Ultra Low Energy, Low Cost Industrial Nanomembrane Manufacturing for Desalination, Water Purification, and Remediation

DE-SC0013182
Covalent LLC
Phase 1: February 2015-November 2015 Phase 2: April 2016-April 2018

Presenter: Gayle Pergamit, Covalent LLC
Principal Investigator: Martin Edelstein, Covalent LLC

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 14-15, 2016

Project Objective

- **Objective**: One atomic-layer-thick, atomically precise membranes for water applications. Disruptive technology.
- Address the Water/Energy Nexus, Worldwide Water Crisis, emerging Groundwater Crisis, climate goals.
- Provide ultra high quality water at 66-99% energy savings and 50-70% cost savings over current best practice from virtually any feedstock, no matter how contaminated.

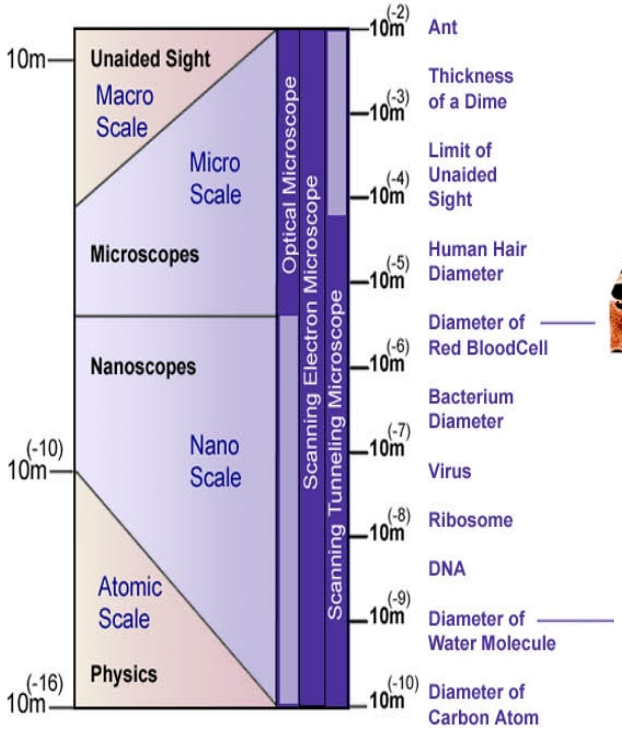
- **Problem**: Clean/cheap water is gone.
- Desalination and removing small contaminants from freshwater is energy intensive and costly.
- Using conventional technologies, water will consume ~40% of global energy expenditure.

Difficulties: Technical, Business

1. **Technical Domain: Water chemistry**
   - **Complex**. ~500,000 contaminants
   - **Tough**. Huge number of foulants and scalants
   - **Changing.** Day/night, seasons, environmental change, human action
   - **Local.** Foulants, contaminants vary from source to source.
   - **Extreme.** Huge pH range, hot, cold, radioactive, oily, etc.
2. **Operations: Success needed on multiple criteria**.
   - Performance
   - Yields of product water
   - Maintenance requirements
   - Membrane/ electrode lifespans
   - Pre-treatment and post-treatment
   - Waste disposal
   - Price

Technical: Conventional

- Today: high energy techniques or bulk, imprecise technologies with high energy requirements. **Difficult** to extract more than incremental technical improvements.



Conventional polymeric membrane used for Reverse Osmosis. High energy costs. Invites fouling, scaling, concentration polarization within the pores.

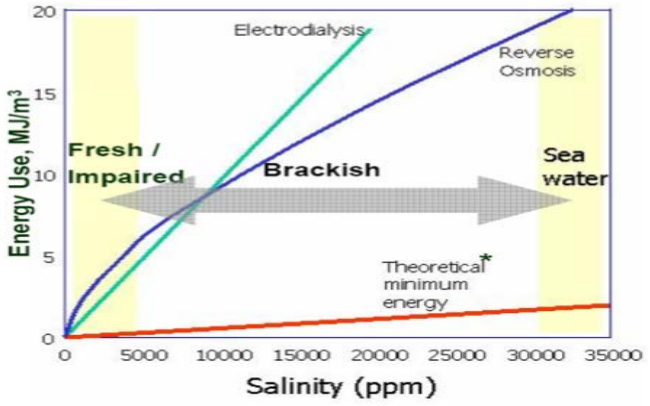
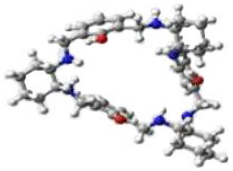


Figure 1-1
Actual vs. Theoretical Energy Intensity for Treating Saline Water

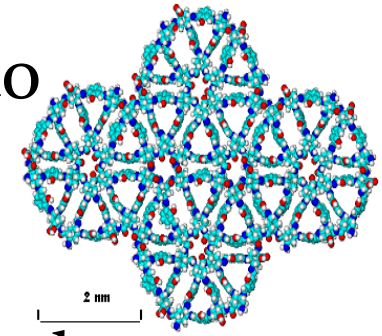
Source: Lawrence Livermore National Laboratory

Scientific/Technical Approach-Innovation

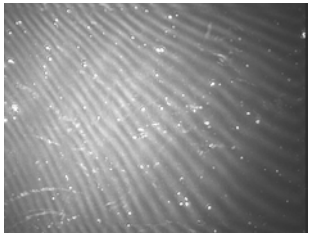
- Rational design and classic pharmaceutical construction of atomically-precise molecular building blocks.



- Then, self-assembly of the building blocks to form 2-dimensional, 1-atomic layer, atomically-precise nanomembranes.



- Then, deposition onto a porous substrate and assembly into filtration cartridges
- Results: unprecedented filtration specificity, high flux, low energy, unprecedented surface control.



Participant Roles. Risks. Mitigation.

- Covalent: technical development and manufacturing of the cartridge.
- Agua Via: license holder addressing end-user engineering, marketing and sales.
- **Project risks:** surviving the GAO financial Valley of Death for manufacturing. Water makes it worse.
- **Mitigation**: Alternate financing: DOE, NSF, DOD have provided funds and **credibility**. Bonds? Loans? Private equity.
- T**imeline**: Now. To market in <3 years.

The AMO Oasis in the Valley of Death 2008-2015

- *"For all of the movement focusing on engaging institutional investors and asset owners in solving water issues, there is a shocking lack of angel/venture capital in the water technology."* Scott Mosley. The Curious Case of Water Innovation. Water is unlike any other investment
- VCs low on the water educational curve: technology, business, market. Minimal experience, knowledge.
- Biggest water investment year 2015: 2.2% of the clean tech funding market and 0.07% of the broader startup market. $44.17M total investment over 39 deals.
- Knowledgeable VC turned us down due to manufacturing risk concerns…. 2 weeks before DOE SBIR Phase 1 grant.
- AMO: 1) understands Water/Energy Nexus, 2) the technical issues, 3) technology and relevance of atomic precision.

Unique Execution Attributes

- In an influencer-mediated market, we are influence-rich.
  - Former CEOs of 1st and 2nd largest US water companies, American Water and American States Water.
  - World's top desalination tech talent, Head of Thames R&D
  - Former US Secretary of State George Shultz, who also built out Middle East desalination as Bechtel CEO.
  - Leading engineering/installation team: UEM/Toshiba.
  - Largest US water company on Advisory Board, VP and Chief Environmental Officer, American Water
- 1st customer: Semitropic, world's largest water bank. 5,500,000M³/45,000AF same volume as $1B Carlsbad, largest desal plant in Western Hemisphere.
  - Customers in process: more California water districts, leading direct-to-consumer water sales partner with international presence US, Europe, India, China, South East Asia, Africa

Results and Accomplishments

- **2014**: membranes made one at a time. Manual process.
- **Goal**: fully automated, massively parallel, high quality, low cost, atomically precise membrane manufacturing.
- **Phase 1 2015**: achieved **Proof of Concept.** Forming multiple nanofilms simultaneously could be performed as well as making a single nanofilm.
- **Phase 2 2016-18**: Improve and expand Phase 1 mechanical design, in stages, for larger scale parallel nanofilm formation. Add automation. Adapt control system for larger scale. Add Environmental controls and add basic in-process analysis.
- **Additional DOD funds 2016-2017**: Add nanomembrane/substrate composite. Add internal and external membrane performance testing.