New Materials and Separations Science for Sustainable Water

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Where to go for additional water … a list prioritized by relative cost

• Water re-use
  – Re-cycle water from treatment plants to aquifers
  – Use dual distribution systems
• Treatment of marginally impaired waters
  – Need “smart” membranes for low-cost treatment
• Desalination of brackish waters
  – U.S. uses 500 km$^3$/year, brackish water reservoir in U.S. is 1,500,000 km$^3$
• Sea water desalination
  – Expensive using existing technologies, but secure

Develop the technologies that are needed the most!
Existing desalination technologies use too much energy

Reverse osmosis:

Electrodialysis:

Thermal methods
What will the next generation of treatment technologies look like?

• Still using technologies developed 30-40 years ago
• New materials and new insights have not been applied to water treatment
• Potential exists for major reduction of energy use for desalination
• Selective membranes could be developed for efficient treatment of impaired waters and for resource recovery
Nanoporous polycarbonate performs much better than commercial ED membranes

- Functionize membranes to be selective for target species such as nitrate, arsenate, perchlorate or others
- Combine ion exchange and electrodialysis in one technology

Pilot testing at LLNL will begin soon using California Prop 50 funding
The “Cussler Ion Pump” provides a new way to significantly lower desalination energy use.

Method uses coupled fluid flow and application of charge to "pump" ions across electrodes and separate salt from fresh water.

Development at LLNL underway using CA Prop 50 funding.
More energy and water using existing technologies in innovative ways: Three example pilot studies

- Water use and mineral recovery at Mammoth Lakes geothermal plant

- Thermal desalination and brine re-charge at the Salton Sea geothermal site

- Combined water production, brine re-charge, and mineral recovery at the Coso geothermal power plant
Water desalination can solve water needs for the Mammoth Pacific geothermal power plant

- Plant is currently air-cooled
- Want to increase power in summer using water-cooling
- Geothermal fluid causes scale to form on the cooling panels

If we can somehow use geothermal fluid, we save 1.5 MGD of fresh water for community use (1700AF/y)
Cooling with geothermal fluid causes the panels to become coated with mineral scale.
We desalinate the geothermal fluid that exits the heat exchanger using reverse osmosis.

- Permeate - to evaporative cooler
- Concentrate - for silica and metals extraction

(LLNL project funded by CEC and DOE Geothermal)
Geothermal energy production is plagued by scaling.

Can we turn geothermal scale into this?

Yes! And our economic analysis says we reduce energy production cost by 1.3¢ / kW-hour.
Co-production of resources from all types of saline waters can turn waste into profit

- Produce additional revenue from marketable by-products
- Eliminate scaling and re-injection problems
- Save energy used and avoid waste generated in mining

Some common brine constituents
- Silica
- Lithium
- Zinc
- Manganese
- Industrial salts
- W, Cs, Rb, PGE

**Apply extraction technologies to produced waters (~3 million acre feet) and brines from desalination plants**
Geothermal Energy Primer

You Need

Heat  Common
Permeability  Rare
Water  Rare

More water for re-injection

More geothermal energy!
Water desalination using waste geothermal heat can help solve Southern California water needs.

USBR/Sephton Energy Salton Sea thermal desalination project

- Use excess heat to power Multiple Effect Distillation
- Desalinate Salton Sea water
- Re-inject concentrate into geothermal field

Potential to create 80,000 AF product water per year, and dispose of waste brine in geothermal aquifer.
Ridgecrest California needs more potable water

- Currently mining water that is 20-30,000 years old (ice age)
- Only available new sources are brackish water wells
- Zero liquid discharge requirement makes desalination expensive ($1700/AF)
- 2/3 of that cost is for brine disposal

What can they do?

- 10 miles to Salton Sea
Use the nearby Coso geothermal site to power thermal desalination and dispose of brines

- Pump brackish waters from well field to Coso site
- Use low-grade geothermal heat for desalination
- Discharge waste brine into geothermal reservoir to recharge geothermal aquifer
- Pump distillate to Ridgecrest for community use

Get potable water AND more geothermal energy from waste water and waste heat!
Net Primary Resource Consumption ~97 Quads

Source: Production and end-use data from Energy Information Administration, Annual Energy Review 2002.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

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Waste heat can provide a lot of water through thermal desalination

- Total of almost 56 quads of “lost energy” from industrial and commercial sources in the U.S.
- Each quad can produce about 15 million AF using thermal desalination at 60 kWh per 1000 gallons
- How much of this energy is available and useable?

The Jubail desalination plant in Saudi Arabia
Combine power production, water desalination and CO₂ sequestration

CONCEPT
Use desalination to separate CO₂ for geologic sequestration

\[
\text{HCO}_3^- + \text{H}^+ = \text{CO}_2(g) + \text{H}_2\text{O}
\]

BENEFITS
- Fresh water and pure carbon dioxide by-products
- Power plant uses brackish water as source for boiler water and coolant
- Produces space in subsurface for CO₂ injection

Roughly equivalent in cost to amine stripping
Conclusions

• Provided funding, significant improvements in water treatment technologies are likely, especially:
  – Energy efficient desalination
  – Selective extractions for impaired waters
• Geothermal reservoirs provide a useful sink for waste brines
• New technologies for co-production of resources from waste brines could make brine re-cycling profitable
• “Waste” heat can power desalination to generate additional water
• Desalination can be used to separate CO$_2$ for sequestration
Ideas for Future Technologies: Use genetically modified plants to remove salts

Genetically modified tomato plants concentrate up to 14 wt % salt
Zhang & Blumwald, 2001 Nature Biotech.19:765

- Grow GM crop to extract salt into plant foliage
- Distill plant material to make ethanol
- Discard or re-cycle salt residue

BENEFITS
- Solar energy used to remove the salt
- Produce ethanol by-product
- Can be used as needed to remove salt build-up in soils
- You can eat the fruit!
High throughput, selective membranes exist in life – ion channels and aquaporins

- Ion channel in pore wall
- Selective for K$^+$ over Na$^+$
- Mimic K$^+$ hydration sphere

2003 Nobel Prize in chemistry went to Rod MacKinnon of Rockefeller University for determining the structure of the potassium ion channel

Leverage off of work to understand functionality of ion channels
The economics of silica production at Mammoth Lakes are favorable

**Estimated for 1.5 MGD flux**

- **Capital** $2,300,000
  - Includes all equipment, buildings, and design costs
- **Operating** $670,000/y
  - Includes membrane cleaning and replacement, filtration maintenance, energy and manpower (2 FTE)
- **Income**
  - Silica $1,042,000/y
  - Water $150,000/y
  - Net $400,000/y

For 20 year operating life
- Payout in year 7
- Rate of return ~14%

Estimates based on WTCOST, a water treatment cost estimation program (Mooch, 2003).

Reduces energy production cost by 1.3¢ / kW-hour
Fast water transport observed through aligned carbon nanotubes

- Transport of water up to 8000 times faster than predicted by continuum hydrodynamics, resulting in lower energy and/or capital costs for desalination

- Fabricated from low-cost materials – silicon, hydrocarbons, metal alloys, and vapor-deposited polymers/ceramics.