

CHALLENGES IN BIO-INSPIRED MEMBRANES

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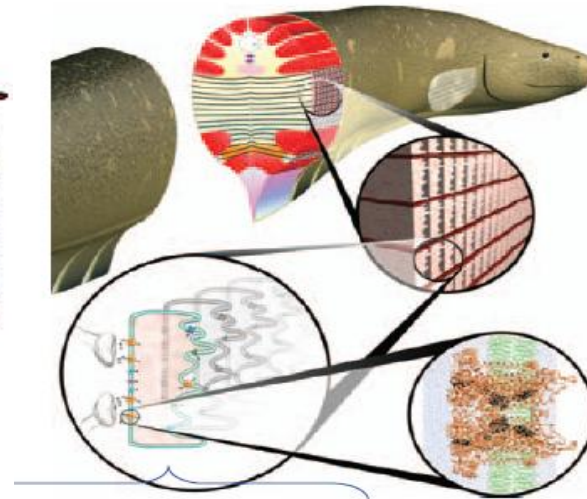
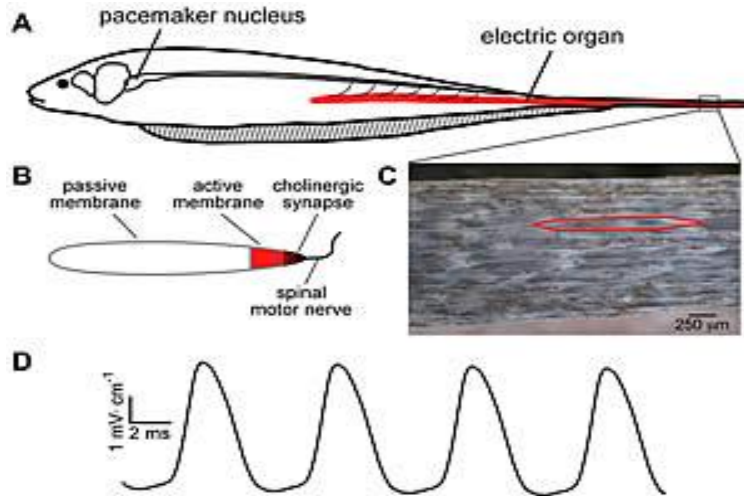
OUTLINE

- Attributes of biological membranes
- Importance of selective membranes in energy
- Current efforts in bio-inspired membranes
- Future directions through self-assembly?



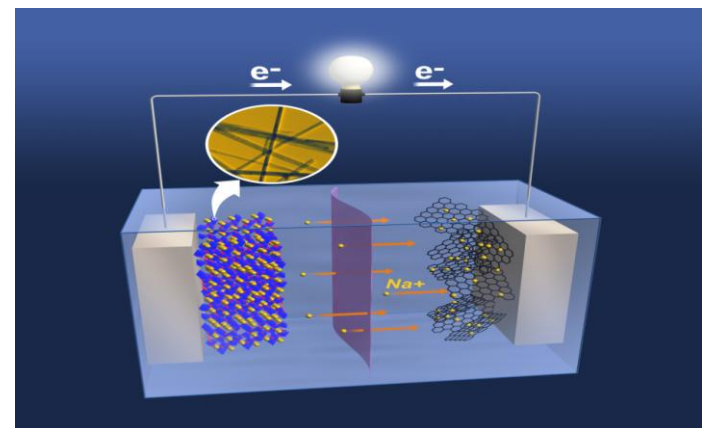
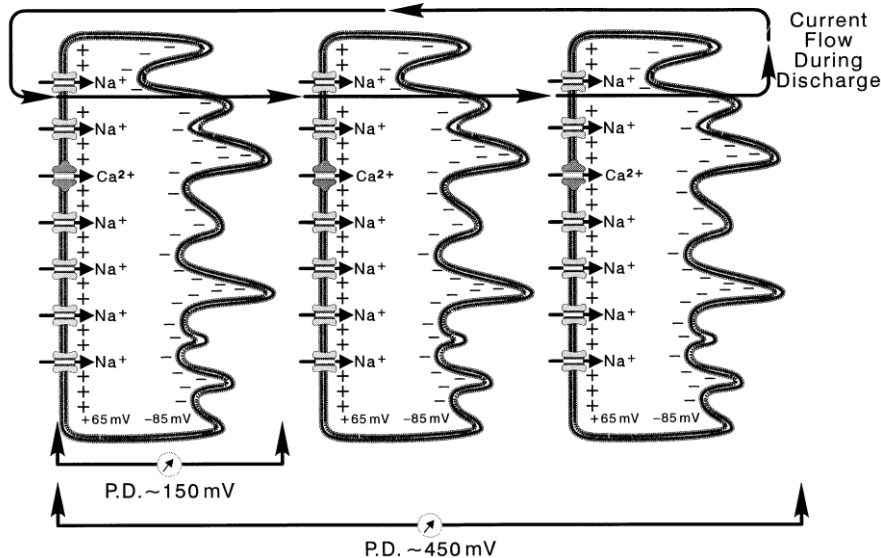
Lessons form biological membranes to develop low cost energy storage devices

Biology stores energy with Na, K, Ca ions, not Li ions (electrical eels).



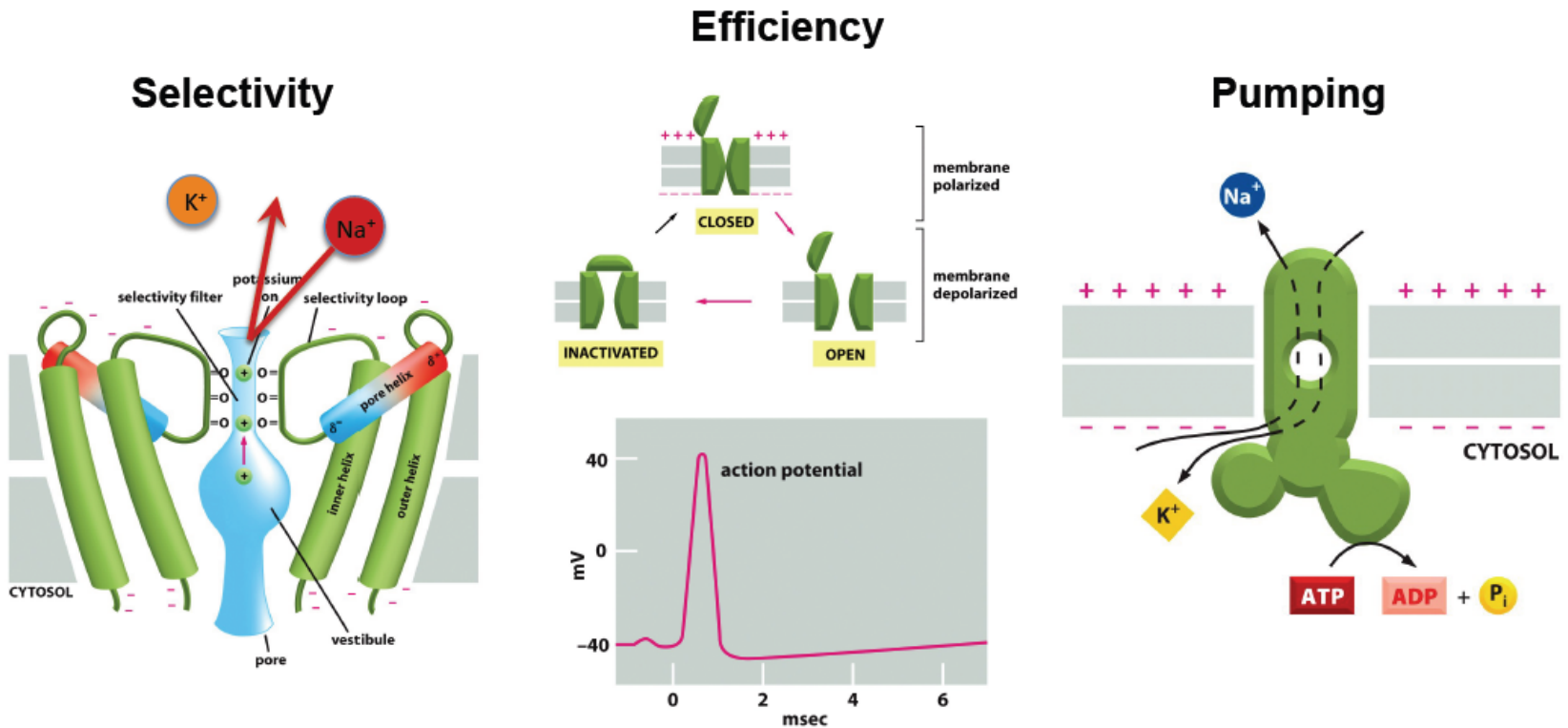
J. Xu, D. A. Lavan, *Nature Nanotechnology* 2008, 3, 666.

PNNL's Na ion battery



Jun Liu's group, PNNL, *Advanced Materials*, 2011

Attributes of biological membranes

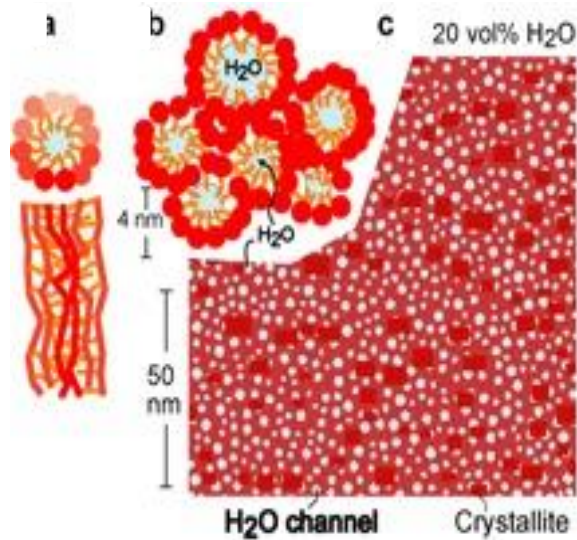
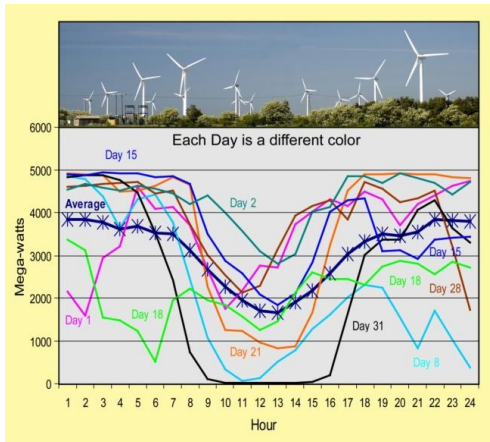


Collective effect of size selectivity, solvation, ion-coordination, hydrophobicity, etc.

Protein conformational change triggered by very specific chemical reactions

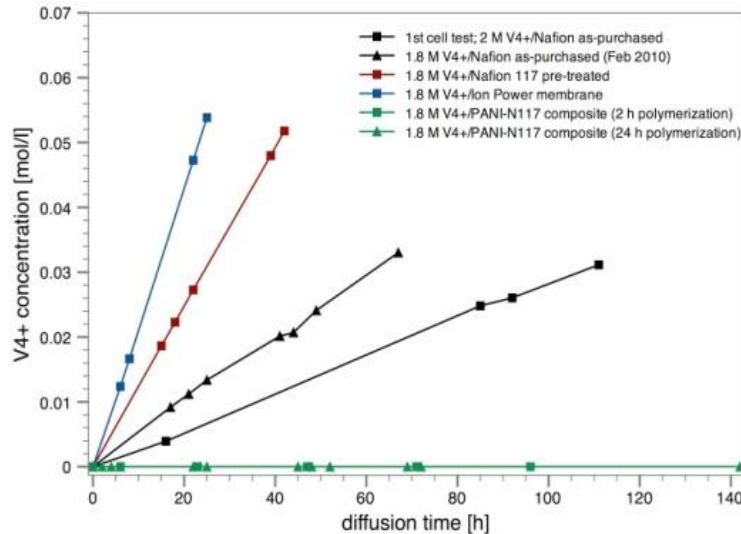
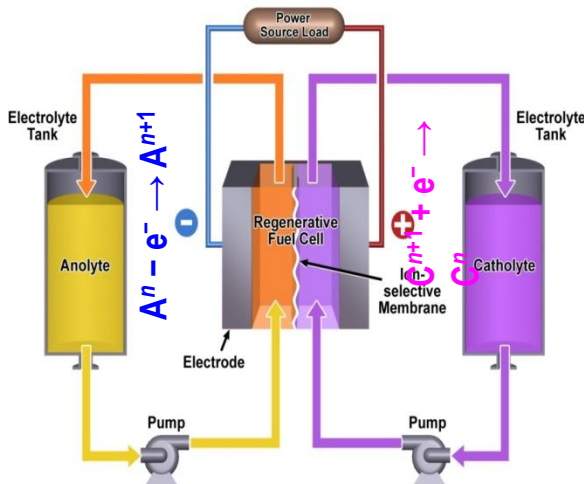
The key component in redox flow batteries, Nafion membrane, is not selective towards cations, causing degradation of the device.

Redox flow battery is a leading candidate to store wind energy



Nafion membranes are expensive and have large water channels to allow hydrated cations to cross.

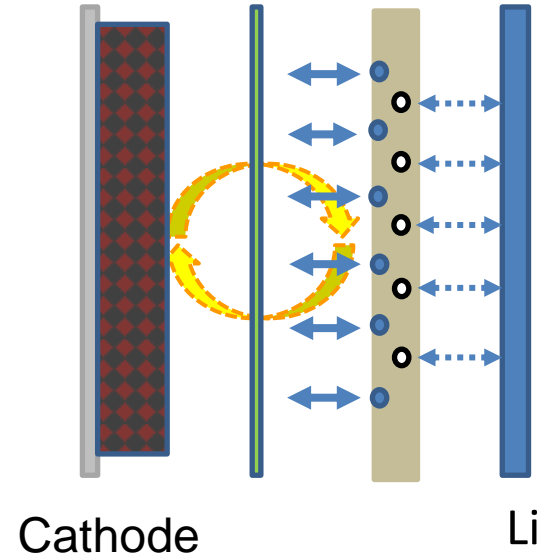
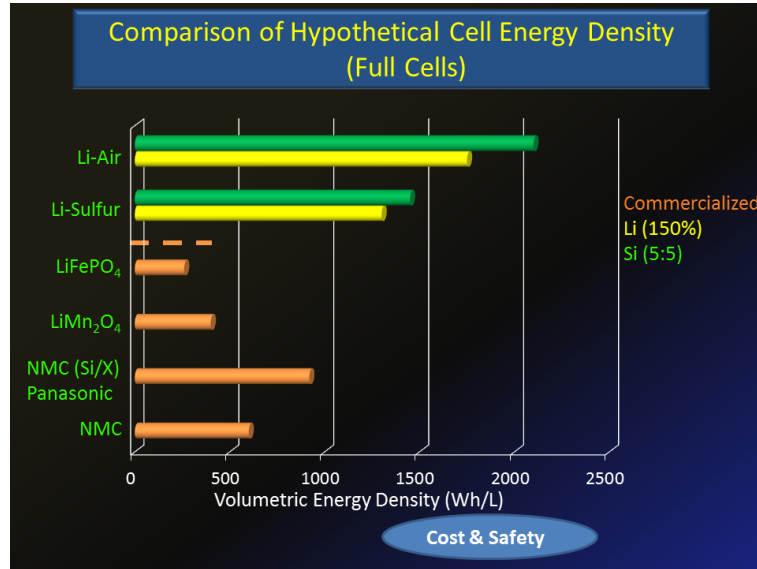
K. Schmidt-Rohr, Q. Chen, *Nature Materials* 2008, 7, 75.



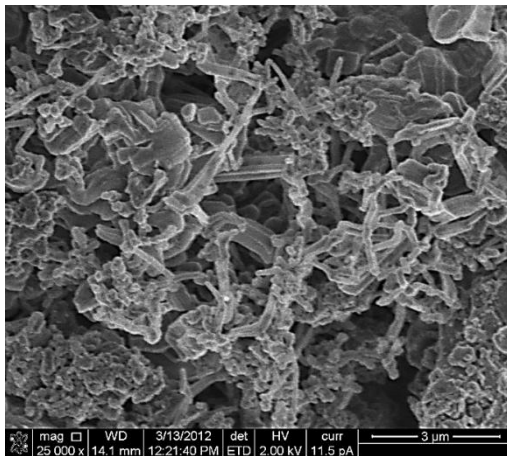
The cross contamination causes self-charge and degradation of efficiency

Ion selective membranes are critical for the safety and reliability of Li-ion batteries, and Li-S and Li-air batteries.

Energy density of advanced Li batteries (L. Nazar)



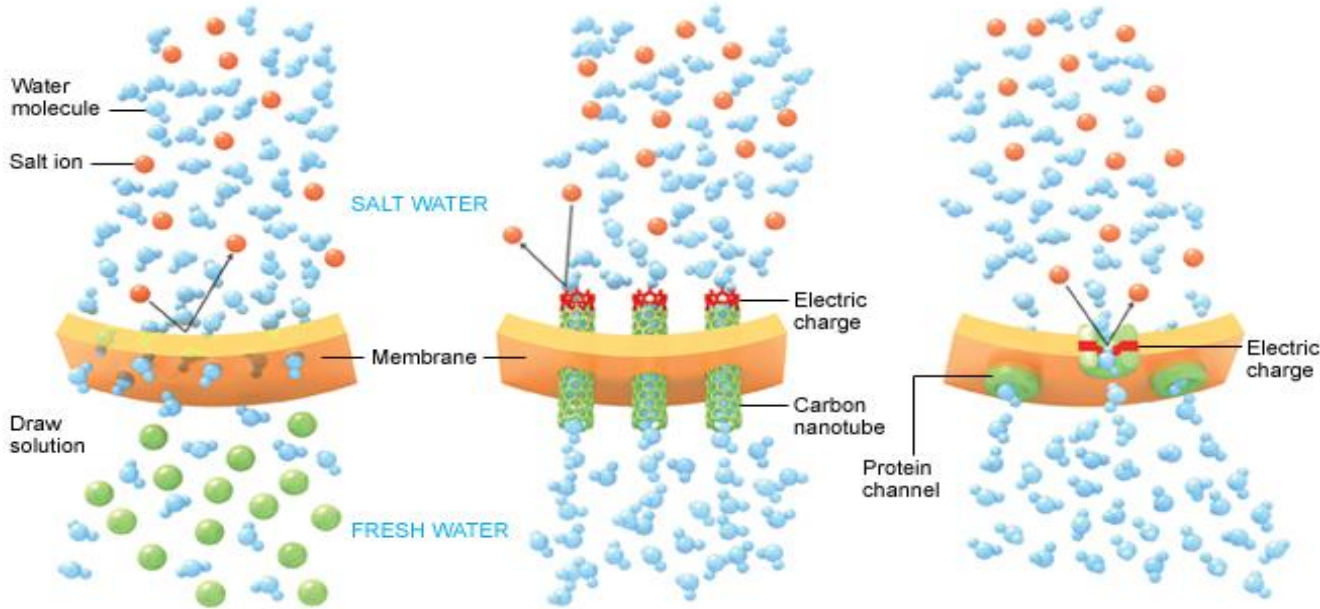
Dendrite formation in Li-S battery (Jun Liu's group, PNNL unpublished research,).



Smart membranes may prevent run-away reactions by shutting off the diffusion channels as activated by heat or high current.

Examples of bio-inspired membranes

Three technologies promise to reduce the energy requirements of desalination by up to 30 percent. The race is on to see which will take the lead.



FORWARD OSMOSIS

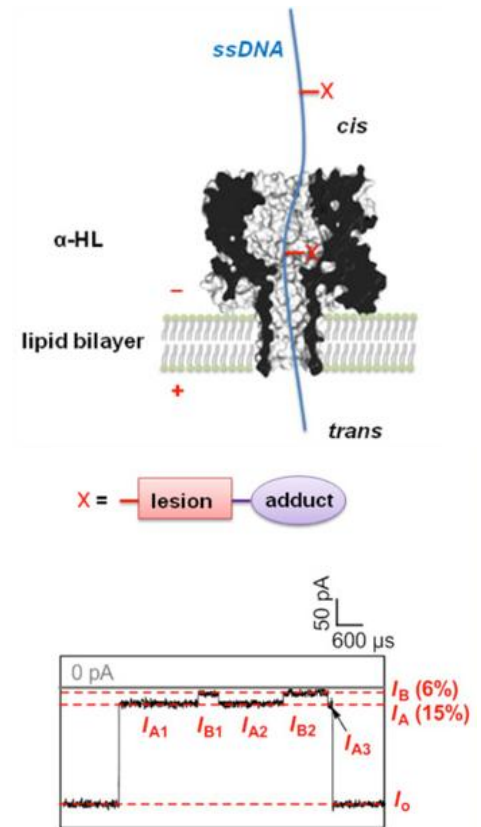
Water molecules migrate by natural osmosis, without energy input, into an even more concentrated "draw solution," whose special salt (green) is then evaporated away by low-grade heat.

CARBON NANOTUBES

An electric charge at the nanotube mouth repels positively charged salt ions. The uncharged water molecules slip through with little friction, reducing pumping pressure.

BIOMIMETICS

Water molecules pass through channels made of aquaporins, proteins that efficiently conduct water in and out of living cells. A positive charge near each channel's center repels salt.



(Cynthia Burrows, University of Utah)

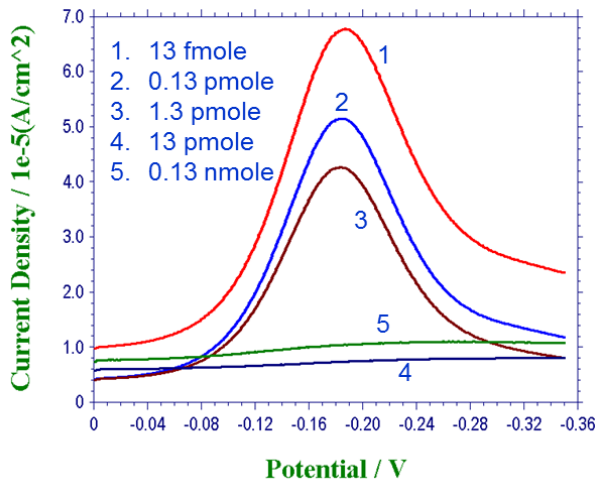
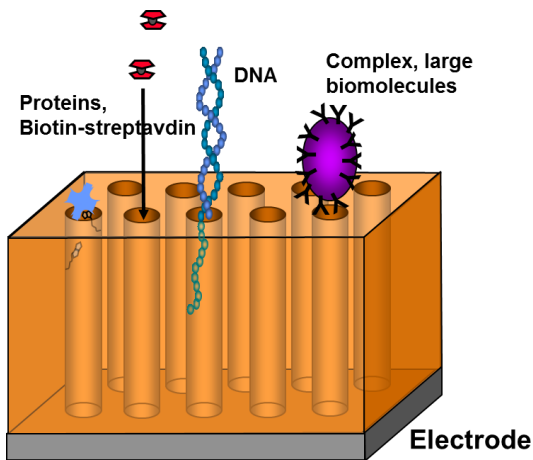
Biomaterials may be too fragile for practical applications.

(from Karen E. Lange, National Geography, August, 2012)

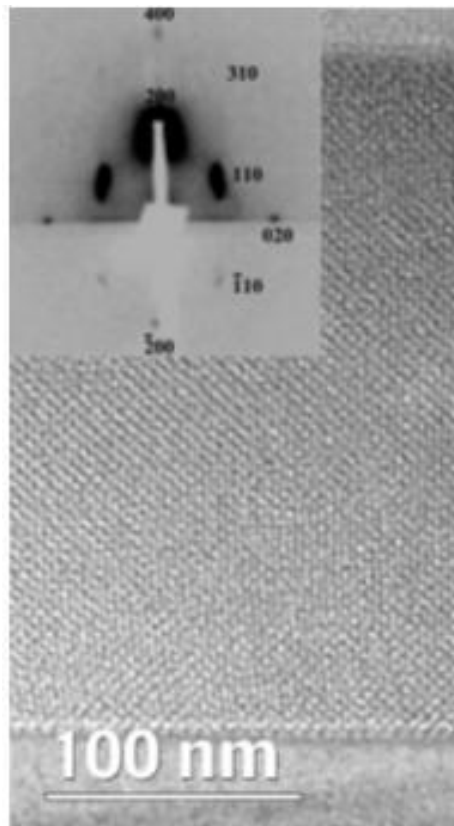


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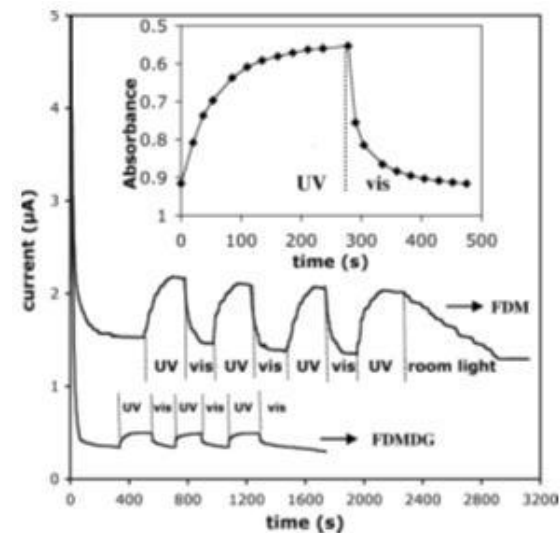
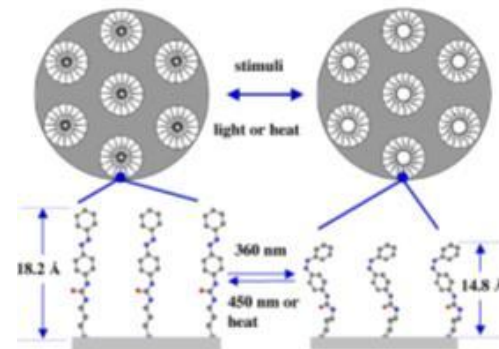
Self-assembled materials as a platform for bio-inspired membranes



Jun Liu's group, PNNL



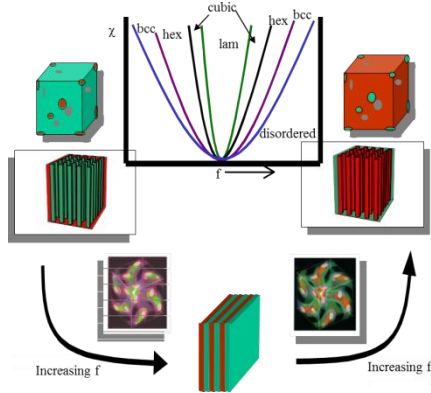
Jeff Brinker's group,
Sandia National labs



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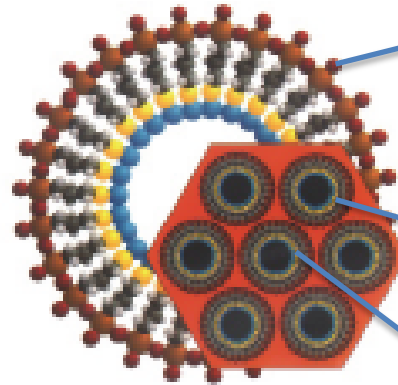
Pathway forward for bio-inspired membranes using self-assembly

Using self-assembly to control pore structures of ceramics and polymers



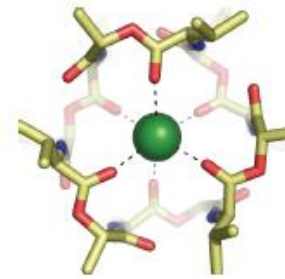
Greg Exarhos, PNNL

Build in functionality in the pore channels

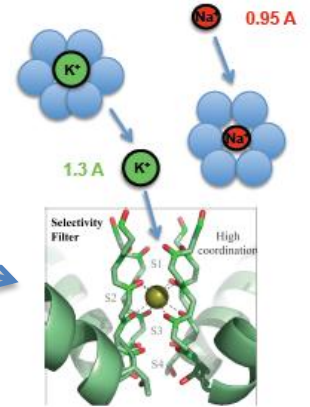


Jun Liu's group, PNNL

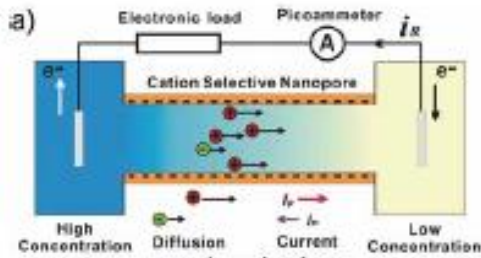
Steric Effects



Competitive Solvation

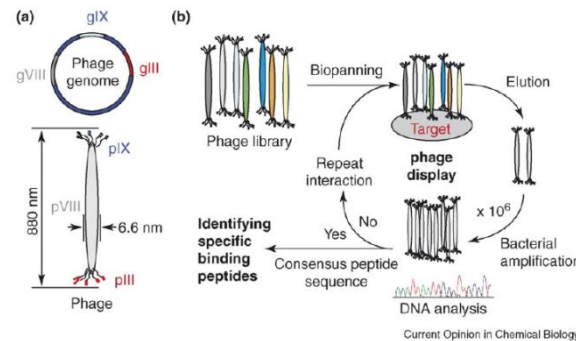
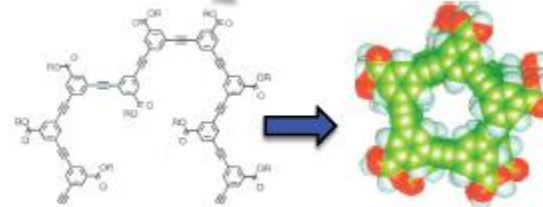


Artificial pumping or switching



Nanoscale ion current measurements using microfluidic platforms

Coupling with external field (Lei Jiang's group)



New ways of engineering selectivity

Anna Merzlyak and Seung-Wuk Lee

(some figures courtesy Bruce Bunker)