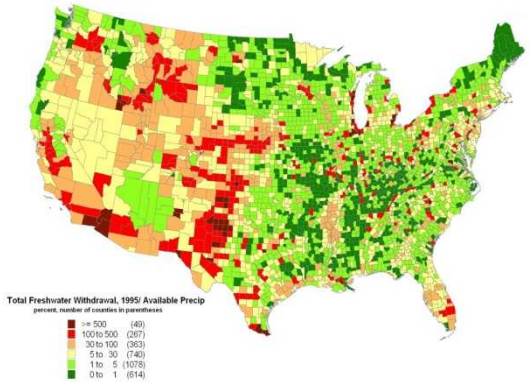
SAND2016-12539PE



Sandia Water Treatment & Desalination Research, Development & Demonstration

December 12, 2016

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia Sites

Albuquerque, New Mexico

Livermore, California

Kauai, Hawaii

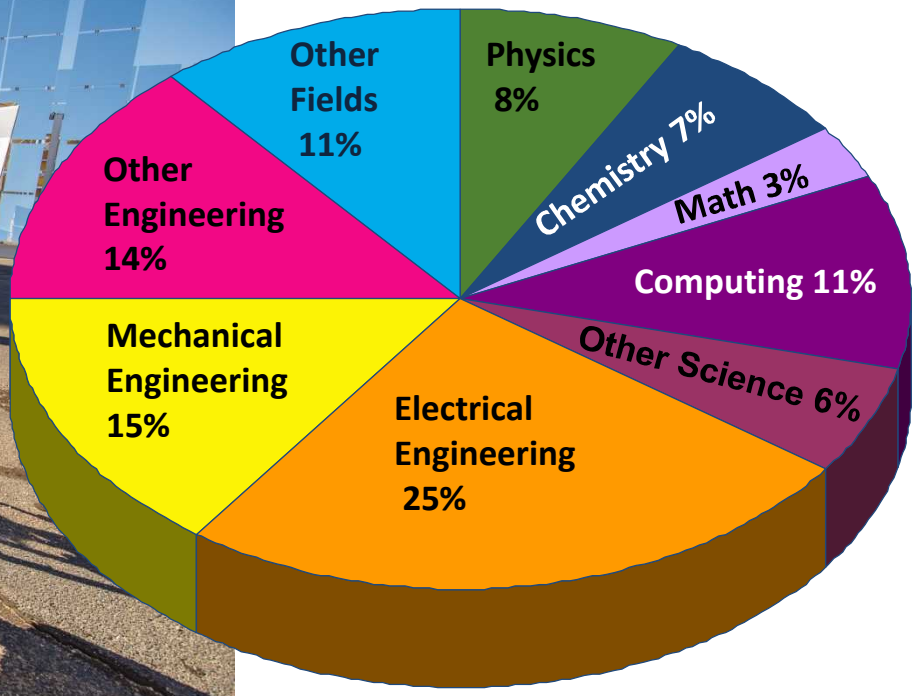
Waste Isolation Pilot Plant, Carlsbad, New Mexico

Pantex Plant, Amarillo, Texas

Tonopah, Nevada

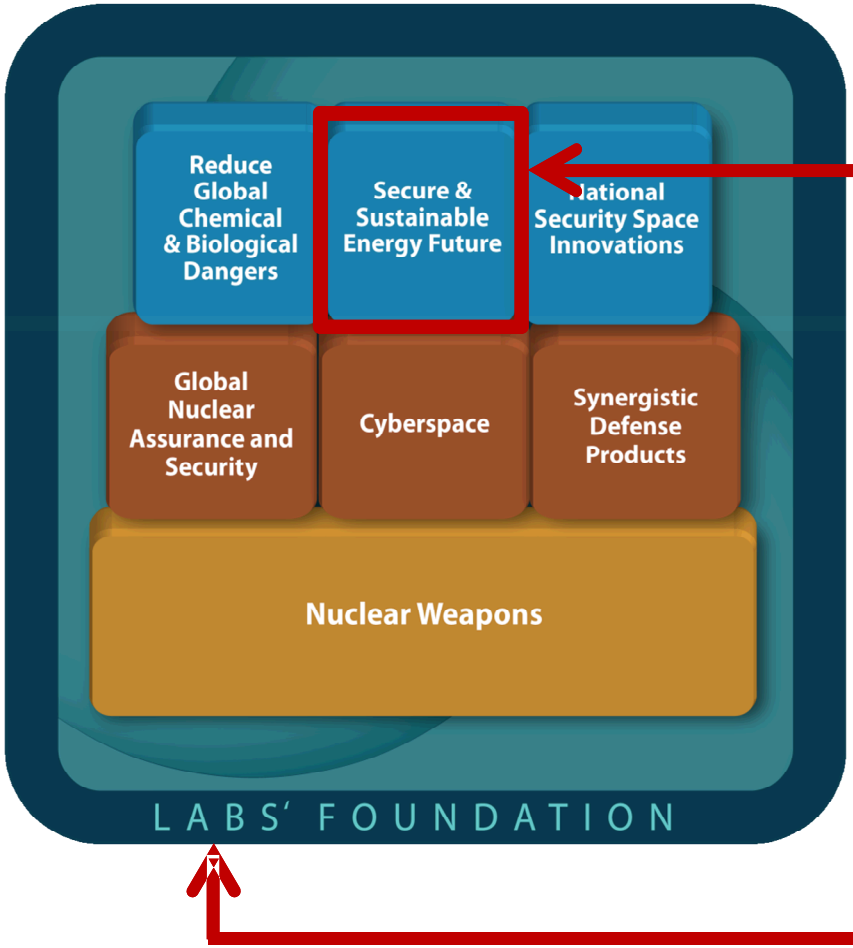
Our Workforce

- Total Sandia workforce: 12,001
  - New Mexico: 10,715
  - California: 1,286
- Advanced degrees: 5,859 (55%)
- Total FY16 budget: $3B

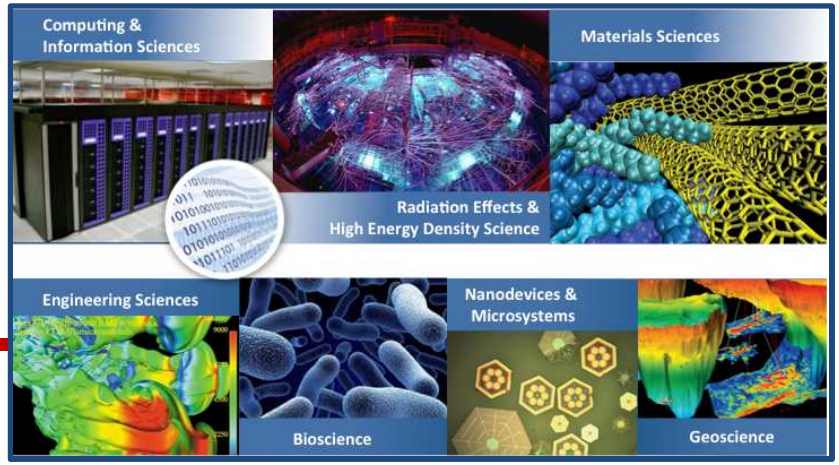


Sandia Mission Framework

Seven Mission Areas draw from and contribute to Lab's Foundation

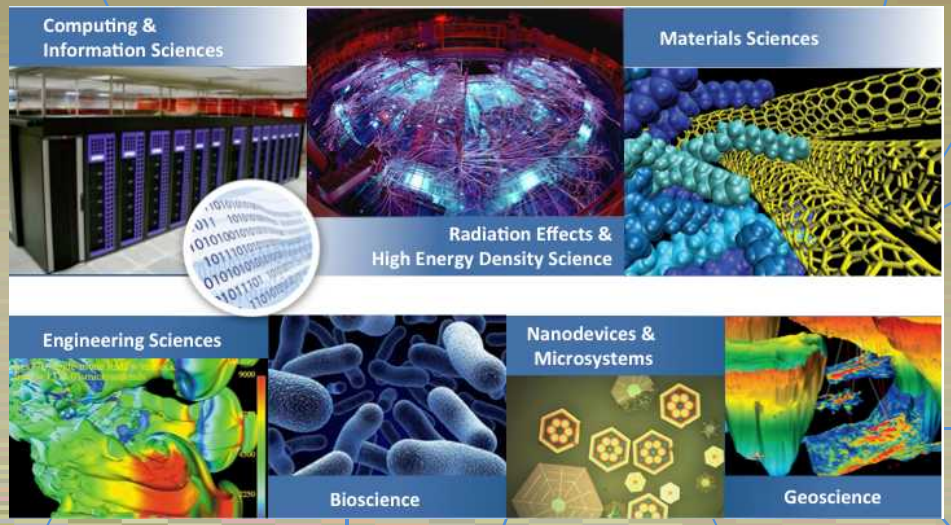


Secure & Sustainable Energy Future **- science-based understanding of the complex interdependencies between energy and climate**



Lab's Foundation includes LDRD, Office of Science Research and major computational and experimental capabilities

Capabilities Represented Today



Molecular Scale Modeling

Advanced Materials Laboratory

Novel Membrane Development

Chemical Treatment Technologies

Chemical Treatment Technologies

Topology Optimization Additive Manufacturing

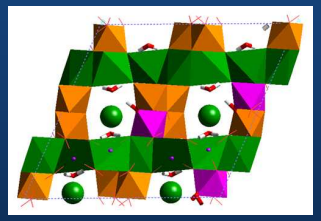
Sensor Development

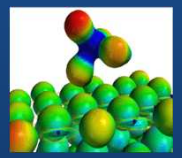
Novel Membrane Development

Molecular Scale Modeling

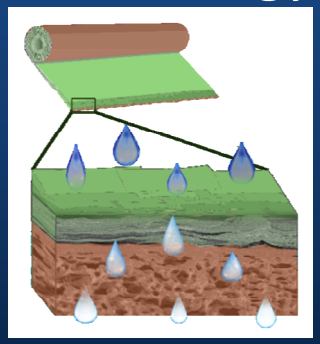
We Manage the Life-Cycle of our Technology

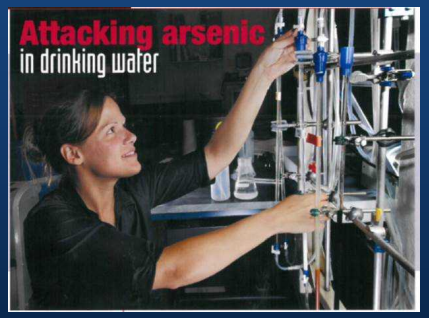
Research





Technology Development

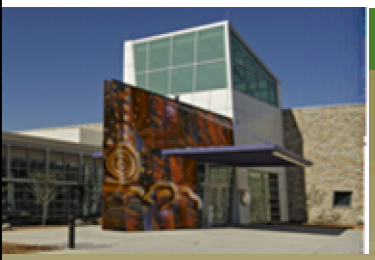




Commercialization

Pilot Programs

Energy & Climate Mission

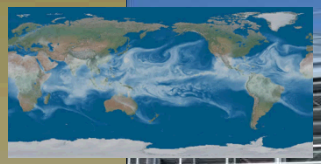


Energy Research

ARPAe, BES Chem Sciences, ASCR, CINT, Geo Bio Science, BES Material Science

Climate & Engineered Earth Systems

Climate Modeling & Measurement, Energy & Water, Fossil Energy Management, Biofuels

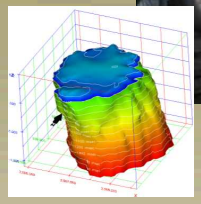


Nuclear Energy & Fuel Cycle

Commercial Nuclear Power & Fuel, Nuclear Energy Safety & Security, DOE Managed Nuclear Waste Disposal

Renewable Systems & Energy Infrastructure

Renewable Energy, Energy Efficiency, Grid and Storage Systems



Transportation Energy & Systems

Vehicle Technologies, Biomass, Fuel Cells & Hydrogen Technology

Sandia National Laboratories

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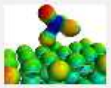

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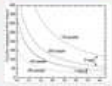

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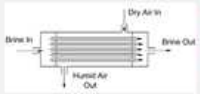
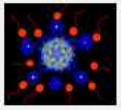


2001 — UV ULTRAVIOLET WATER PURIFICATION SYSTEMS FOR RURAL ENVIRONMENTS AND MOBILE APPLICATIONS

2002 — ARSENIC PILOT DEMONSTRATION PROJECTS

2003 — FRONTIERS OF INTERFACIAL WATER RESEARCH WORKSHOP

2004 — CAPACITIVE IONIZATION FOR COAL-BED NATURAL GAS PRODUCED WATER



PATENT FOR NEXT-GEN COAGULENT FOR THE REMOVAL OF BACTERIA AND VIRUSES

2005 — PRODUCED WATER PILOT SAN JUAN BASIN

2006 — IMPLEMENTATION OF THE NATIONAL DESALINATION AND WATER PURIFICATION TECHNOLOGY ROADMAP

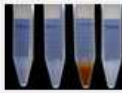
2007 — EXPLOITING INTERFACIAL WATER PROPERTIES FOR DESALINATION & WATER PURIFICATION APPLICATIONS

MEMBRANE DISTILLATION WATER TREATMENT USING POWER PLANT WASTE HEAT

2008 — SELF-SEALING EVAPORATIVE POND LINER

BIOMIMETIC MEMBRANE R&D 100 AWARD

2009 — CRYSTALLINE SILICOTITANATES FOR RADIOACTIVE CESIUM REMEDIATION



COAGULATION CHEMISTRIES FOR SILICA REMOVAL FROM COOLING TOWER WATER

2010 — USE OF FLUE GAS TO CONTROL SILICA AND CALCITE SCALE IN COOLING TOWERS

2011 — MEMBRANE DISTILLATION PROJECT FOR SMALL NEW MEXICO BUSINESS

NMSBA

2012 — WASTE WATER FOR POWER GENERATION VIA ENERGY EFFICIENT SELECTIVE SILICA SEPARATIONS

GRAPHENE OXIDE/POLYMER MEMBRANES

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

U.S. DEPARTMENT OF ENERGY | NNSA

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Sandia Water Treatment Partnerships: Past and Present

TROJAN technologies
el paso WATER
Imperial Oil
uop A Honeywell Company
conoco
CalgonCarbon
carollo
ABQ Bernalillo County Water Utility Authority
Jemez Pueblo
WateReuse Foundation
Water Research Foundation
Electric Power Research Institute EPRI
Brackish Groundwater National Desalination Research Facility
HDR Engineering
B&W Global Tech LLC
MIOX Corporation
Bureau of Reclamation
Environmental Protection Agency
Los Alamos National Laboratory
NETL National Energy Technology Laboratory
National Renewable Energy Laboratory
UT El Paso
New Mexico State
University of New Mexico
New Mexico Tech
University of Illinois Affordable Desalination Coalition
Colorado School of Mines
Water Education Foundation
iea International Energy Agency

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

Contact
Name: Susan Altman
Phone: (505) 844-2397
E-mail: sjaltma@sandia.gov

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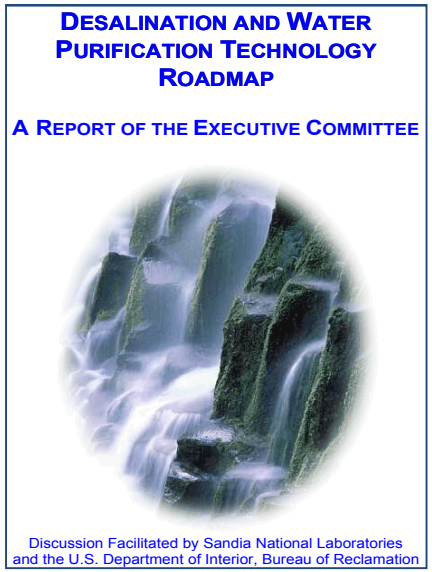
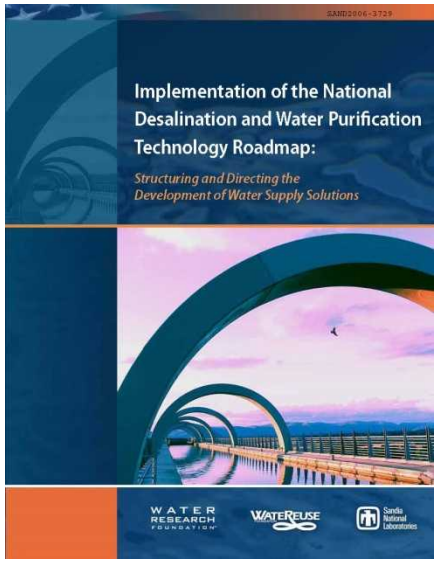
Efforts in Charting the Course of National Desalination Research and Development





2003 – With EPA and Bureau of Reclamation (BOR)
Summarized water challenges facing US and charted the course of R&D to meet these challenges

Defined critical objectives to reduce cost and increase performance and energy efficiency

Quantified needs and five broad technology areas to meet these needs:
- **Membrane Technologies**
- **Alternative Technologies**
- **Thermal Technologies**
- **Concentrate Management Technologies**
- **Recycle/Reuse Technologies**

2007 – With Bureau of Reclamation and WateReuse Foundation
Identified objectives for technology implementation
- **Hasten the rate of technological advances**
- **Reduce the cost of new technologies**

Organized into 4 broad National Research Areas with 25 Research Agendas and 58 Research Projects
- **Membrane Technologies**
- **Alternative Technologies**
- **Concentrate Management Technologies**
- **Institutional Issues**

Efforts to Accelerate Brackish Water Desalination Technology Development

Sandia National Laboratories

Brackish Groundwater National Desalination Research Facility (BGNDRF) Alamogordo, NM

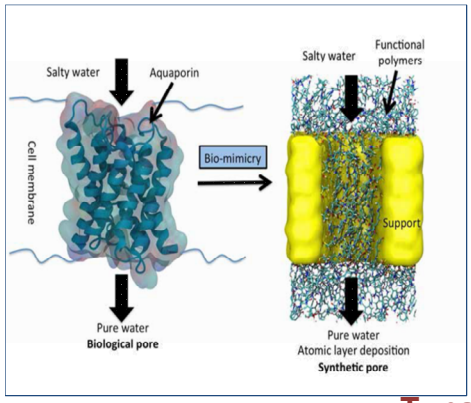
- Led effort with Bureau of Reclamation on a Report to Congress for the conceptual design of a national brackish water desalination research facility - 2003
- Supported BOR on final design, construction, and operation - 2004 - 2009

Clients:

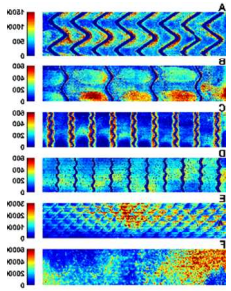
UTEP
NM State University
Texas Tech
Atlantis Technologies
Cost-effective Wastewater Desalination
GE
OASYS WATER
University of Nevada, Reno
VEOLIA
Voltea
LG
LG WATER STANDARD
A global water solution in partnership with nature

Research and Development of Next Generation Water-Treatment Membranes

INTERNAL FUNDING

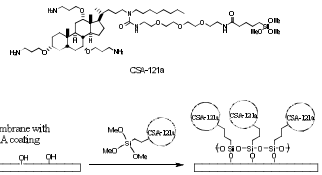


Tunable Biomimetic Membrane for Water Desalination

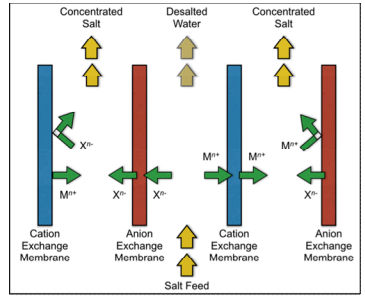


Micro-mixers for Mitigating Membrane Fouling

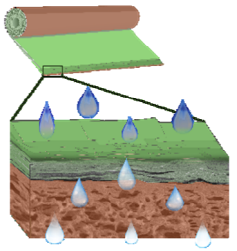
Bio-fouling Resistant Ceragenin-modified Water Treatment Membranes



Nanoporous Membranes



Bio-inspired Ion-Selective ED Membranes

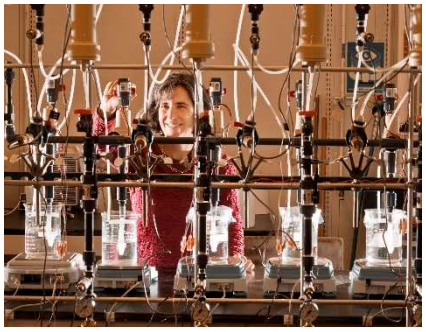


Graphene Oxide/Polymer Membranes

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

EXTERNAL FUNDING

DOE Building of Membrane Testing Equipment



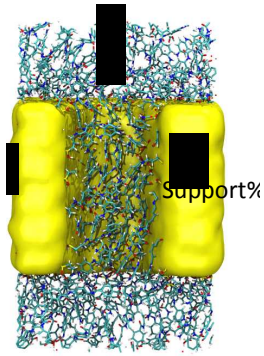
EPRI GO/polymer Membrane Treatment of Cooling-Tower Water

Sandia solid-water interfacial projects relevant to water-treatment membrane design

INTERNAL FUNDING

Behavior of Water in Zeolite Nanopores

CO_2 Memzyme

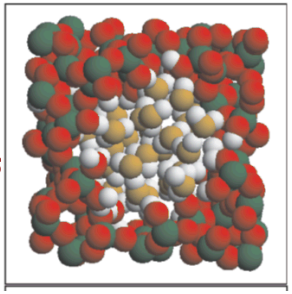


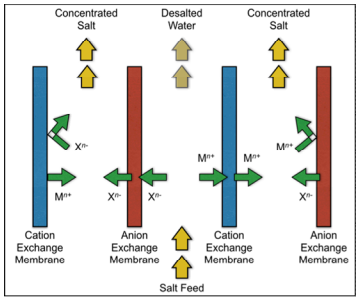
Exploiting Interfacial Water Properties for Desalination and Purification Applications

Tunable Biomimetic Membrane for Water Desalination

Functionalized Silica Nanopores

Nanoporous Membranes





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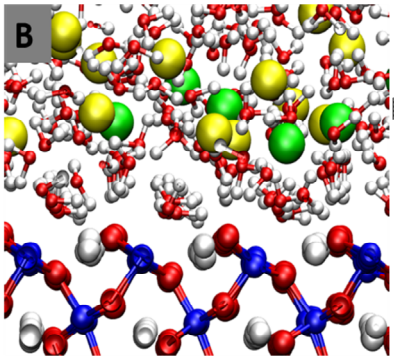


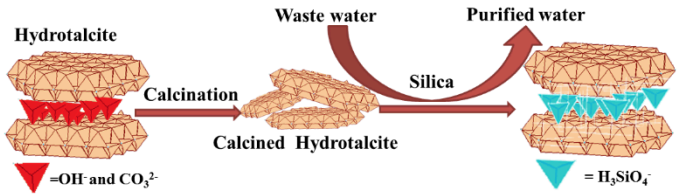
Office of Science, Basic Energy Science

Electrolyte Adsorption to Fe-Oxyhydroxide

NIH Nanomedicine Design of Biomimetic Nano-conductors

Airforce Biomimetic Nanostructures

Research and Development of Next Generation Desalination Membranes



Sandia Designer Sorbents 1993-2016

Sandia National Laboratories

Target	Sorbent(s)	Application	1st Sandia paper/patent submitted
Cs^+	Crystalline silico-titanate	Radwaste separations	1993
I^-	HgS, Cu_2S, Bi-doped clays	Radwaste backfills/ separations	1996
TcO_4^-	AlOOH, Ca-phosphates	Radwaste backfills/ separations	1998
Sr^{++}	CST, Ca-phosphates, calcite	Radwaste backfills/ separations	1998
As(V)	Spinels, MgO	Drinking water	2004
Salts	Zeolites	Desalination	2004
Cr(VI)	Spinels	Drinking water	2004
ClO_4^-	Metal-doped GAcs	Drinking water	2005
Silica	Metal-silicates, Catechol	Industrial water treatment	2009
Selenium	Ca-phosphates	Groundwater cleanup	2016

TRL 1 → 9

Desalination Technology Large-scale Demonstration and Evaluation

Coal Bed Methane produced water treatment for rangeland rehabilitation, Bloomfield NM
In cooperation with Bureau of Land Management, Los Alamos National Laboratory, NM Oil Conservation Division, New Mexico Agriculture Department, and New Mexico State

Laboratory and pilot-scale testing of Zero Discharge Desalination (ZDD) at BGNDRF with 97% water recovery - technology license purchased by Veolia

Coal fines accumulating in the modified zeolite filtration medium.

Commercialization Experience Shows Benefits of Early Systems Engineering Coordination

2001 — Concept: Sandia's Microchemlab has the potential to be used for monitoring the disinfection byproducts of chlorination.

2002 — Sandia invests 1.3 M over three years to develop a sensor for detecting disinfection byproducts.

2005 — Sandia completes prototype sensor capable of detecting disinfection byproducts in the ppm range.

Sandia presents technology at AWWA Conference and attracts the attention of Parker Hannifin.

Parker Hannifin makes first investment for Sandia to improve sensor detection limit.

2007 — In collaboration with Sandia materials scientists, the sensor detection limit is improved from ppm to ppb.

2008 — Sandia licenses technology to Parker Hannifin. PH invests 2M to develop disinfection by product detection instrument.

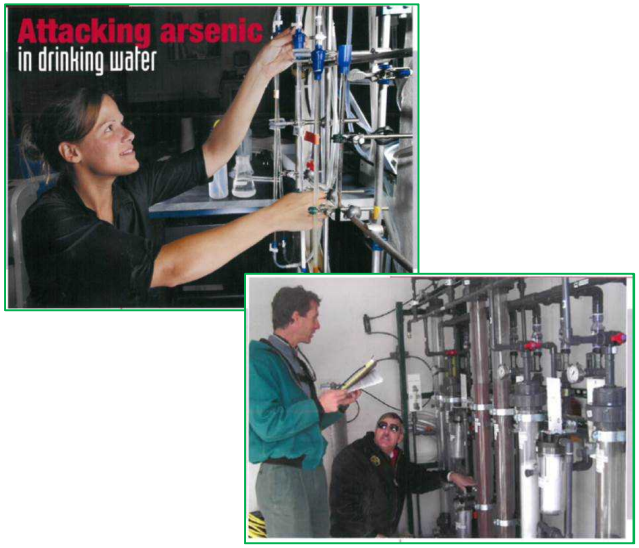
2011 — Parker Hannifin begins sales of instrument with batch sampling capability.

2015 — Parker Hannifin begins sales of instrument with continuous sampling capability.

Simple Solution to Complex Water Challenge Facing Rural New Mexicans

2001: EPA lowers maximum limit for arsenic in drinking water from 50 ppb to 10 ppb. As a result, rural New Mexico communities will be required to deploy costly, sophisticated treatment systems.

Installation of high-tech treatment systems which will cost $58 to $237 per year for households already experiencing financial strain.



In response to request from NM Senator Pete Domenici, Sandia develops a low-cost solution, known as Hedgehog, that requires no added operation or infrastructure costs and created no added financial burden for rural New Mexicans.

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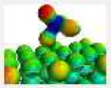

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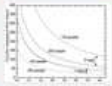

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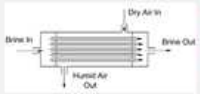
APATITE PERMEABLE REACTIVE BARRIERS FOR IN SITU REMEDIATION OF URANIUM IN SUBSURFACE OF UMTRA SITE

2000 — DEVELOPMENT OF SWEEPING GAS MEMBRANE DESALINATION USING COMMERCIAL HYDROPHOBIC HOLLOW FIBER MEMBRANES

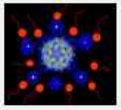


2001 — UV ULTRAVIOLET WATER PURIFICATION SYSTEMS FOR RURAL ENVIRONMENTS AND MOBILE APPLICATIONS

2002 — ARSENIC PILOT DEMONSTRATION PROJECTS

2003 — FRONTIERS OF INTERFACIAL WATER RESEARCH WORKSHOP

2004 — CAPACITIVE IONIZATION FOR COAL-BED NATURAL GAS PRODUCED WATER



PATENT FOR NEXT-GEN COAGULENT FOR THE REMOVAL OF BACTERIA AND VIRUSES

2005 — PRODUCED WATER PILOT SAN JUAN BASIN

2006 — IMPLEMENTATION OF THE NATIONAL DESALINATION AND WATER PURIFICATION TECHNOLOGY ROADMAP

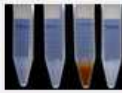
2007 — EXPLOITING INTERFACIAL WATER PROPERTIES FOR DESALINATION & WATER PURIFICATION APPLICATIONS

MEMBRANE DISTILLATION WATER TREATMENT USING POWER PLANT WASTE HEAT

2008 — SELF-SEALING EVAPORATIVE POND LINER

BIOMIMETIC MEMBRANE R&D 100 AWARD

2009 — CRYSTALLINE SILICOTITANATES FOR RADIOACTIVE CESIUM REMEDIATION



COAGULATION CHEMISTRIES FOR SILICA REMOVAL FROM COOLING TOWER WATER

2010 — USE OF FLUE GAS TO CONTROL SILICA AND CALCITE SCALE IN COOLING TOWERS

2011 — MEMBRANE DISTILLATION PROJECT FOR SMALL NEW MEXICO BUSINESS

NMSBA

2012 — WASTE WATER FOR POWER GENERATION VIA ENERGY EFFICIENT SELECTIVE SILICA SEPARATIONS

GRAPHENE OXIDE/POLYMER MEMBRANES

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

U.S. DEPARTMENT OF ENERGY | NNSA

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BACK-UP SLIDES

Energy & Climate Mission

Strategy Elements

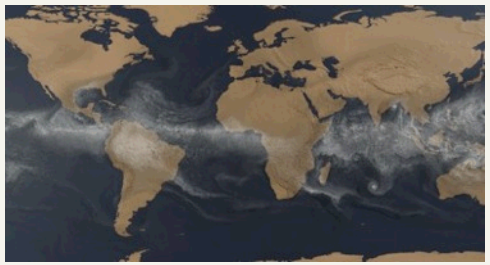
STATIONARY POWER

High Efficiency Conversion to Electricity

Safety, Security, & Resilience of the Energy Infrastructure

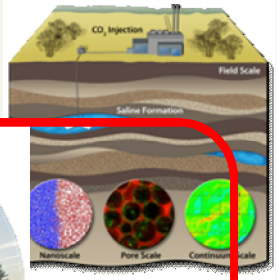
Back End of the Nuclear Fuel Cycle

CLIMATE & EARTH SYSTEMS



Climate Measurements & Modeling

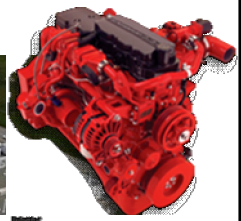
Sustainable Subsurface Energy Development

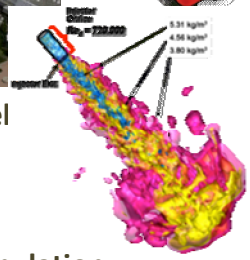


Water/Energy Nexus

TRANSPORTATION ENERGY

Convergence of Biofuel & Powertrains





Predictive Simulation of Engines

Enabling a Hydrogen Infrastructure

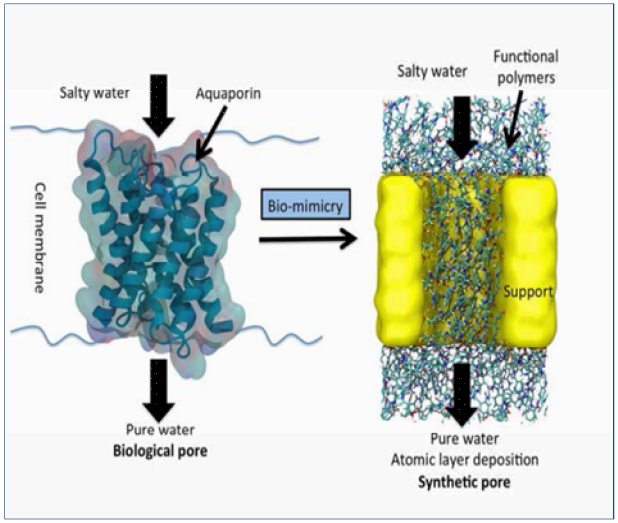
Safe & Reliable Electrical Storage & Components

Research and Development of Next Generation Desalination Membranes

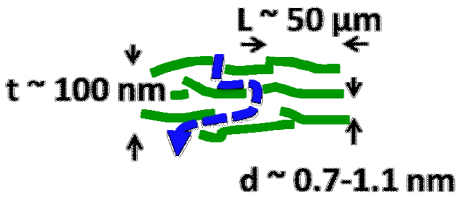
Sandia National Laboratories

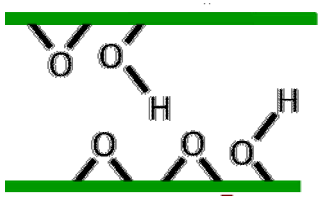
Developed biomimetic-based (kidney-like) reverse osmosis (RO) membrane with 5 times higher permeate flow per unit of pressure than traditional RO membranes (RD100).

Also developing bio-based electrodialysis membranes.



https://www.youtube.com/watch?v=11RQ3N9uH1w



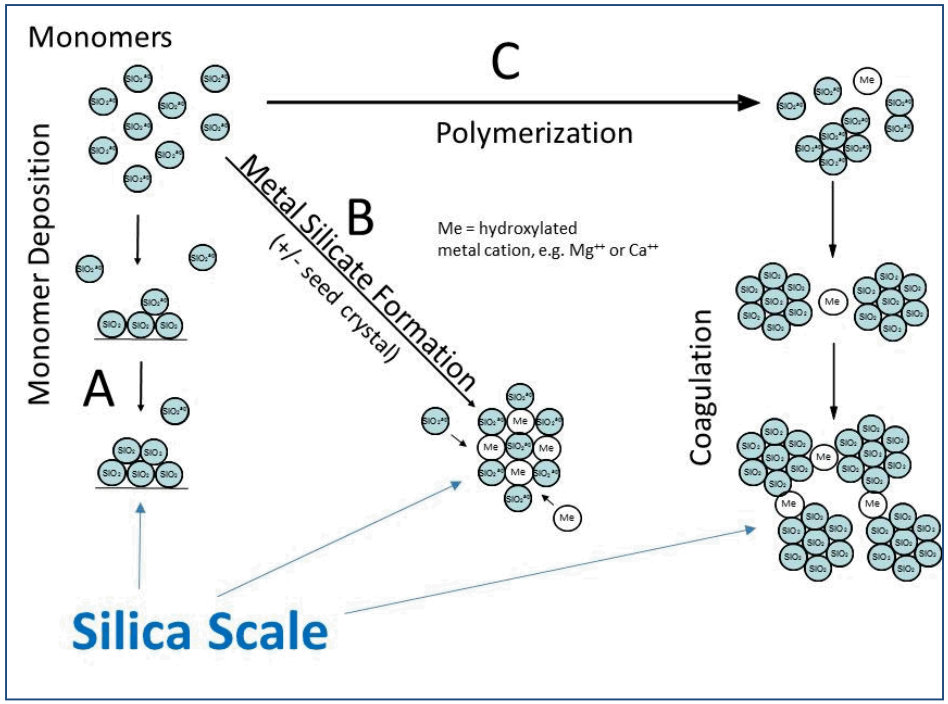


Developing laminar graphene oxide (GO) membranes, whose structure is ideal for water desalination.
Structure is chemically tolerant to 1-ppm, one month, free chlorine exposure, as well as hydrocarbons (ie: toluene, oils)

Developed and tested reverse osmosis membranes with integrated biocide nanoparticles to reduce biofouling.

Research on Chemical Treatments for Selective Ion Removal to Enhance Desalination

Dissolved silica often limits water recycling in energy extraction, energy production, and CO_2 capture. New methods are also needed to prevent silica scale in cooling towers and boilers.



Recent Projects:

- **Impaired Water Reuse in Power Plant Cooling** (Nenoff LDRD)
- **pH control/scale prevention in Power Plant Cooling** (Brady and Krumhansl, US Patent 9140145)
- **Advanced coagulation for Oil Sands Water Recycling** (Brady et al., WFO)
- **Carbon Mineralization for Climate Change** (Columbia/Sandia ARPA-E).

SiO_2^{aq} concentration in some waters:

Los Alamos tap water, 88 ppm; Cooling tower, 123 ppm; El Paso desal conc. 148 ppm; Canada Oil Sands, 239 ppm; Geothermal (Wairakei, Ohnuma), 520-560 ppm