarian and remote supply, emergency response, and water reuse = market disconnect**

## 2015 and Beyond

The Nanotechnology-Enabled Water Treatment Center (NEWT), now funded by industry with state plus municipal support, continues to produce transformative technologies and systems that improve global health and contribute to sustainable development.

# Gaps with Current Water Treatment Systems

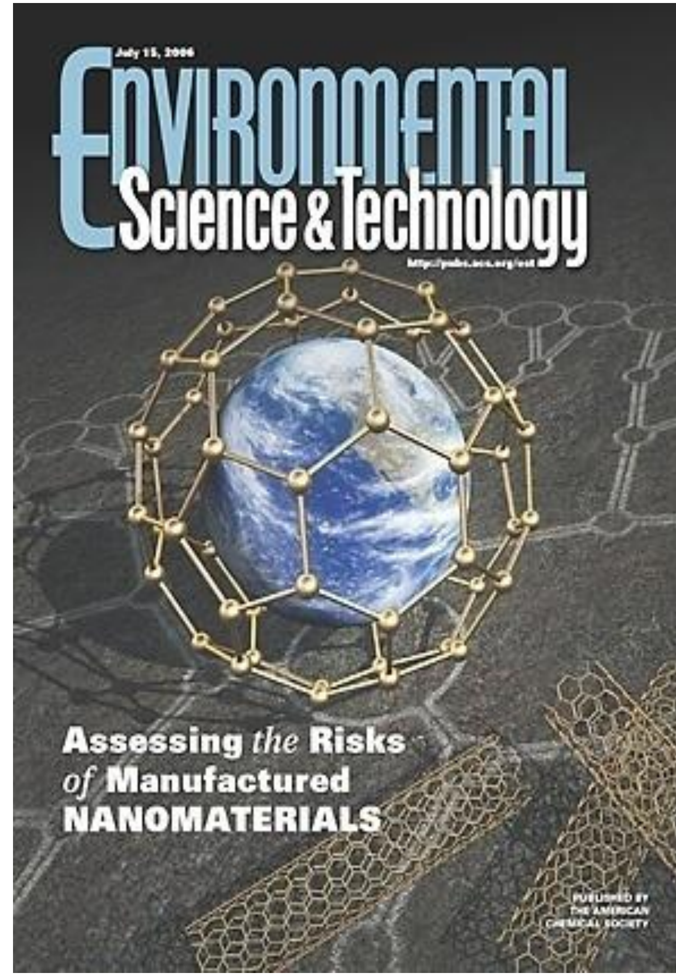
- Water infrastructure was rated **D⁻** by ASCE
- Lack adaptivity to changes in source water
  - New pollutants
  - Climate change
- Lack portability for emergency response or use in remote or constrained places due to large size

http://www.sandiego.gov/cip/about/faq/index.shtml

- Use large quantities of chemicals and electricity
- Do not utilize solar processes for treatment
- Need to improve kinetics, efficiency, capacity, and cost

# Safe Use of ENMs

- Prioritize use of ENMs of benign, low-cost, and earth-abundant compositions (GRAS)
- Experts panel to select ENMs before incorporation into products
- Foster culture of safe manufacturing practice
- Immobilize ENMs to minimize release/exposure and enable reuse
- Model and monitor treated water for potential leaching



# Aspirational Impacts

| | 5 years | 10 years | Beyond |
|---|---|---|---|
| Local | Improved water treatment in rural communities (remove EDCs, POPs, resistant bacteria) | Broader access to affordable potable water for millions of off-grid people who lack it | Higher participation of underrepresented groups in STEM careers & leadership |
| State | Distributed treatment systems lowering the water footprint of oil and gas production | Drought alleviation, enabled by tapping a broader range of source waters | Improved water treatment and industrial wastewater reuse infrastructure |
| National | High-performance materials and mobile systems for disaster relief and emergency response | Energy production with less fresh water withdrawals and lower environmental impact | Globally-competitive, diverse innovators; more jobs to export novel technologies |
| Global | Easy-to-deploy systems for disaster relief and humanitarian water supply | Affordable low-energy (solar) desalination, improved adaptation to climate change | Improved global health, food security, and sustainable development |

# Barriers and *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*

# 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

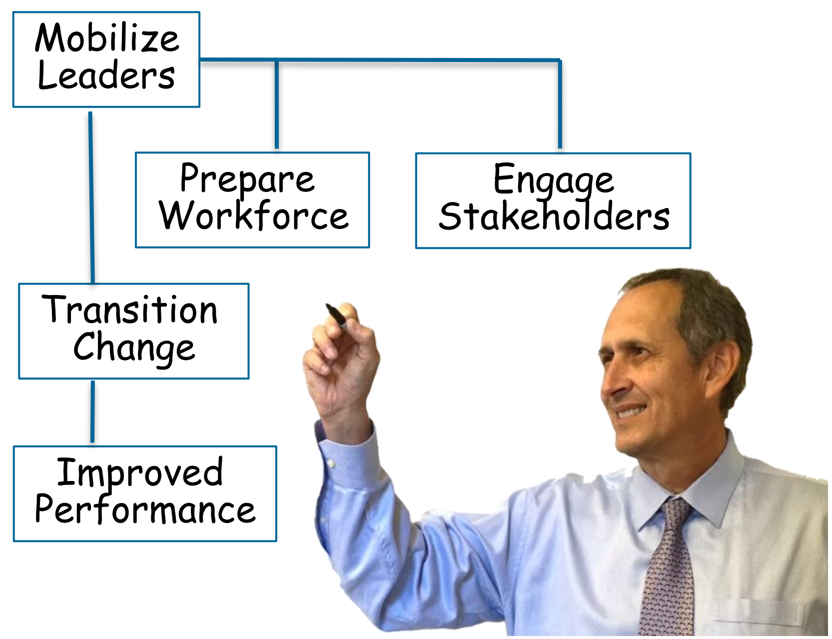
- New professional development course (100 teachers reaching >15,000 students annually)
- Use NEWT's compelling research as "hook" to inspire diverse K-12 students to pursue STEM careers


# Organizational Structure


- Transparent, collaborative, experienced leadership
- Frequently scheduled work and advising sessions
- World-class advisory boards
- Supported by management tools and processes

# Management Objectives

- Leadership built on shared vision, transparency, and effective communication with all stakeholders
- Open and collaborative approach
- Centralized management
- Team-driven projects
- Clearly delineated roles and responsibilities
- Quick identification and timely resolution of problems

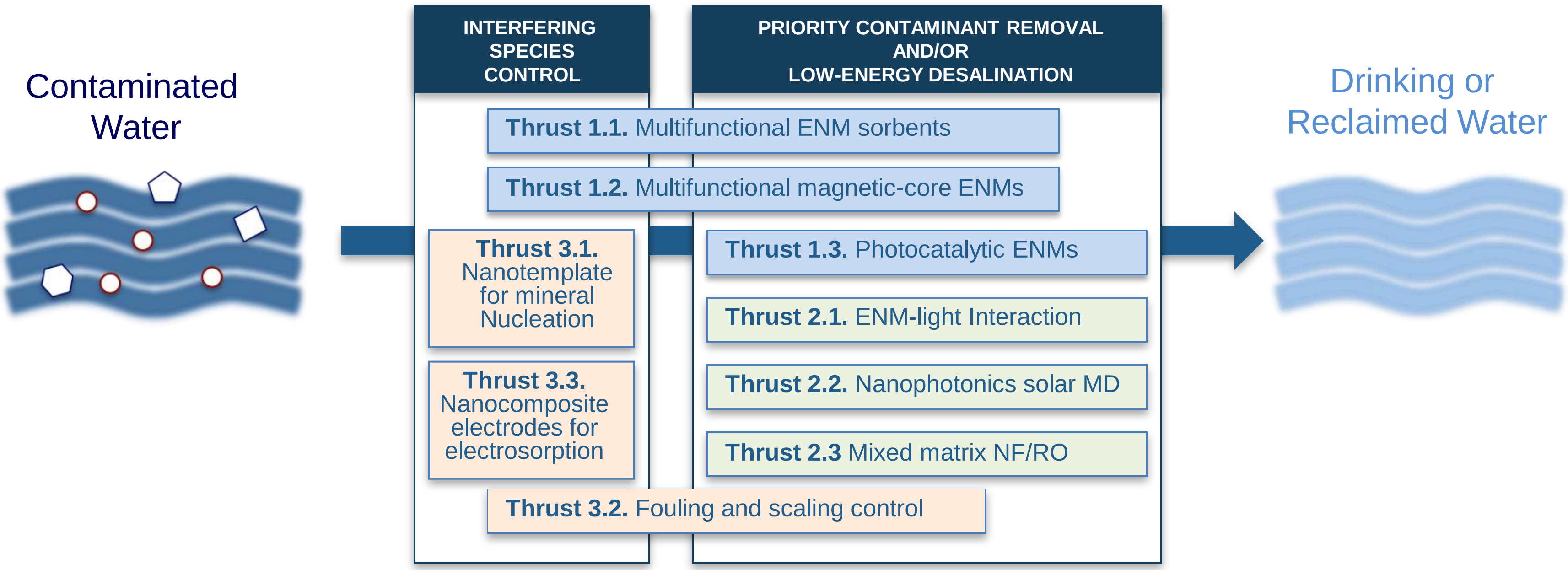


# Crosscutting Research Thrusts and Testbeds

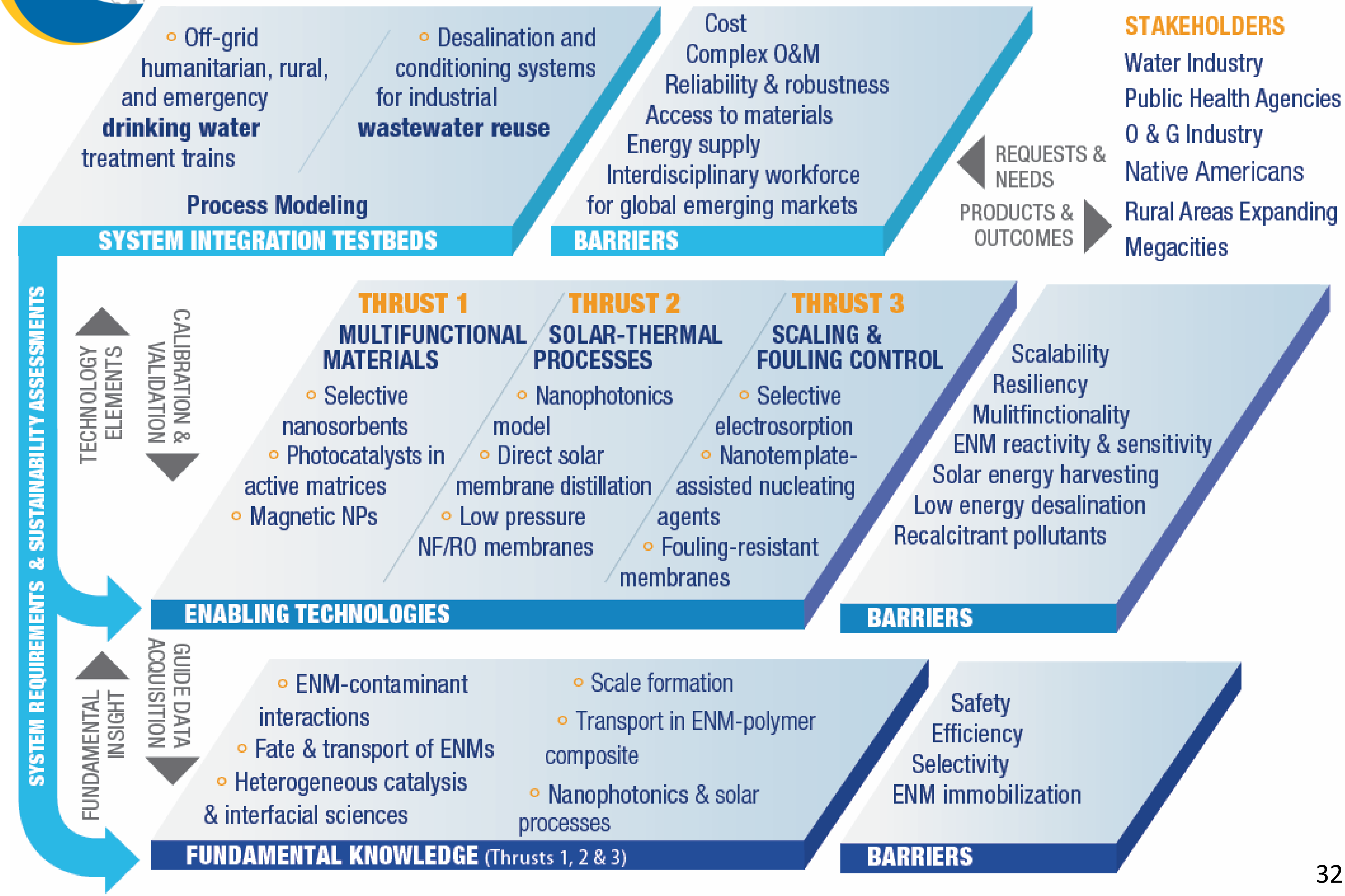
| **Wong** & Kim | **Halas** & Lind | **Elimelech** & Li |
|---|---|---|
| **Thrust 1. Multifunctional ENMs** | **Thrust 2. Solar Desalination Processes** | **Thrust 3. Scaling and Fouling Control** |
| **1.1.** Multifunctional ENM sorbents | **2.1.** ENM-light Inacteraction | **3.1.** Nanotemplate for mineral nucleation |
| **1.2.** Multifunctional magnetic-core ENMs | **2.2.** Nanophotonics-enhanced solar MD | **3.2.** ENM coatings for fouling/scaling control |
| **1.3.** Multifunctional Photocatalytic ENMs | **2.3** Mixed matrix NF/RO membrane | **3.3.** Nanocomposite electrodes for electrosorption |

**Westerhoff**, Alvarez & Li

## Drinking Water/Industrial Wastewater Testbeds



# Top-Down Strategic Approach



# Culture of Inclusion

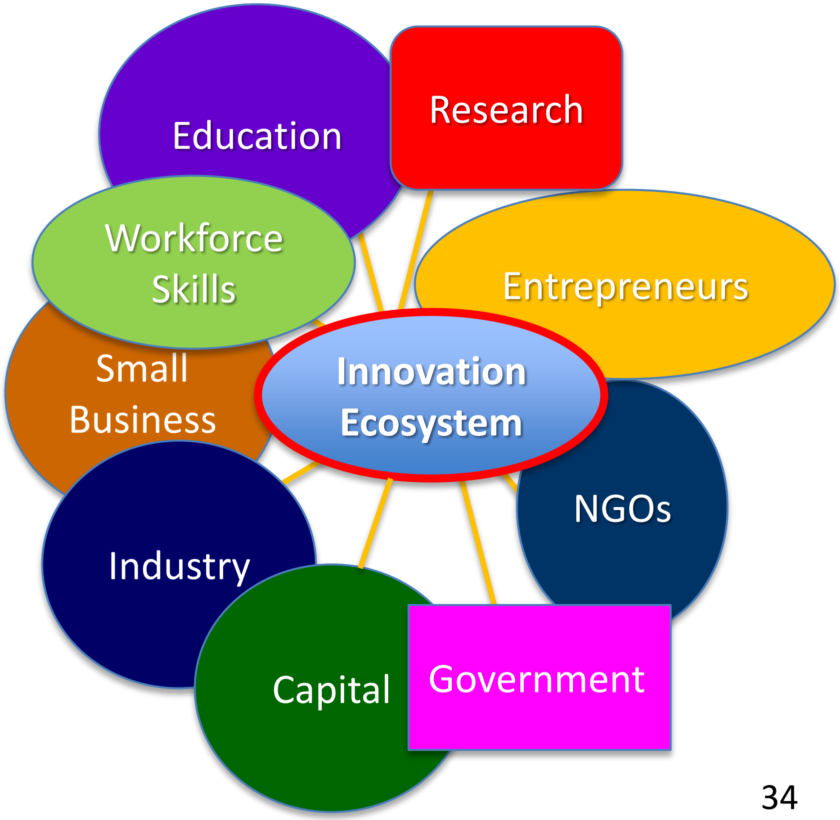
- NEWT will be a magnet to increase the number of underrepresented groups in STEM fields contributing to scientific progress, economic growth, and global health

| Objective | Approach |
| --- | --- |
| Recruit and retain underrepresented UG STEM students (start at K-12) | Form partnerships with school districts and industry (internships) |
| Recruit and nourish diverse GR STEM students | Summer exchange programs and international opportunities |
| Help students develop careers | Promote networking |
| Increase diversity of STEM faculty | Targeted recruitment and placement of graduates |

# 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

***Brad Burke, IE Director***
Runs the Top Global University Business Incubator in the World, and top program In graduate entrepreneurship



# What We Will See in 10 Years

- Affordable access to potable water almost anywhere using modular treatment units that tap unconventional sources (drought alleviation, disaster relief, emergency supply)
- Lower industrial water footprint (e.g., energy production with less fresh water and with lower environmental impact)
- Synergistic research support to/from other NSF investments
- A more diverse technical work force trained to translate basic research into innovative products
- More jobs and exports of innovative water technologies

***"People don't know what they want until you show it to them"*** – Steve Jobs

# BACKUP SLIDES

# Crosscutting Research Thrusts and Testbeds

## Drinking Water Testbeds / Industrial Wastewater Testbed

### Thrust 1. Multifunctional ENMs

**1.1.** Multifunctional ENM sorbents
**1.2.** Multifunctional magnetic-core ENMs
**1.3.** Multifunctional Photocatalytic ENMs

### Thrust 2. Solar-Thermal Processes

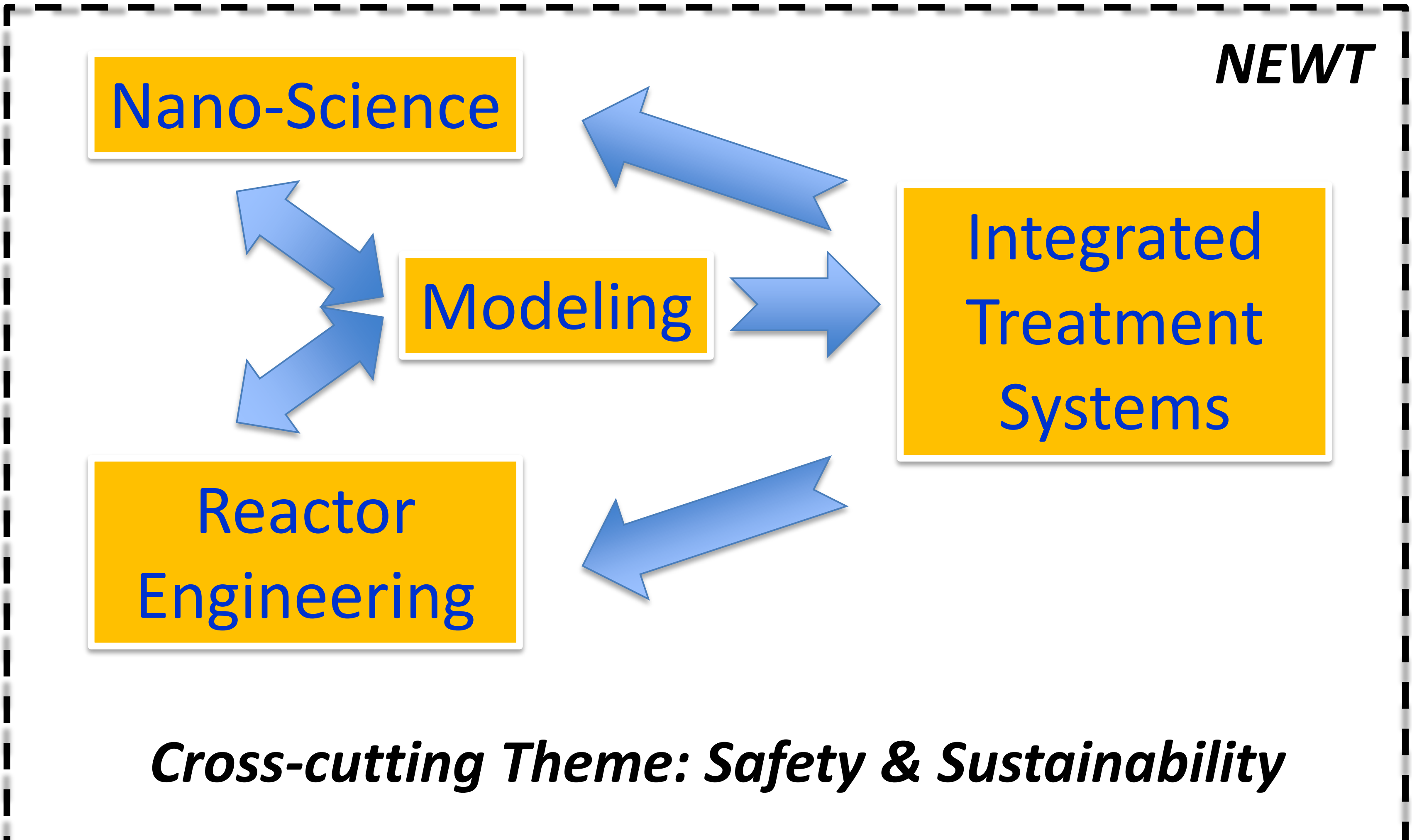
**2.1.** ENM-light Interactions
**2.2.** Nanophotonics-enhanced solar MD
**2.3** Mixed matrix NF/RO membrane

### Thrust 3. Scaling and Fouling Control

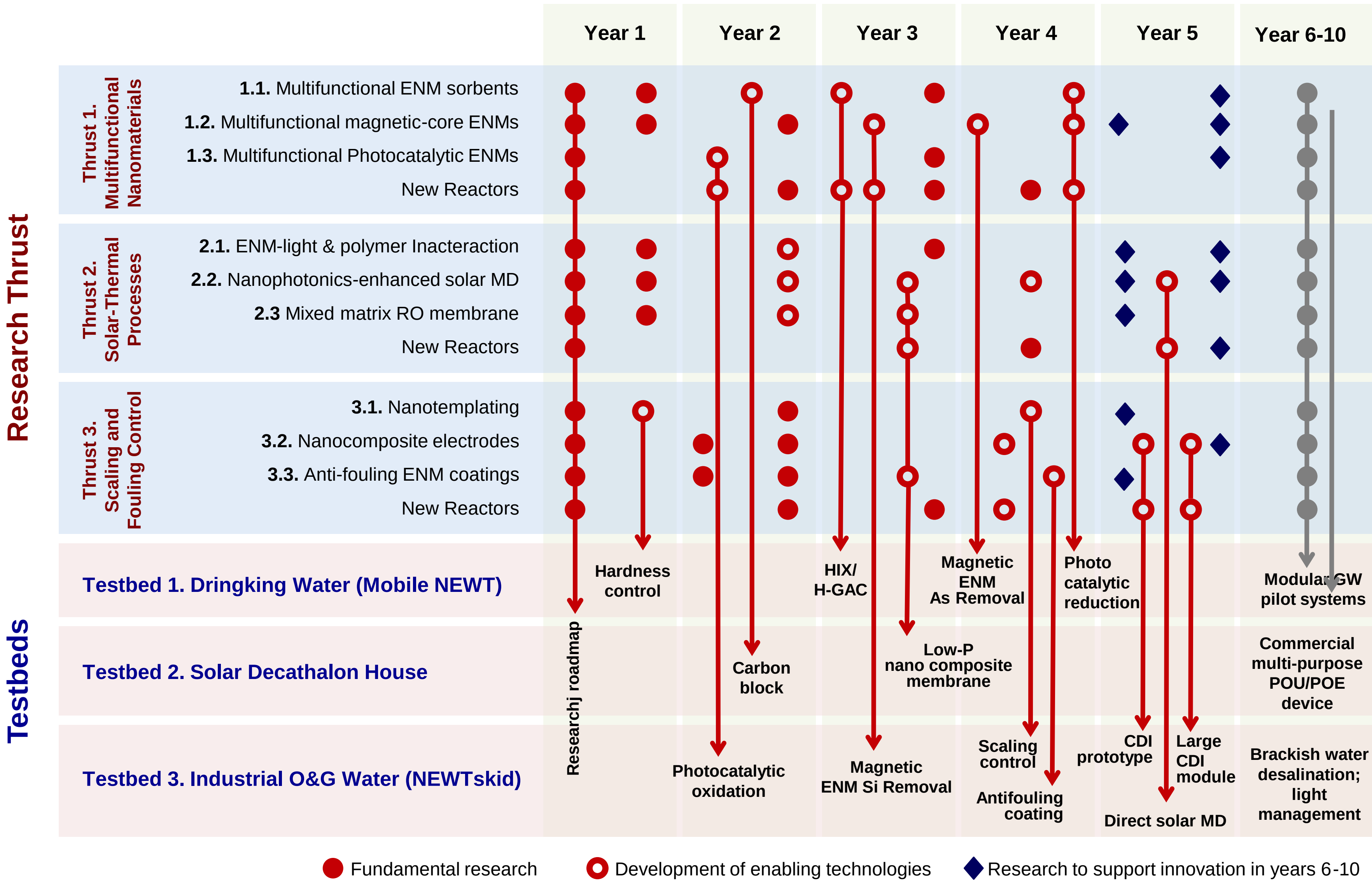
**3.1.** Nanotemplate for mineral nucleation
**3.2.** ENM coatings for fouling/scaling control
**3.3.** Nanocomposite electrodes for electrosorption

| Mobile NEWT (Drinking Water Testbed) | | Solar Decathlon (Drinking Water Testbed) | | NEWTskid (Industrial Wastewater Testbed) | |
|---|---|---|---|---|---|
| Hardness Control | 3 | Carbon Block | 2 | Photo-catalytic oxidation | 1 |
| HIX/ H-GAC | 1 | Direct solar MD | 2 | Magnetic ENM Si Removal | 1 |
| Magnetic NPs for As Removal | 1 | Photo catalytic reduction | 1 | Scaling Control By CDI | 3 |
| Photo-catalytic reduction | 1 | Photo catalytic oxidation | 1 | Antifouling coating | 3 |
| Photo-catalytic oxidation | 1 | | | CDI | 3 |
| | | | | Nano composite membrane | 2 |

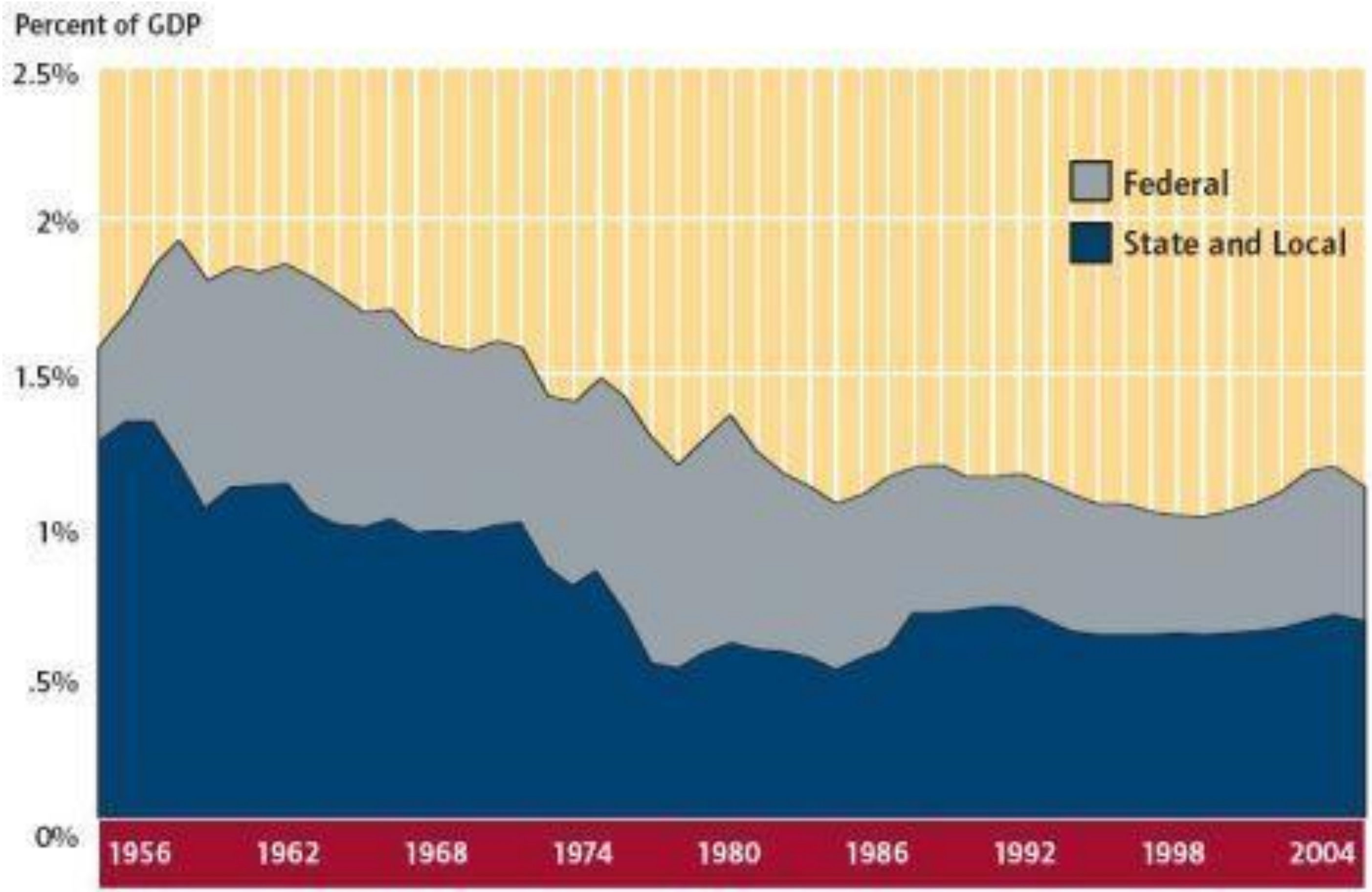
# Research Components



# All thrust template



America's water infrastructure is outdated, worn, and in some cases, failing. Most experts agree that it is inadequate to meet the demands of the 21st-century global economy.




PUBLIC SPENDING ON WATER AND TRANSPORTATION INFRASTRUCTURE AS A PERCENT OF GDP, 1956–2004

Source: Congressional Budget Office.

http://www.newamerica.net/publications/policy/financing_americas_infrastructure

# Why We Need a National Research Center

- Attract the brightest minds/ students to focus on water securit

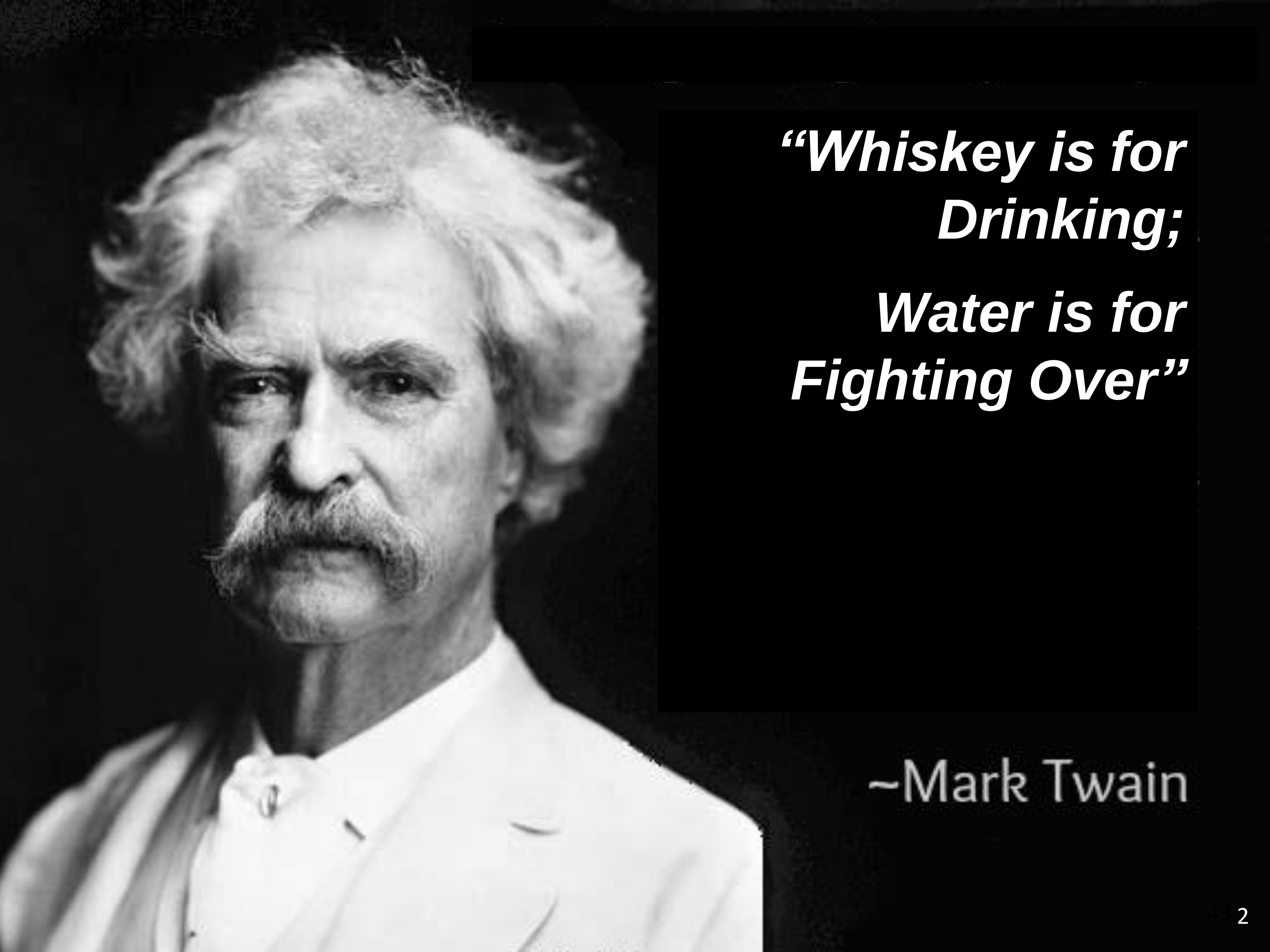
http://www.ngobox.org/wp-content/uploads/2013/08/water-security.jpg

- Provide a platform and resources to synergize and engage industry and other partners to provide a road to deployment and commercialization

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

# By the End of this Visit, You Will See

- ✓ Strong technical team and students
- ✓ Leading-edge research driven by societal and industrial needs
- ✓ Efficient and transparent use of resources
- ✓ Synergism with industrial and government partners across the value chain providing a path for financial sustainability beyond 10 years
- ✓ Award-winning entrepreneurship model for commercialization
- ✓ Education of next-generation, diverse workforce


"Whiskey is for Drinking;
Water is for Fighting Over"
~Mark Twain