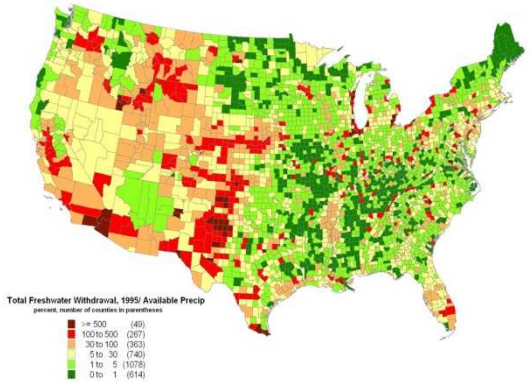
SAND2016-9597PE

Exceptional service in the national interest

Sandia National Laboratories



Sandia Water Treatment & Desalination Research, Development & Demonstration

September 14, 2016

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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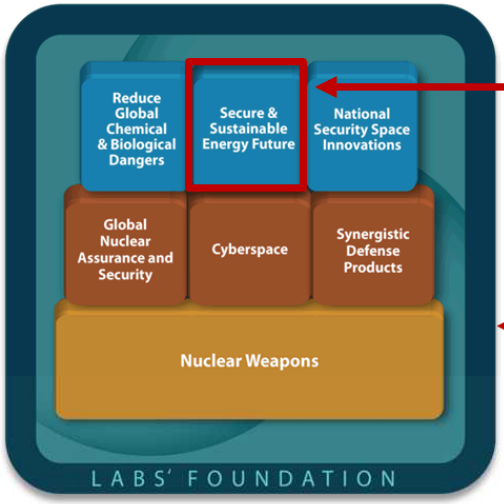
Sandia Mission Framework

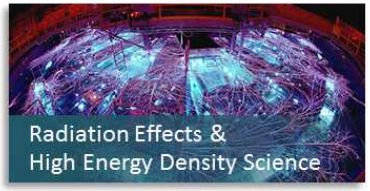
Sandia National Laboratories

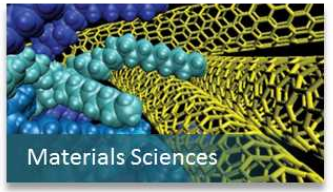
Seven Mission Areas draw from and contribute to Lab's Foundation

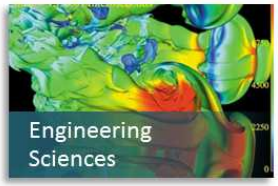


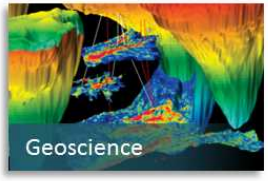
Secure & Sustainable Energy Future -- *Science-based understanding of the complex interdependencies between energy and climate*

Lab's Foundation -- *Seven Research Foundations, Office of Science Research and major computational and experimental capabilities*









Secure & Sustainable Energy Future Mission Area

Sandia National Laboratories

Strategy Elements

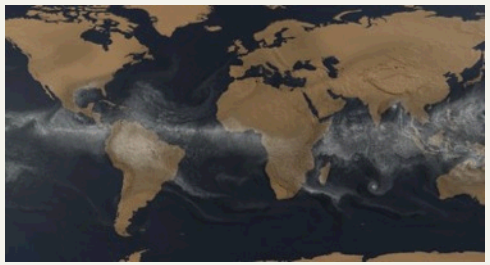
STATIONARY POWER

High Efficiency Conversion to Electricity

Safety, Security, & Resilience of the Energy Infrastructure

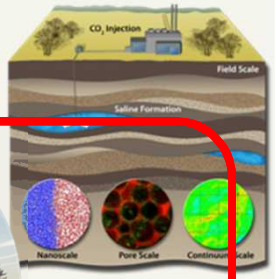
Back End of the Nuclear Fuel Cycle

CLIMATE & EARTH SYSTEMS



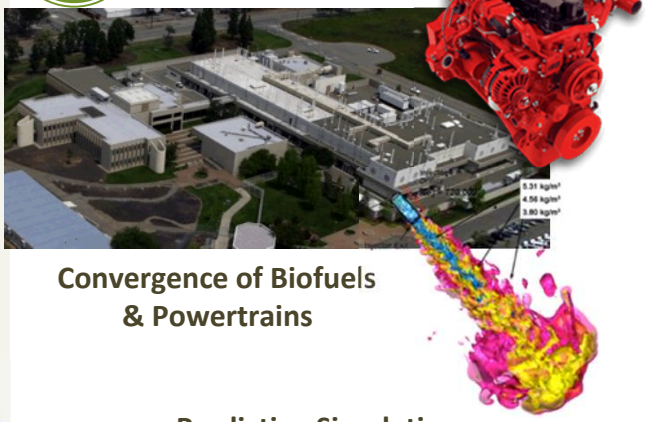
Climate Measurements & Modeling

Sustainable Subsurface Energy Development



Water/Energy Nexus

TRANSPORTATION ENERGY



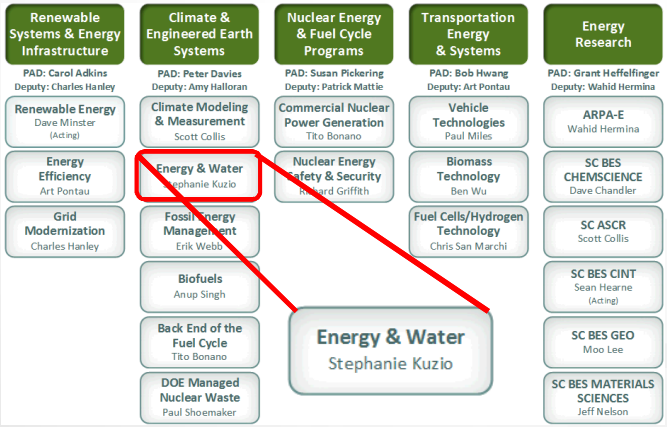
Convergence of Biofuels & Powertrains

Predictive Simulation of Engines

Enabling a Hydrogen Infrastructure

Safe & Reliable Electrical Storage & Components

Energy & Climate (EC) PMU Leadership



Marianne Walck
EC Vice President

Juan Torres
EC Deputy

Carol Adkins
Renewable Systems & Energy Infrastructure

Juan Torres
Deputy

Peter Davies
Climate & Engineered Earth Systems

Amy Halloran
Deputy

Grant Heffelfinger
Energy Research

Wahid Hermina
Deputy

Susan Pickering
Nuclear Energy & Fuel Cycle

Patrick Mattie
Deputy

Bob Hwang
Transportation Energy & Systems

Art Pontau
Deputy

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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
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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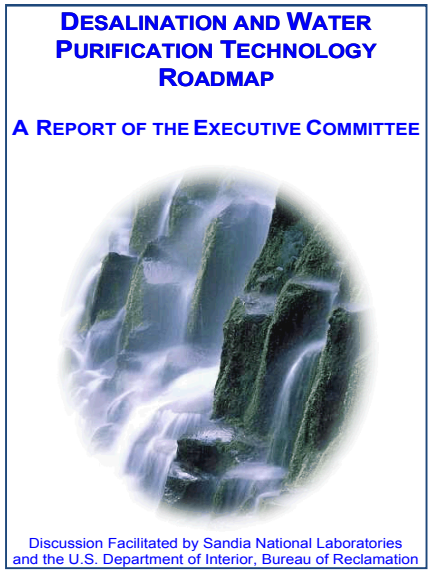
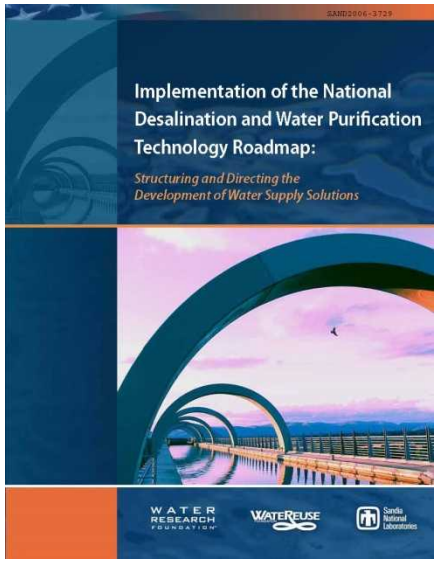
Efforts in Charting the Course of National Desalination Research and Development





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

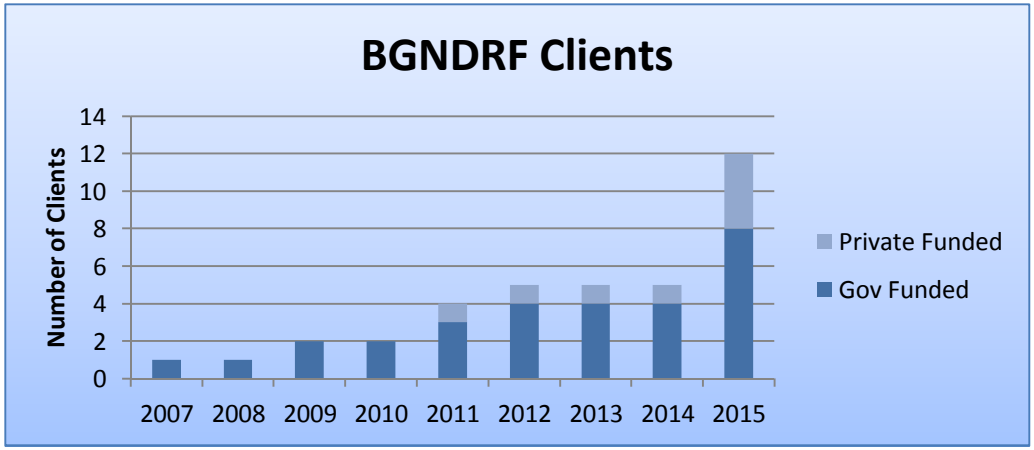
Quantified needs and five broad technology areas to meet these needs:
- **Membrane Technologies**
- **Alternative Technologies**
- **Thermal Technologies**
- **Concentrate Management Technologies**
- **Recycle/Reuse Technologies**

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

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
- Significant growth in research since 2008 commissioning
  - DOW, GE, Veolia, Evoqua, Water Standard Company, Unilever, MIT, Univ. of Arizona, UTEP, Nevada-Reno, Colorado School of Mines, New Mexico State

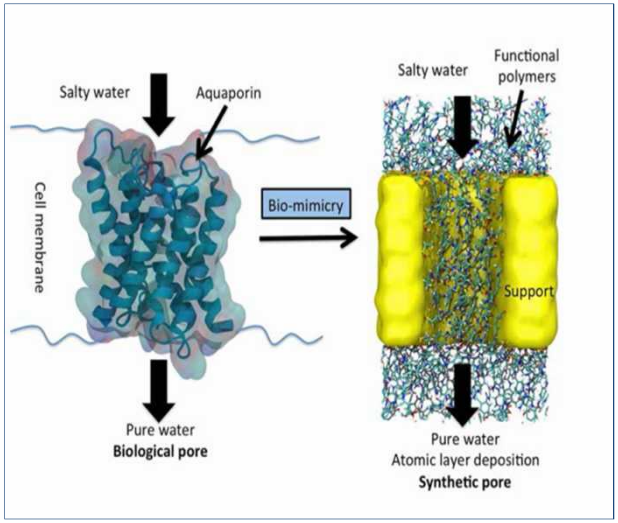
Focus areas - Brackish desalination, concentrate reuse, produced water, and renewable energy integration at large scale testing for cost/performance validation

Research and Development of Next Generation Desalination Membranes

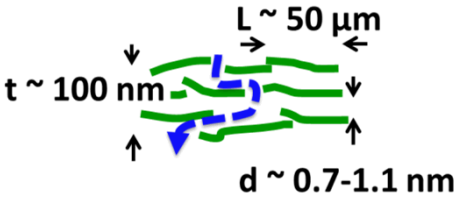
Sandia National Laboratories

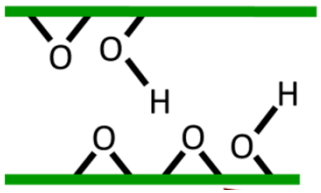
Developed biomimetic-based (kidney-like) reverse osmosis (RO) membrane with 5 times higher permeate flow per unit of pressure than traditional RO membranes (RD100).

Also developing bio-based electrodialysis membranes.



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





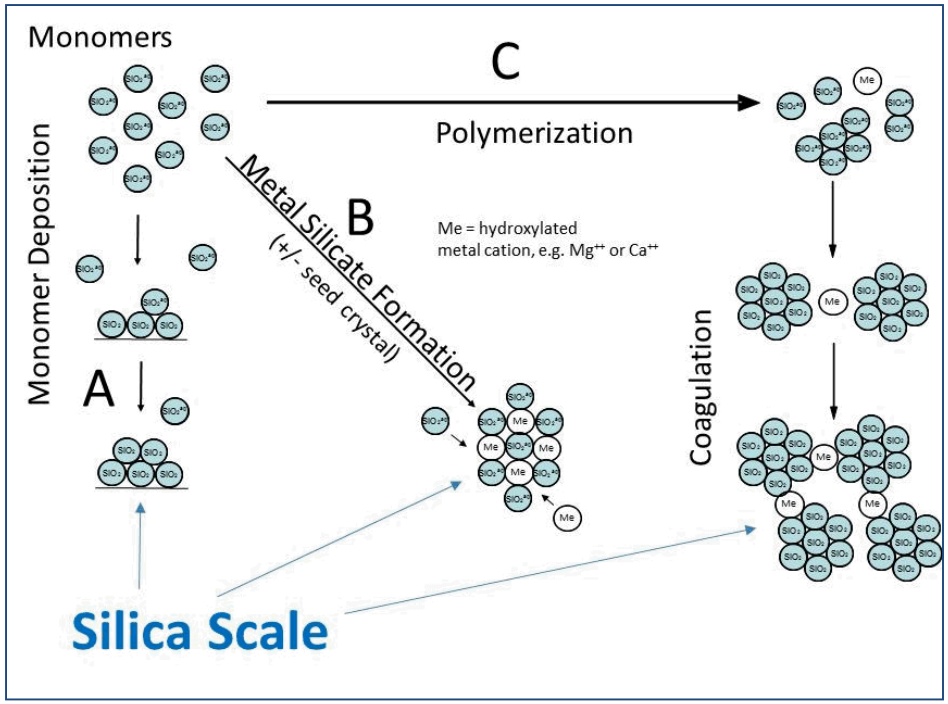
Developing laminar graphene oxide (GO) membranes, whose structure is ideal for water desalination.
Structure is chemically tolerant to 1-ppm, one month, free chlorine exposure, as well as hydrocarbons (ie: toluene, oils)

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

Research on Chemical Treatments for Selective Ion Removal to Enhance Desalination

Sandia National Laboratories

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

Desalination Technology Large-scale Demonstration and Evaluation

Sandia National Laboratories

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

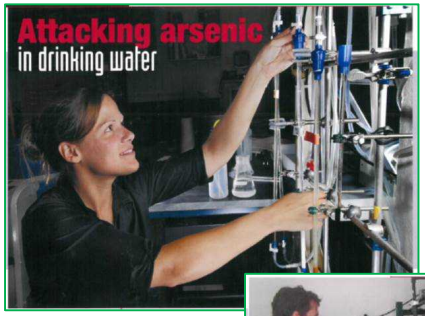
Coal fines accumulating in the modified zeolite filtration medium.

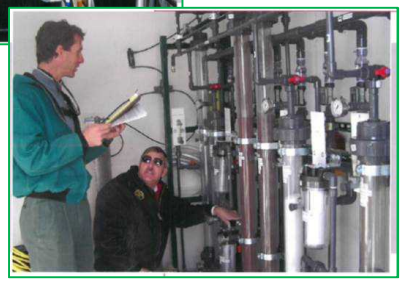
Simple Solution to Complex Water Challenge Facing Rural New Mexicans

Sandia National Laboratories

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

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.





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.

Sandia National Laboratories

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Sandia National Laboratories

BACK-UP SLIDES

Commercialization Experience Shows Benefits of Early Systems Engineering Coordination

Sandia National Laboratories

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.

2006 — Parker Hannifin makes first investment for Sandia to improve sensor detection limit.

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

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.

Energy & Climate Program Areas

Sandia National Laboratories

Renewable Systems & Energy Infrastructure

PAD: Carol Adkins
Deputy: Charles Hanley

- **Renewable Energy** — Dave Minster (Acting)
- **Energy Efficiency** — Art Pontau
- **Grid Modernization** — Charles Hanley

Climate & Engineered Earth Systems

PAD: Peter Davies
Deputy: Amy Halloran

- **Climate Modeling & Measurement** — Scott Collis
- **Energy & Water** — Stephanie Kuzio
- **Fossil Energy Management** — Erik Webb
- **Biofuels** — Anup Singh
- **Back End of the Fuel Cycle** — Tito Bonano
- **DOE Managed Nuclear Waste** — Paul Shoemaker

Nuclear Energy & Fuel Cycle Programs

PAD: Susan Pickering
Deputy: Patrick Mattie

- **Commercial Nuclear Power Generation** — Tito Bonano
- **Nuclear Energy Safety & Security** — Richard Griffith

Transportation Energy & Systems

PAD: Bob Hwang
Deputy: Art Pontau

- **Vehicle Technologies** — Paul Miles
- **Biomass Technology** — Ben Wu
- **Fuel Cells/Hydrogen Technology** — Chris San Marchi

Marianne Walck - Vice President
Energy & Climate Program

Energy Research

PAD: Grant Heffelfinger
Deputy: Wahid Hermina

- **ARPA-E** — Wahid Hermina
- **SC BES CHEMSCIENCE** — Dave Chandler
- **SC ASCR** — Scott Collis
- **SC BES CINT** — Sean Hearne (Acting)
- **SC BES GEO** — Moo Lee
- **SC BES MATERIALS SCIENCES** — Jeff Nelson

Chemical Water Treatment Technology Deployment

Sandia National Laboratories

Permeable Insitu Reactive Wall for Strontium Removal. Uses appetite-based media to intercept heavy metal contaminated ground water. (Patented in 2002 and 2003). Utilized at Hanford since 2007 in 300 foot application with 99% strontium reduction. Being expanded to 3,000 foot long treatment wall.

Crystalline Silico-Titanates - Highly selective cesium adsorbent. (R&D100 in 1996 and Patented in 2002) . Licensed to UOP. Used at Fukushima for cesium removal from over 150 million gallons of seawater used to cool the crippled reactors.

https://www.youtube.com/watch?v=Z9BaQ0OshJU

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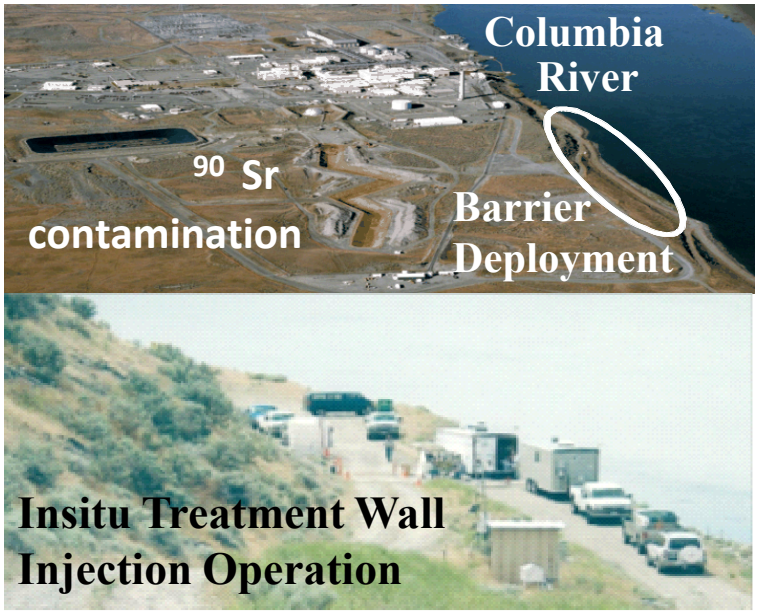

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- NATIONAL CLIMATE ASSESSMENT REPORT: CHAPTER 10, ENERGY WATER, AND LAND USE

- MEMBRANE DISTILLATION PROJECT FOR NM SMALL BUSINESS
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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
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
International Energy Agency

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Efforts in Charting the Course of National Desalination Research and Development

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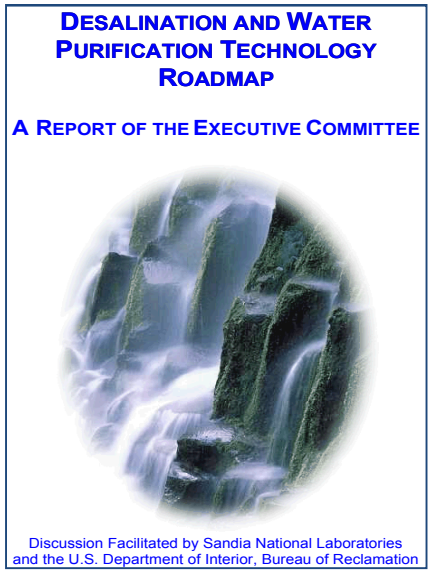
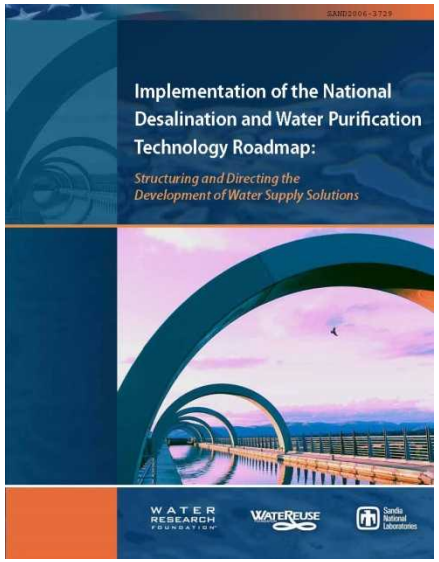




2003 – With EPA and Bureau of Reclamation (BOR)
Summarized water challenges facing US and charted the course of R&D to meet these challenges

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

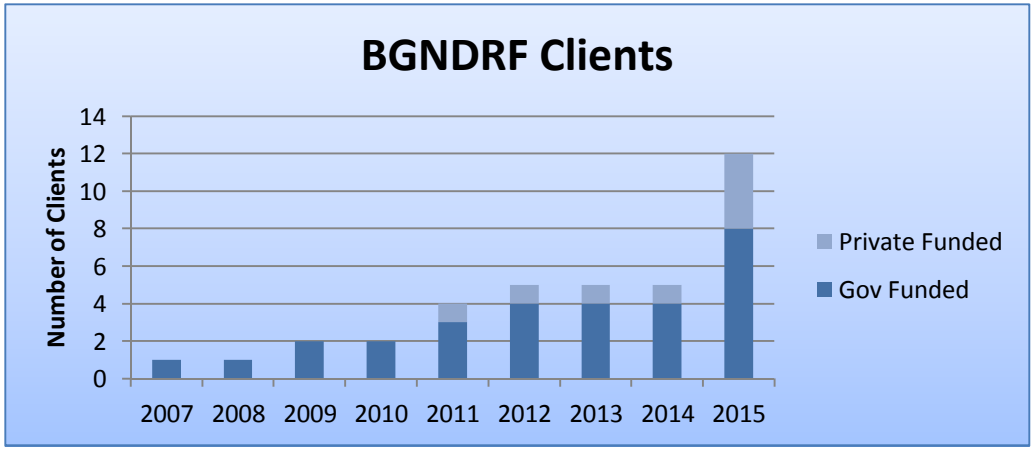
Quantified needs and five broad technology areas to meet these needs:
- **Membrane Technologies**
- **Alternative Technologies**
- **Thermal Technologies**
- **Concentrate Management Technologies**
- **Recycle/Reuse Technologies**

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

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
- Significant growth in research since 2008 commissioning
  - DOW, GE, Veolia, Evoqua, Water Standard Company, Unilever, MIT, Univ. of Arizona, UTEP, Nevada-Reno, Colorado School of Mines, New Mexico State

Focus areas - Brackish desalination, concentrate reuse, produced water, and renewable energy integration at large scale testing for cost/performance validation

Research and Development of Next Generation Desalination Membranes

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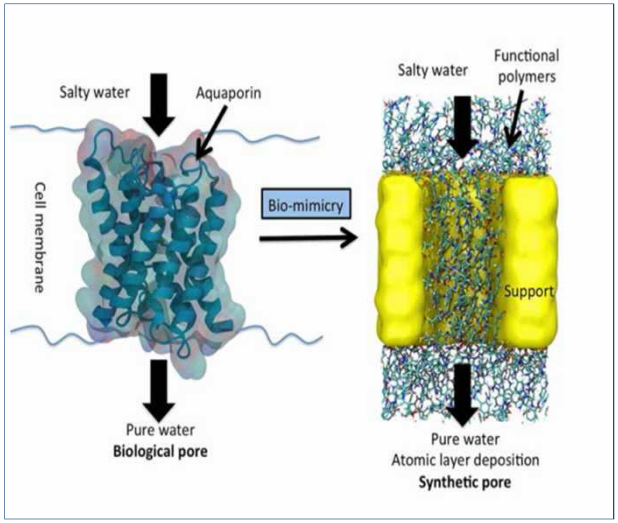
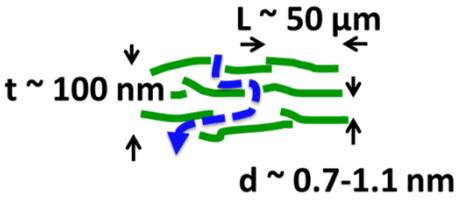
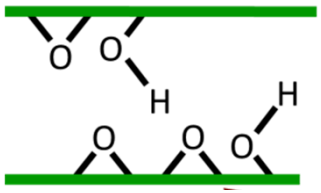
Developed biomimetic-based (kidney-like) reverse osmosis (RO) membrane with 5 times higher permeate flow per unit of pressure than traditional RO membranes (RD100).

Also developing bio-based electrodialysis membranes.



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





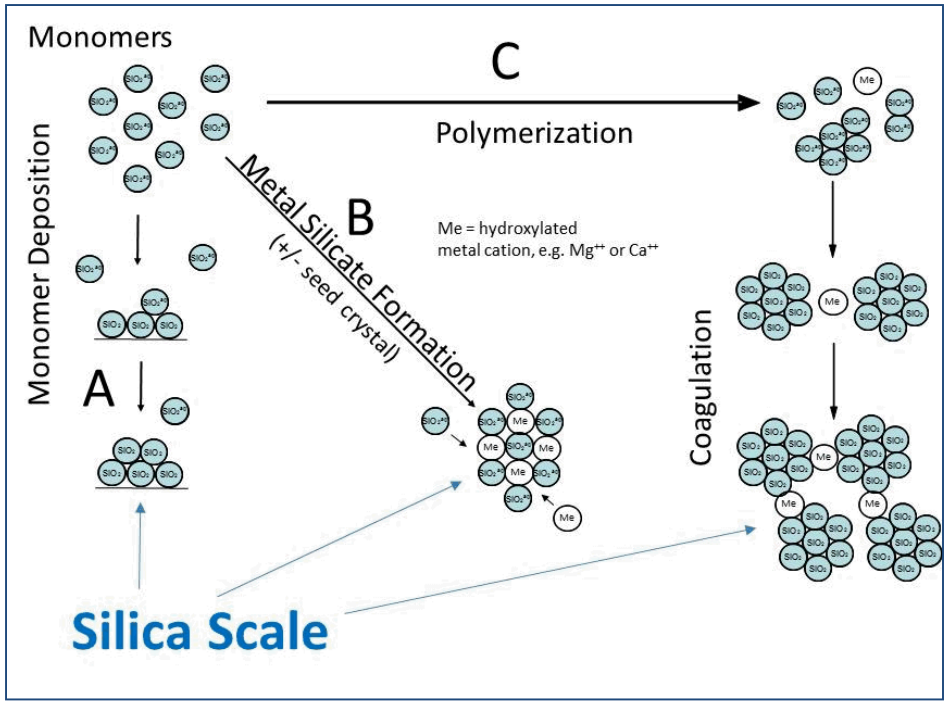
Developing laminar graphene oxide (GO) membranes, whose structure is ideal for water desalination.
Structure is chemically tolerant to 1-ppm, one month, free chlorine exposure, as well as hydrocarbons (ie: toluene, oils)

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

Research on Chemical Treatments for Selective Ion Removal to Enhance Desalination

Sandia National Laboratories

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

Desalination Technology Large-scale Demonstration and Evaluation

Sandia National Laboratories

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

Sandia National Laboratories

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.

2006 — Parker Hannifin makes first investment for Sandia to improve sensor detection limit.

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

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.

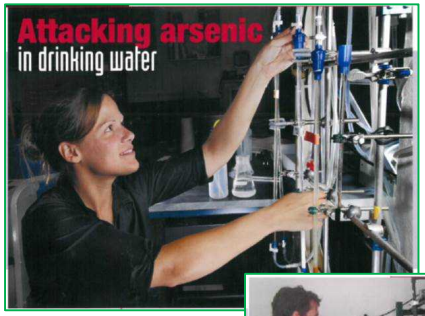
2015 — Parker Hannifin begins sales of instrument with continuous sampling capability.

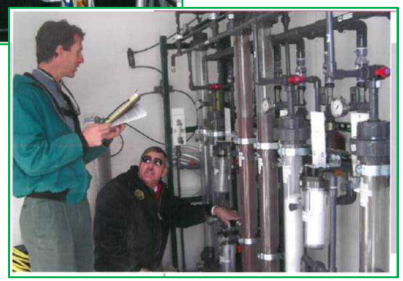
Simple Solution to Complex Water Challenge Facing Rural New Mexicans

Sandia National Laboratories

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

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.





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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Sandia has been actively working in a broad range of water treatment technical challenges for over a decade

2000
- ADVANCED CONCEPTS DESALINATION PROGRAM BEGINS

2001
- PATENT DESCRIBING A METHOD FOR SYNTHESIZING A LAYERED DOUBLE HYDROXIDE CAPABLE OF SORBING BOTH ANIONIC AND CATIONIC CONTAMINANTS FROM FLUID

2002
- DEVELOPMENT OF SWEEPING GAS MEMBRANE DESALINATION USING COMMERCIAL HYDROPHOBIC HOLLOW FIBER MEMBRANES

2003
- DESALINATION TECHNOLOGY ROADMAPS

2004
- SELF-SEALING EVAPORATIVE POND LINER
- DESALINATION OF BRACKISH GROUND WATERS & PRODUCED WATERS USING IN-SITU PRECIPITATION
- CAPACITIVE DEIONIZATION FOR COAL-BED NATURAL GAS PRODUCED WATER TREATMENT
- UV ULTRAVIOLET WATER PURIFICATION SYSTEMS FOR RURAL ENVIRONMENTS AND MOBILE APPLICATIONS
- BRACKISH GROUNDWATER NATIONAL DESALINATION RESEARCH FACILITY

2005

2006
- CHEMICALLY SELECTIVE SILICA REMOVAL FROM COOLING WATER
- PRODUCED WATER PILOT SAN JUAN BASIN, NM

- REVERSE OSMOSIS with NANOPARTICLE BIOCIDE

2007
- COMMERCIALIZATION OF ZERO LIQUID DISCHARGE PROCESS FOR BRACKISH WATER DESALINATION (PARTNERSHIP WITH USC & ZDD)
- ARSENIC PILOT DEMONSTRATION PROJECTS

2008
- INTERFACIAL WATER PROJECT TO UNDERSTAND INTERACTIONS AMONG WATER, MEMBRANES AND CONTAMINANTS

- PATENT FOR MITIGATING MEMBRANE BIOFOULING

2009

2010
- BIOMIMETIC MEMBRANE R&D 100 AWARD

- PATENT FOR NEXT-GEN COAGULENT FOR THE REMOVAL OF BACETERIA AND VIRUSES
- MEMBRANES & SURFACES NANO-ENGINEERED FOR PATHOGEN CAPTURE AND DESTRUCTION

- NOVEL SILICA REMOVAL STRATEGIES FOR INDUSTRY PARTNER

2011
- COAGULATION CHEMISTRIES FOR SILICA REMOVAL FROM COOLING TOWER WATER
- CSTS FOR RADIOACTIVE CESIUM REMEDIATION
- WATER RECOVERY USING WASTE HEAT FROM COAL FIRED POWER PLANTS
- PATENT ON BIOFOULING-RESISTANT CERAGENIN-MODIFIED MATERIALS

2012

2013
- PATENT ON METHODS FOR RECOVERING ALKALI METALS

- MEMBRANE TREATMENT OF SIDE-STREAM COOLING TOWER FOR REDUCTION OF WATER USAGE

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BACK-UP SLIDES

Chemical Water Treatment Technology Deployment

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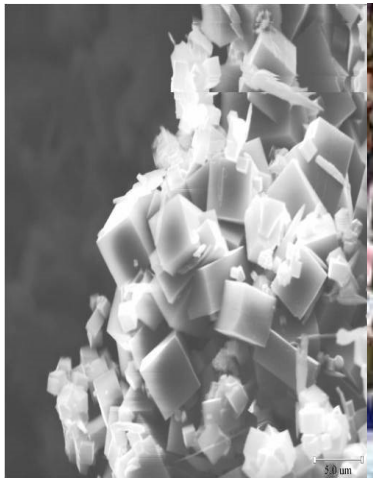

Crystalline Silico-Titanates - Highly selective cesium adsorbent. (R&D100 in 1996 and Patented in 2002) . Licensed to UOP. Used at Fukushima for cesium removal from over 150 million gallons of seawater used to cool the crippled reactors.

https://www.youtube.com/watch?v=Z9BaQ0OshJU

https://www.youtube.com/watch?v=UJgvXbL5_Nw

Permeable Insitu Reactive Wall for Strontium Removal. Uses appetite-based media to intercept heavy metal contaminated ground water. (Patented in 2002 and 2003). Utilized at Hanford since 2007 in 300 foot application with 99% strontium reduction. Being expanded to 3,000 foot long treatment wall.