The Challenge of Water

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Water and Energy are Interdependent

Energy and power production require water (only agriculture uses more):

- Thermoelectric cooling
- Hydropower
- Fuel Production (fossil fuels, H₂, biofuels)
- Emission control
- CO₂ separation and sequestration

Water production, processing, distribution, & end-use require energy:

- Pumping
- Conveyance
- Treatment

4% of US electrical power

Dr. Michael Hightower, Sandia National Labs, 2010
Why are materials advances are needed in water purification?
- Increase supplies efficiently at low cost
- Remove micropollutants
- Disinfect without creating dangerous byproducts

Two examples of materials research
- Separate with membranes
- Sense with DNA enzymes
Using Saline Waters

- Current methods to remove salt from water (desalinate) need large amounts of capital, energy, and chemicals.
- Current methods are prone to fouling, scaling, and cost a lot to operate, needing lots of maintenance and trained workers.
- Inland salt waters are full of hard salts, and disposal of brine is expensive.
- However, new methods are being developed to reduce all these problems, making certain saline source water relatively inexpensive to recover.
Desalination by Reverse Osmosis

RO has been around a long time, works well, but much more can be done.

Asymmetric membranes: Current state of RO art, first developed in the 1960’s and 1970’s

Typical flow rate is 10 µm/s
Research Needs for Reverse Osmosis

- Poor rejection of neutral, molecular contaminants
- Biological fouling
- Poor chemical stability to chlorine
- Disposal of concentrated brine

(Concentration polarization is not to scale)
Needs lots of area: 1 million gallon/day requires one football field of membrane.

Reverse osmosis plant at Bandar Imam, Iran
www.water-technology.net
Thermodynamic limit of sea water desalination

- For 50% recovery, ideal solution, 3.5% by mass NaCl ($V_0 = 2 \text{ m}^3$ to recover $1 \text{ m}^3$ pure water)

\[ W = nV_0 k_B T \ln(2) \]

\[ W = 3.8 \text{ MJ} \approx 1 \text{ kWh} \]

- No process can do better than this at 50% recovery. (For 0% recovery, no $\ln(2)$ term.)
- State-of-the-art RO is only a factor of 2 higher than this limit.
Almost no microscopic understanding of transport in interfacially polymerized membranes

Real-world “nanotechnology”: active layer is only 100 nm thick
Use “Rutherford backscattering spectroscopy” as a tool for analytical chemistry on a 100 nm polymer layer.

Layer 1: $C_{18}H_{12}O_3N_3$

Layer 2: $C_{27}H_{22}O_4S$

FT30 reverse osmosis membrane, Dow Liquid Separations
Same physics that Rutherford used to reveal the structure of the atom in 1910

2 MeV He ion accelerator at U. Illinois Materials Research Laboratory

analityca.blogspot.com
Incomplete polymerization produces charged functional groups—label RCOO$^-$ with Ba$^{++}$ and Ag$^+$
Think of this as a titration on 100 nm of membrane

FT30

$C_{T,R-COOH} = 0.43 \text{M}$

$pK_{a1} = 5.23$

$pK_{a2} = 8.97$

$w_1 = 0.19$

$w_2 = 0.81$

$AR_{Ba^{2+}} = 0.37$

$a = 5.16$
Active areas of “high-risk/high payoff” research

Forward Osmosis

Carbon Nanotubes

Biomimetics
The Ammonia-Carbon Dioxide Forward Osmosis Desalination Process

Energy Input preferably from waste heat

Schiermeier Nature (2008)
Advances in membrane materials could have large impact in many areas of water-energy

- Treat non-conventional sources for cooling water to reduce scaling, and remove organics that aggravate biofouling.
- Treat produced water generated by fossil fuel recovery to reduce environmental impact.
- Membranes for bioreactors (aerobic and anaerobic) that minimize biofouling.

Savings in energy possible in treatment of source and waste waters

- U.S. ensures water safety by brute force: High pressures to prevent contamination from sewage, and high residuals of chemical disinfectants. Huge leakage.
- Downstream water quality impaired by treatment itself. Salts and disinfection byproducts
- New point-of-source, use, and discharge systems can mitigate these issues.
Disinfection of Hard to Treat Pathogens, Without Intensive Chemical Treatment

- Disinfect water WITHOUT using chlorine or other powerful oxidants that can themselves form toxic compounds
- Use of materials to trap pathogens, including viruses
- Use particles, catalysts, and photocatalysts with plentiful, free light to inactivate pathogens in water

Benito Mariñas, UIUC

http://nobelprize.org/
Robust Sensing of Contaminants in Real Time
Could be a Game Changer

- High cost in treating all waters all the time, when need may be much less.
- Most sensing today done in batch mode and sent to lab periodically: Difficulties in getting reliable results.
- ppb levels of toxic compounds are hard to sense in a high background of organics.
- Need to detect pathogens, including viruses.
- Fouling stops even simple sensors from working after a relatively short time.
DNAzymes for Highly Selective Heavy Sensing of Heavy Metals

http://montypython.scs.uiuc.edu
ANDalyze, Inc.

Real time water testing “Powered by DNA”
Some final thoughts…

- Water purification is an incredibly important problem that is underserved by the scientific community.
- Many opportunities across disciplines; we need everyone’s talents.
  - Materials, transport physics, engineering
  - Polymer chemistry, molecular biology
  - Microbial ecology, virology, toxicology