SAND2018-2200PE

CLEAN WATER
TECHNOLOGY CONSORTIUM
CWTC

Sandia National Laboratories

Partner Capabilities

PRESENTED BY

Thushara Gunda & Vincent Tidwell

U.S. DEPARTMENT OF ENERGY | NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

- Summary of strengths (*ongoing*)
  - Treatment Technologies
  - Energy & System Capabilities
  - Water Sources & Chemicals
  - Industrial partners
- Opportunities
- Gaps
- Supplementary: University Partner Summaries

CAVEAT: ONGOING PROCESS

Treatment technologies

- Pre-treatment
  - Graphene-oxide composite membrane (Arkansas)
  - CDI (Texas Tech)
  - Hybrid ceramics (MSU: ozone-fouling)
  - Electrocoagulation + chemical coagulation to remove dissolved silica (Arizona)
  - Granular ferric hydroxide to remove phosphonate antiscalants (Arizona)
  - Brine precipitation/bipolar membrane electrodialysis (Arizona)
  - Precipitation (SNL – hydrotalcite, Arizona, LANL)
  - Zeolites (SNL, LANL, PNNL)
  - Acoustic separation (LANL: mainly algae/oil emulsions)
  - E-field flocculation (LANL)
- Desalination
  - RO (Clemson: shark-skin patterns and MSU: snake-skin patterns, UTEP, SNL, LANL: high temp)
  - FO (Clemson, NMT, SNL)
  - MD + PRO (NMT) – using low grade heat
  - Biomimetic (SNL)
  - Graphene (SNL, PNNL)
  - Electrodialysis (UTEP)
  - Clathrate (SNL, LANL, PNNL: gas hydrates)
  - CDI (SNL, LANL, MSU: + Graphene nanoplatelet)
  - Coatings (PNNL, LANL)
  - Micro-channel heat exchangers (PNNL)
- Post-treatment
  - Carbon nanotubes (Arkansas)
  - CDI (Texas Tech)
  - Hybrid ceramics (MSU: UV- virus)
- Concentrate Management
  - Fe-based treatment for arsenic and radionuclide removal (Texas Tech)
  - Selective removal of ions (Texas Tech)
  - Fluidized bed crystallization (Arizona)
  - Mineral recovery/ZLD (UTEP)
  - FO: volume reduction (NMT)
  - Brine recovery (LANL)
  - Nanomaterials + magnetic separation (PNNL)
- Plant Manufacturing
  - Ceramic coatings of PVC (NMT)
  - Composite tanks for MED (MSU)
  - Additive manufacturing (SNL, LANL)
  - Electrochemical corrosion inhibition in metals (LANL)
  - New metal alloy development (PNNL)
  - Dissimilar solid materials joining (PNNL)
  - Smart manufacturing (PNNL)

Energy & System Capabilities

- Leveraging photocatalytic properties (NMT)
- Waste heat utilization
  - To drive desal (Clemson)
  - For energy storage and generation (Arizona)
- Renewable energy
  - National Wind Institute (SWiFT) with coupled water treatment demonstration (Texas Tech, SNL)
  - General integration (Clemson)
  - CSP (UTEP, SNL)
  - Geothermal energy (NMT, SNL)
  - Compact solar thermal (LANL)
  - Tidal energy production energy (PNNL, SNL)
- Within plant analyses
  - Unit configuration (NMT) – produced
  - Virtual water treatment system: real-time chemical needs prediction (MSU)
- Modularization
  - Mobile MF+NF+RO lab (Texas A&M)
  - Solar thermal mobile unit (LANL)
- Immediate plant analyses
  - Intake and pipe distribution networks (MSU)
- Techno-economic analyses
  - Focused on water treatment: Clemson, LANL, Arizona, SNL
  - Most of the institutions have some capabilities in this arena
- Decision support system tools
  - Pork industry to farm tools (Arkansas)
  - O&G (Texas Tech)
- Regulations
  - CA Water Board (Fresno)
- Work force development
  - Reese Technology Center – Texas Tech

Specifics (cont'd)

Water Sources

- Seawater (Clemson, PNNL, SNL)
- Inland brackish (SNL - BGNDRF, NMT, UTEP, Texas Tech, LANL, Arkansas)
- Produced (SNL, Arizona, Arkansas, LANL, MSU, NMT, NETL, Texas A&M, Texas Tech)
- Agriculture (Arizona, Arkansas, MSU, Texas A&M, Fresno)
- Industrial/Municipal Wastewater (SNL – funded UNM, Texas Tech, Arkansas-Food, Fresno-Food, LANL-cooling tower)
- Geothermal (NMT, LANL)

Chemicals

- Metals (SNL - As, LANL, Arkansas, Arizona)
- Organic Matter/DBPs (Clemson)
- Acetic Acid/Ammonia/Oxides (Arkansas)
- Hydrogen sulfide (SNL)
- Dissolved silica (SNL - NETL, Arizona)
- Alkalinity, phosphates (Arizona)
- Emulsified oil (MSU)
- Radionuclides/Cs/Sr/U (SNL, LANL, Texas Tech)

Partners' Industrial Connections

- Apache: concentrated thermodynamic electrolyte (Texas Tech)
- AcceleteraH2O: nascent stages to develop hub (Texas Tech)
- O&G – west TX (Texas Tech)
- Dow Water & Process Solutions (Clemson)
- Duke Energy (Clemson)
- Black & Veatch (Clemson)
- Tyson Foods (extremely strong!) (Arkansas)
- Flexible water systems (Arkansas)
- Clean Environmental Technologies (Arkansas)
- Process Dynamics (Arkansas)
- Mannco (Arkansas)
- 3M (Arkansas)
- Proton Onsite (Arkansas)
- Pajarito Powder (Arkansas)
- AxNano (Arkansas)
- HI DoA (Arkansas)
- Southwestern Energy (Arkansas)
- Asahi Kasei (Arkansas)
- Membrane Science (Arkansas)
- EPRI (Arkansas)
- DTRA (Arkansas)
- Garver (Arkansas)
- Millipore (Arkansas)
- USACE (Arkansas)
- Pima County Wastewater (Arizona)
- EconoPure Water Systems (Arizona)
- Tucson Water (Arizona)
- AZ Municipal Water Users Associations (Arizona)
- Jacobs Engineering (Arizona)
- Sonoran Institute (Arizona)
- US Bureau of Reclamation (Arizona)
- Nature Conservancy (Arizona)
- Saint-Gobain - France (MSU)
- Singapore and Turkey membrane centers (MSU)
- TB Simon power plant (CO_2 sequestration and water treatment facility) (MSU)
- Metawater-USA (MSU)
- Nanostone water (MSU)
- Pall (MSU)
- Uniceram Advance Materials (MSU)
- El Paso Water Utilities (UTEP)
- Blue Tech valley and water cluster (Fresno)
- Pacific Gas & Electric Company (Fresno)
- California Energy Commission – EPIC program (Fresno)

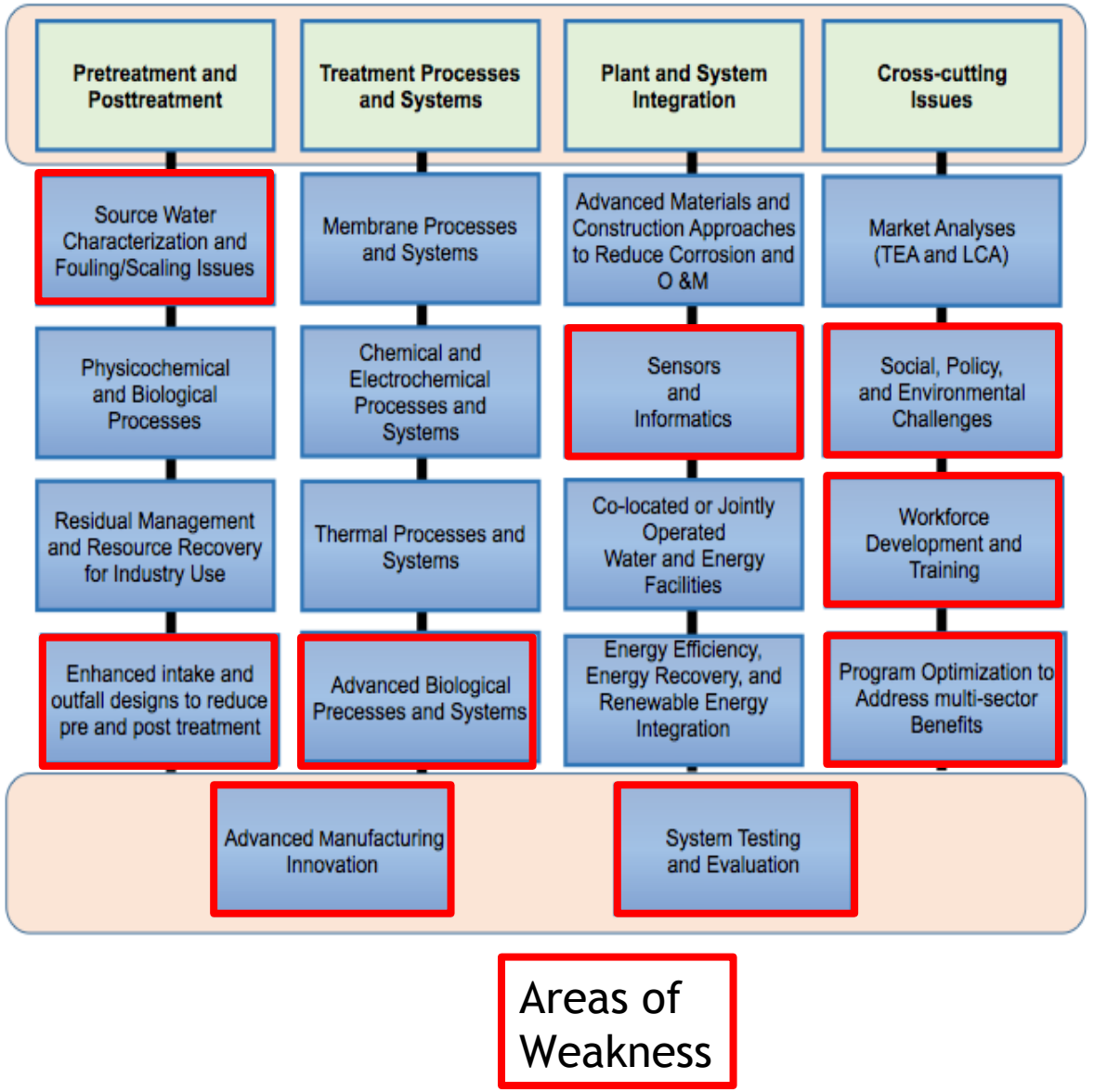
Opportunities

- Combine CDI + selective ion removal (Texas Tech) with ZLD (UTEP)
- Combine ceramic expertise (Clemson) with technologists in that space (NMT - coatings, MSU – hybrids for virus/antifouling)
  - Connect with catalyst design folks (MSU)
  - Improve microfilters using graphene or ceramic coating (Texas A&M)
- Evaluate technologies at higher temperatures and pressures
  - Shark-skin and snake-skin patterns
- Access facilities to drive discovery
  - Micro-CT/NMR/TEM (NMT)
- Convert analytical techniques to automated, online ones (Texas A&M)

Gaps

- Technology
  - Pre-treatment: filters, hydrocyclone, flotation, adsorption, settling, MF/UF, …
  - Desal: multi-stage flash, vapor compression, dewvaporation
  - CM: deep well injection
- Relatively little overlap in technical capabilities of research partners
  - Source of opportunity?
  - Challenge for integration?
- Lack of manufacturing partners to demonstrate technology scalability
  - CDI (Texas Tech)
  - PRO (NMT)
- Poor water treatment specific coverage in cross-cuts

Data (well-defined metrics, dtb. mgmt., predictive algorithms)	Sensors (real-time/IoT, SMART, cyber)	Optimization (sys-level integration, decision-making tool, markets for recovery)
Arkansas (DNA sequencing, Fluorescence -based)	SNL	Arizona (TEA/LCA, decision tools)
Clemson (informatics)	Clemson (if needed)	Arkansas (Econ/env LCA, profitability/willingness to pay)
MSU (real-time chemical needs ID in offshore O&G)	Arkansas (fledgling)	Clemson (TEA-LCA)
Fresno (EPA Water Sense technical standards)	Texas A&M (techniques that need to be automated)	LANL
	PNNL	



Areas of Weakness

Supplementary: University Partner Summaries

University of Arizona

- Technology of Focus:
  - Membrane Distillation
    - Application: mineral recovery
  - FO
    - Produced water treatment
  - PRO
    - Assessed current state of available membranes
    - TEA of thermal membrane with PRO
  - RO
    - HERO-high efficiency
  - Fluidized bed crystallization
    - Electrochemical methods for RO pretreatment
    - Bipolar membrane electrodialysis
- Facilities
  - Water Energy Sustainable Technology (NF and pretreatment systems)
  - Arizona Laboratory for Emerging Contaminants
  - Institute for Energy Solutions
  - Water Resources Research Center
- Industry
  - Pima County Wastewater (Arizona)
  - EconoPure Water Systems (Arizona)
  - Tucson Water (Arizona)
  - AZ Municipal Water Users Associations (Arizona)
  - Jacobs Engineering (Arizona)
  - Sonoran Institute (Arizona)
  - US Bureau of Reclamation (Arizona)
  - Nature Conservancy (Arizona)

University of Arkansas (Lauren Greenlee)

- Technology of focus:
  - Graphene-oxide composite membranes
    - Application: pretreatment
    - Can remove selected contaminants (e.g., low explosive munitions, PFOAs, chlorinated solvents) by changing graphene flake sizes
    - Focused on reducing pressure demand
    - Have created a scalable flat-sheet that can be spiral-wound
    - Novel: low fouling, possible replacement for NF/UF pore-size regimes (1 kwh/m^3 vs 5 kwh/m^3 for NF)
  - Cellulose fiber construction
    - To drive hydrolysis of certain sugar conversions
  - Carbon nanotubes
    - Address disinfection byproducts and precursors
  - Catalytic nanoparticles and fledgling electrochemical sensors
    - Fingerprint approach
    - Very early stages
    - Need water quality information for real waters
- Decision support system tools
  - Wastewater and agriculture-focused (from pork to farms)
- Waters of focus
  - Industrial wastewater
  - Produced water

- Facilities
  - Nanoscience/engineering facility; mass spectrometry center;
  - Research hog farm, chicken facility, row crop facilities
- Industry Partners
  - Tyson Foods (extremely strong!)
  - Flexible water systems
  - Clean Environmental Technologies
  - Process Dynamics
  - Mannco
  - 3M
  - Proton Onsite
  - Pajarito Powder
  - AxNano
  - HI DoA
  - Southwestern Energy
  - Asahi Kasei
  - Membrane Science
  - EPRI
  - DTRA
  - Garver
  - Millipore

University of Colorado - Boulder

- Membrane Science, Engineering and Technology (MAST) Center at CU Boulder has 27-year history in membrane

research, covering all areas of liquid and gas based separations. Relevant to the desalination application, our expertise

include

(a) Nano, micro, and macro-scale materials for membrane applications: This includes polymers and polymer

composites, zeolites, ionic liquids-based materials, liquid crystals, carbon-based materials (CNT, graphene and

graphene oxide), and other engineering materials.

(b) Membrane formation and modification process: This includes phase inversion, interfacial polymerization

process, solution-based process, chemical modification of membrane surface, topographic patterning of

membranes (e.g. nanoimprint lithography and other pattering based methods).

(c) Membrane characterization: This include analytical and numerical modelling of membrane material and

processes, sensing (acoustic, optical and magnetic methods), and spectroscopic studies of membrane structures

and processes (e.g. single molecular spectroscopy and other advanced probe-based methods).

Clemson University (Gary Amy)

- Polymeric membranes: outperform RO/improve RO
  - Shark-skin patterning on surface to reduce fouling
  - Implemented in RO but interested in expanding to FO, PRO, and MD
  - Application:
    - Desalting
    - Decontamination: ZLD with MD integration
- Water quality
  - Expertise in ceramics
  - Final product water quality: chlorine, NOM, etc.
- Energy integration:
  - technology-agnostic
  - Waste heat integration with desal.
- TEA-LCA: specifically in water treatment systems
- Informatics: data analytics as part of cyber-decision support systems
- Facilities
  - Membrane-testing capability from small-coupon tests to single-module experiments, incl. high-pressure conditions
  - Two mobile RO for demonstrations/outreach
  - Electron microscope facilities
  - Restoration Institute allows collaboration between advanced materials + water resources + wind/biofuels; coastal location prime for pilot-scale seawater desa
- Industry partners
  - Dow Water & Process Solutions
  - Duke Energy
  - Black & Veatch

Florida Gulf Coast University

- Geothermal integration?
- Intakes/outfalls for managing algal blooms?
  - Soil filters as a subsurface intake?

University of California-Fresno (Sarge Green, Karl Longley)

- Extensive connections with industry and agriculture folks throughout CA
  - Water Institute: connects with private industry
  - Water Quality Board: sets regulations for water quality
- Consider ‘fit for purpose’ and level of treatment needed (esp. on ag. side: salt-tolerant plants)
- Technologies of focus – note: conversation focused on high-level (vs specifics)
  - Ion exchange optimization through development of selective resins
  - Low thermal gradient technology for concentration salt in evap. Ponds (solar ponds)
  - Hybrid desal. With graphene + pulse electrical discharge for treating irrigation waters
- Work with EPA Water Sense to develop technical standards
- Work closely with UC-MERCED (has a solar center) on EPIC program
- Facilities
  - Water-Energy Laboratory
  - Irrigation Innovation Consortium
- Needs:
  - Interested in exploring produced water residuals with Texas A&M
  - Connect with Texas Tech on low-income/rural communities water treatment needs
- Industry partners
  - Blue Tech valley and water cluster
  - Pacific Gas & Electric Company
  - California Energy Commission

University of Kentucky

- Graphene membrane?

Michigan State University (Vlad Tarabara et al.)

- Technology of focus:
  - Membrane fouling
    - Characterization of surface
    - Solution composition modification
    - Snake-skin surface design
  - Ceramic membranes
    - Ozone integration: reduce fouling
    - UV integration: virus elimination
    - Ceramics currently being used are commercially available – would be open to manufacturing with those that create them
  - Graphene nanoplatelets
    - In conjunction with CI, could be cost-competitive with RO
    - Already been commercialized with other applications (batteries, Callaway golf balls)
  - Composite tanks
    - For MED application (low-weight approach)
    - Conceptual stage now
    - Multiple patents for denitrification process
- Models
  - Reduce chemical usage by modeling chemical requirements real-time
  - Intakes and pipe distribution networks in Great Lakes and how water distribution could interface with that
- Ag
  - Converted ag waste into bioenergy and chemical energy products
  - More than one project funded by DOD to develop mobile units to generate energy for on-site water treatment
- Industrial partners
  - Saint-Gobain
  - Singapore and Turkey membrane centers
  - TB Simon power plant (CO_2 sequestration and water treatment facility)
- Facilities
  - Composite material center (incorporates atomistic, molecular, polymer, and process stage)

New Mexico Tech (Frank Huang and Paul Fuierer)

- Technology of Focus
  - FO
    - Focus: on volume reduction
    - Use geothermal energy in produced water to assist with energy reduction (by switching between hydrophobic and hydrophilic)
    - Current process at LNL is too complex but have ideas for streamlining this process
      - Between lab-scale and pilot-scale now
      - Can't describe details now
  - Membranes
    - Contain photonic properties (incorporating solar energy) and utilize geothermal
  - PRO
    - Direct contact membrane distillation
    - Best for low grade heat
    - Modeling focused on understanding pore structure influences on output
    - Needs
      - Micro-CT scan/NMR/TEM
      - Manufacturing partnership to mass produce membranes
  - System analysis
    - Implement technology in a range of conditions to understand system optimization opportunities
  - Ceramic coatings
    - Dry aerosol deposition (vacuum kinetic spray)
    - Hard, temperature/abrasion resistant properties (lose some nano-crystallinity at 500-700°C that would influence photocatalytic properties)
    - Successfully coasted glass, metal, and now experimenting with spraying PVC tubes
    - Needs:
      - Newer pumps/apparatus to develop larger systems
      - TEM to evaluate finer properties

- Facilities
  - Geothermal plant at Radium Springs, NM to co-gen heat and purify water
  - Two dry jet-wet spinning lines and an automatic fil caster
  - Custom-built AD apparatus – one of few in the world
  - Metawater-USA
  - Nanostone water
  - Pall
  - Uniceram Advance Materials

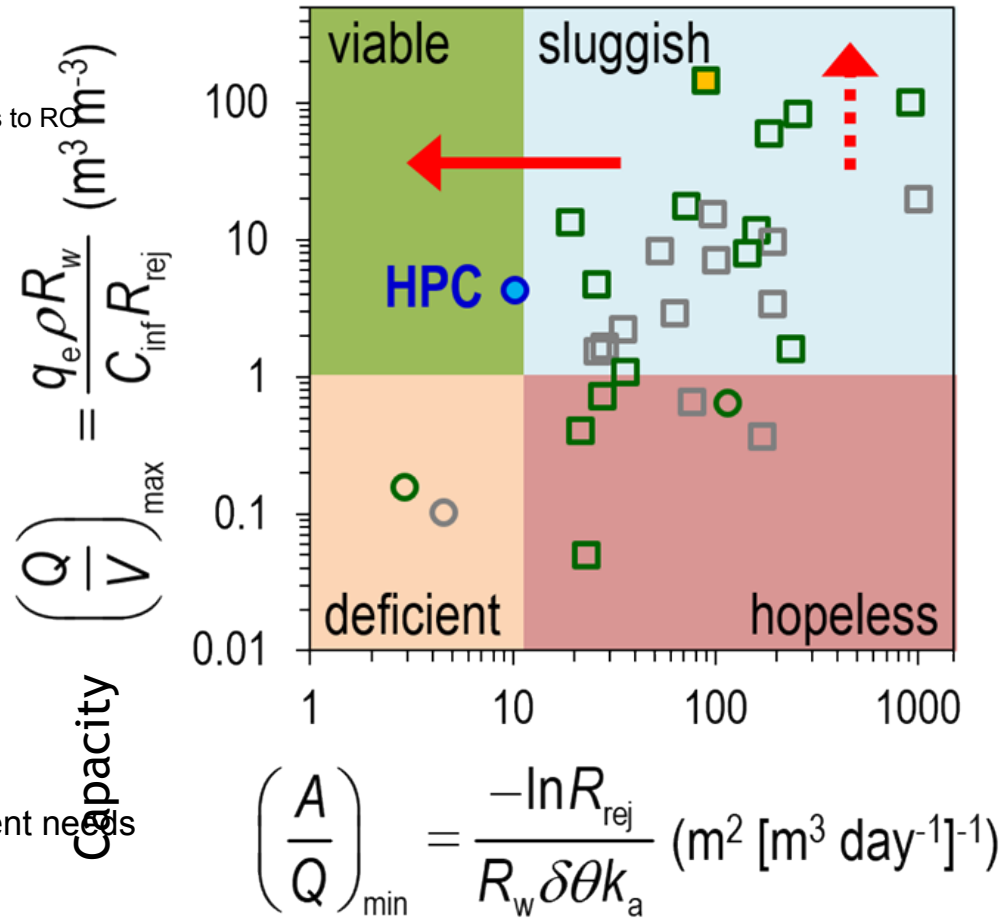
- Industrial partners
  - Tilapia producer (aquaculture)

Texas A&M (Dave Burnett)

- Technology of focus:
  - Mobile lab with MF+NF+RO
  - Rapid analytical tests
    - HCs, suspended solids, bacteria, and dissolved ions measurements: only need 3ml without pretreatment
- Decision support system
  - Mathematical model to allow O&G to quickly screen costs based on application of water for specific source
- Needs
  - Improve effectiveness of microfilters (perhaps with graphene coating/ceramics)
  - Convert analytical techniques into automated, online processes
- General ag expertise (Mohtar)
- Municipal water treatment and policy (Susan Roberts)
- Produced water emphasis, integrated in expanding into ag. Ww

Texas Tech (Danny Reible)

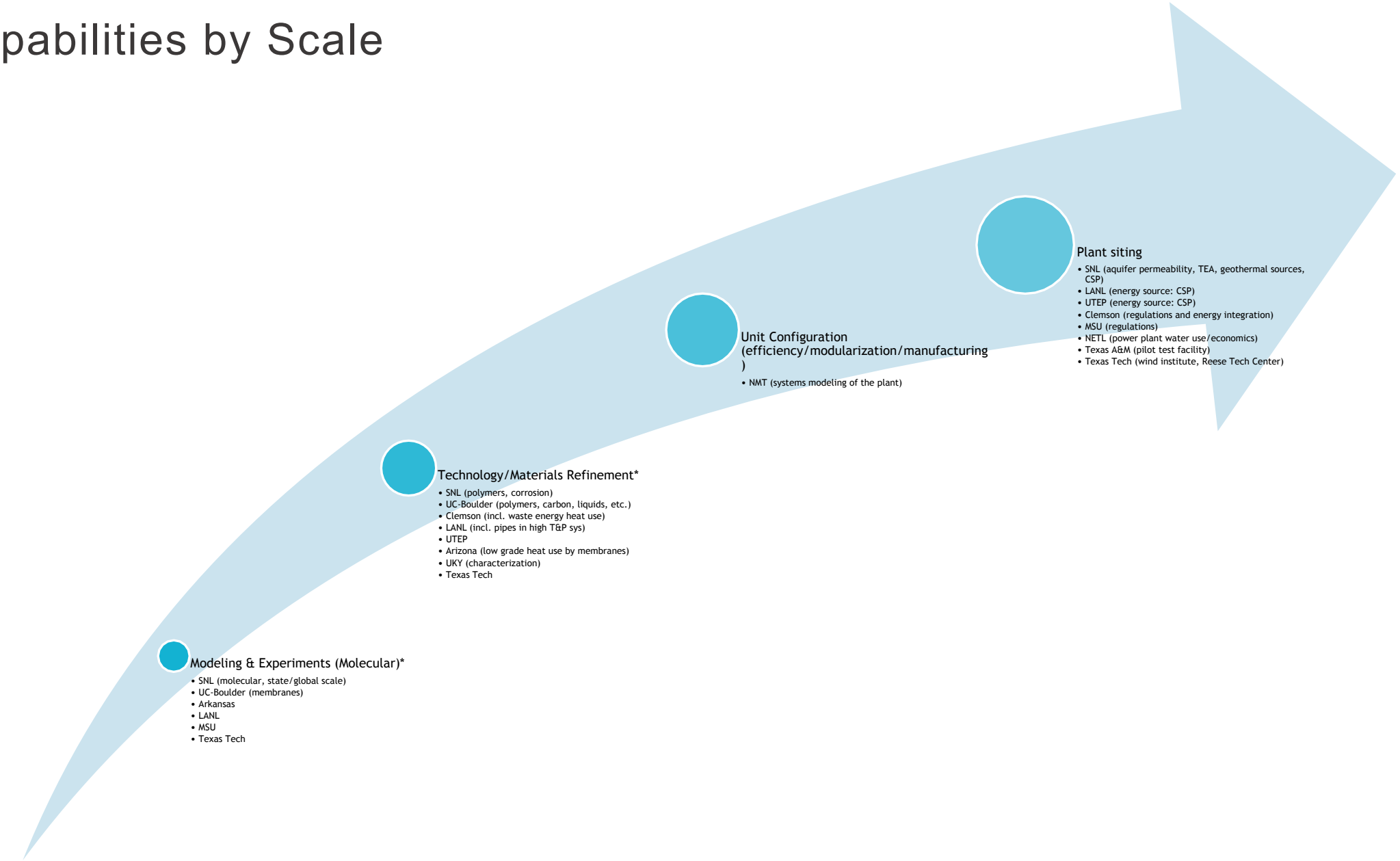
- Technology of focus:
  - Capacitive deionization
    - Scale: Modeling (thermodynamics: electrical distribution/field) to material development
    - Modified system design and unique electrode have yielded comparable flux rates and power requirements to RO
    - Applications:
      - Rural households
      - Pre-treatment before ion exchange for high quality industrial water
      - Post-treatment to achieve high quality boiler feed water
    - Need:
      - Testing (possibly at Reese Technology Center)
      - Connect with ZDD (UTEP?) to integrate CDI into larger process
  - Iron-based treatment for arsenic and radionuclide removal
    - Novel component: cellulose support
  - Selective removal of ions
    - Tailor-making polymers and crowning ethers
    - Fundamental stage
    - Application: pre-treatment or CM (latter likely more economical)
    - Produced water application
- National Wind Institute
  - Demonstration: coupled with water treatment in Seminal, TX
  - Possible research topic: optimization of timing of wind generation with water treatment needs
- Industrial partners
  - Apache: concentrated thermodynamic electrolyte
  - AcceleteraH2O: nascent stages to develop hub
  - O&G – west TX focus
  - (Rural communities)



UTEP

- Focus on high-recovery inland brackish gw
- Technology of focus:
  - Electrodialysis
  - RO
- Applications: mineral recovery, desalting
- CSP
- Facilities
  - Pilot-scale RO/NF/ED @ the USBR BGNDRF
  - EPW Kay Bailey Hutchison (KBH) desal. Plant

Capabilities by Scale



*Both the modeling and refinement stages focus on biofouling, efficiency of technology, and recovery (incl. ZLD). Materials focus is heavily weighted towards membrane technologies.