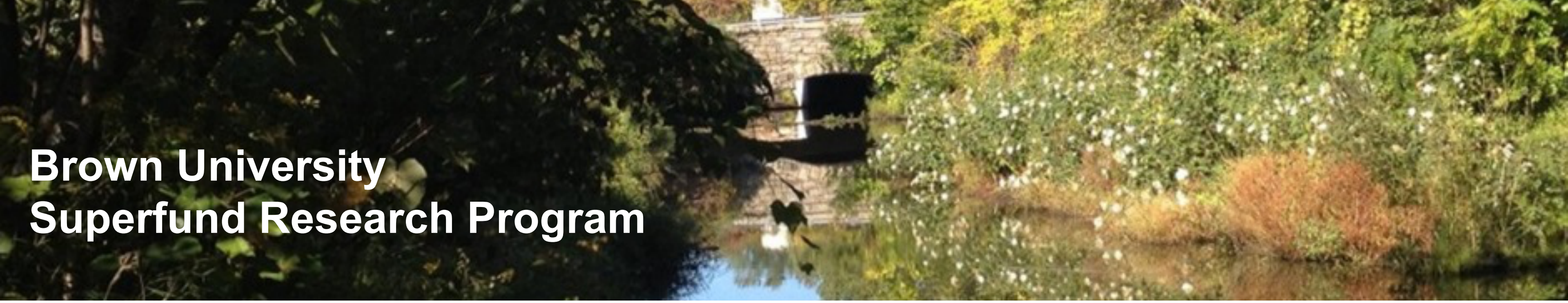
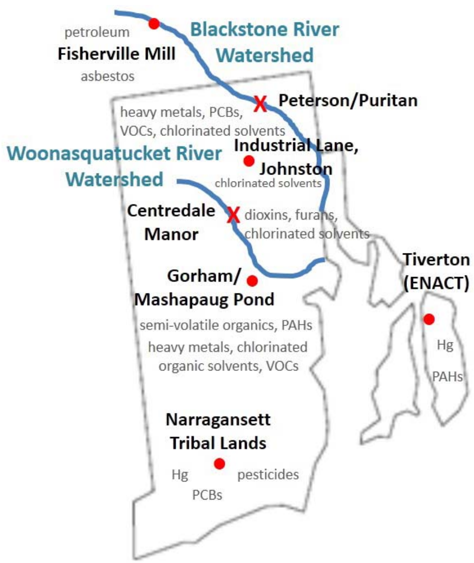


Nano-Enabled Technologies for Environmental Health

Robert Hurt, Brown University



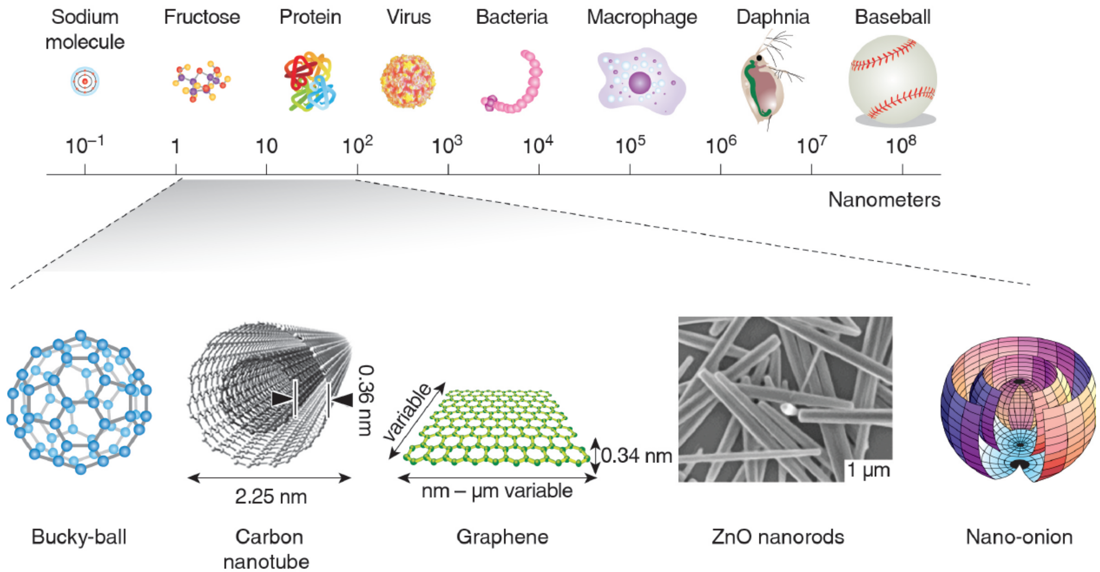
NIEHS 50 YEARS 1966-2016
PART OF THE 50TH ANNIVERSARY EVENT SERIES

National Institute of Environmental Health Sciences
Superfund Research Program

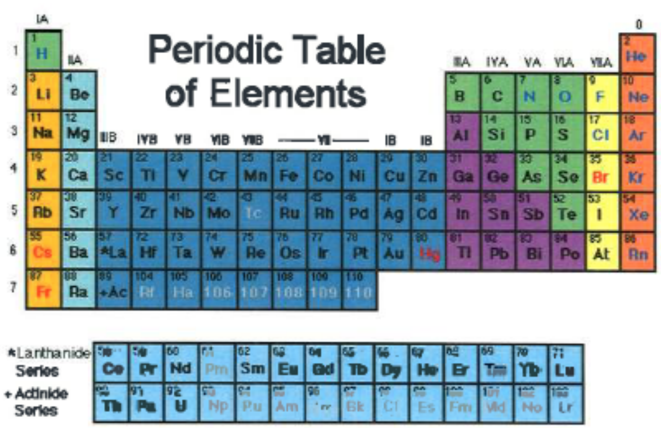
The Superfund Research Program at Brown University
http://brown.edu/Research/SRP

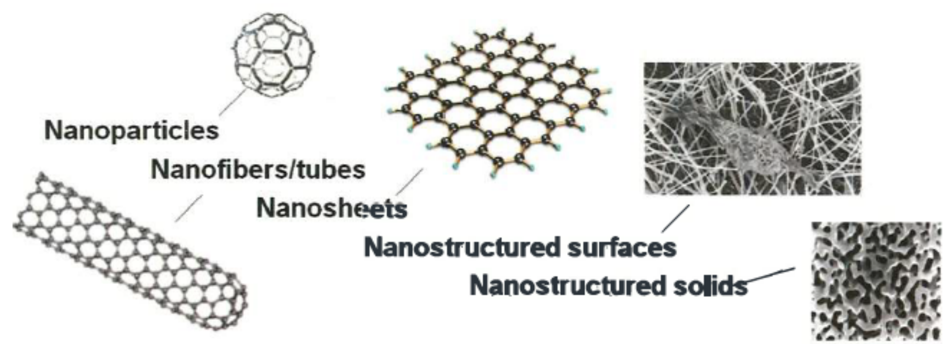
Nanotechnology

Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1-100 nm range, in order to understand and create materials, devices and systems with fundamentally new properties and functions because of their small structure. Definition from http://nano.gov

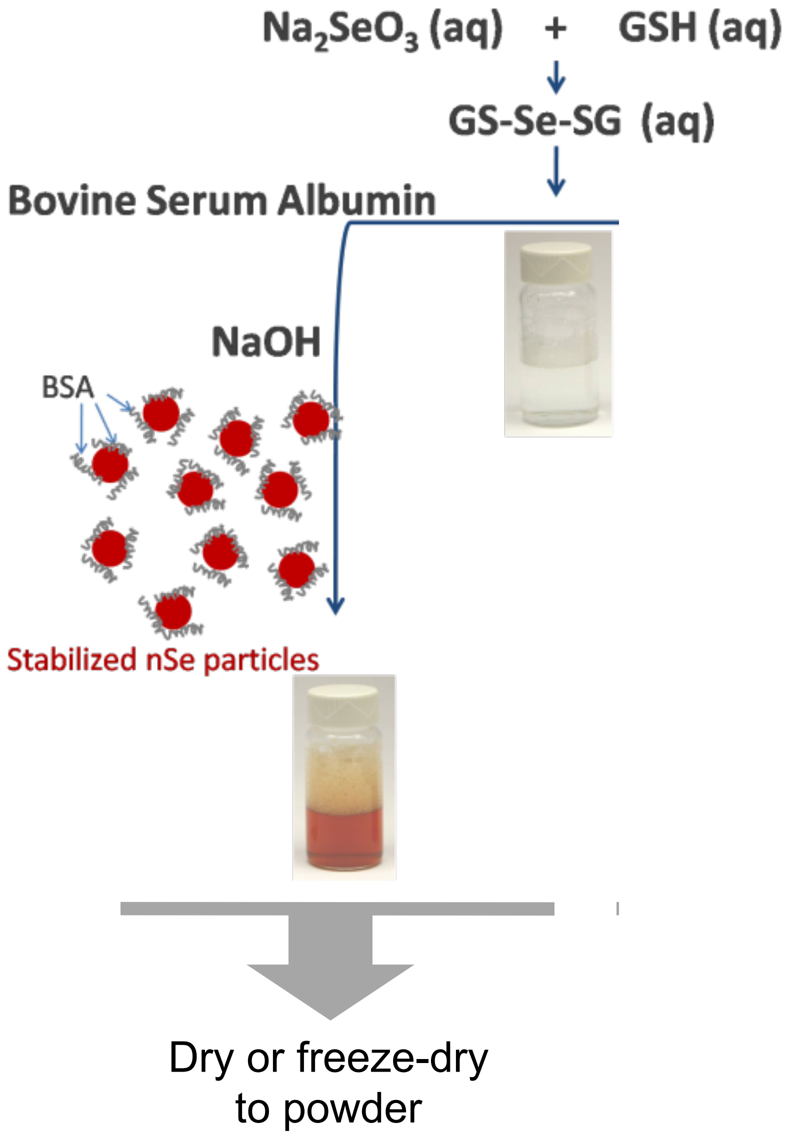


A toolkit of new materials for environmental applications

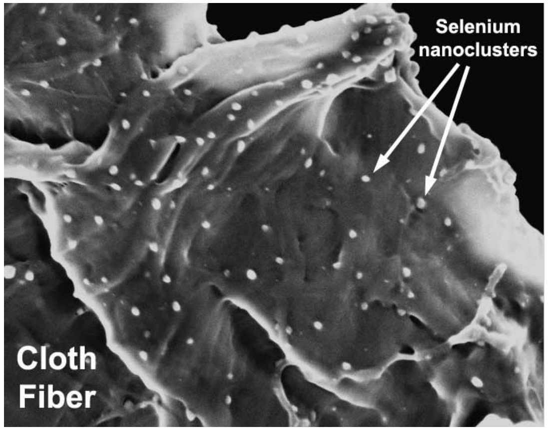




Case Study: Nano-selenium for Hg capture



selenium nanoculsters on cellulose fiber surfaces

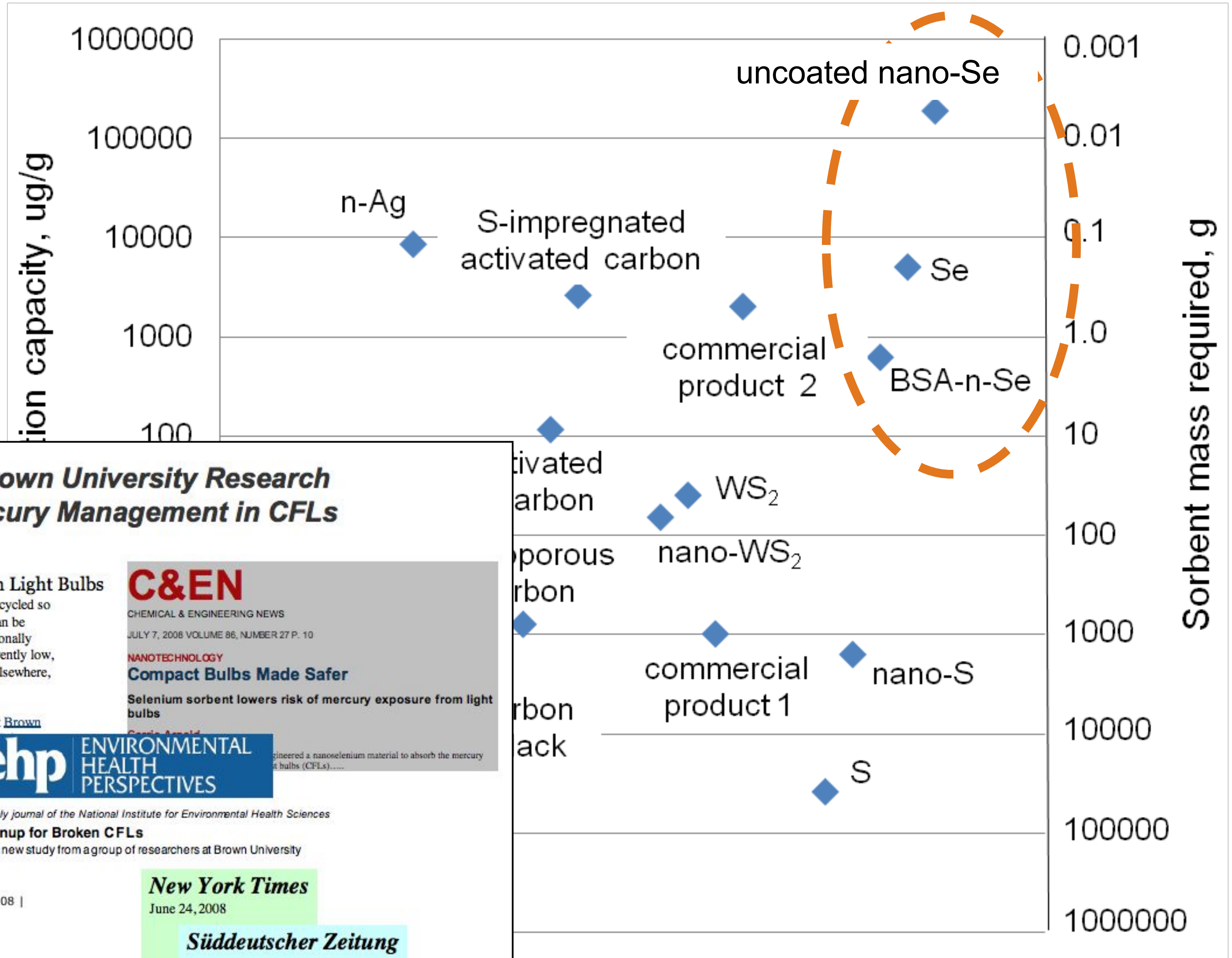


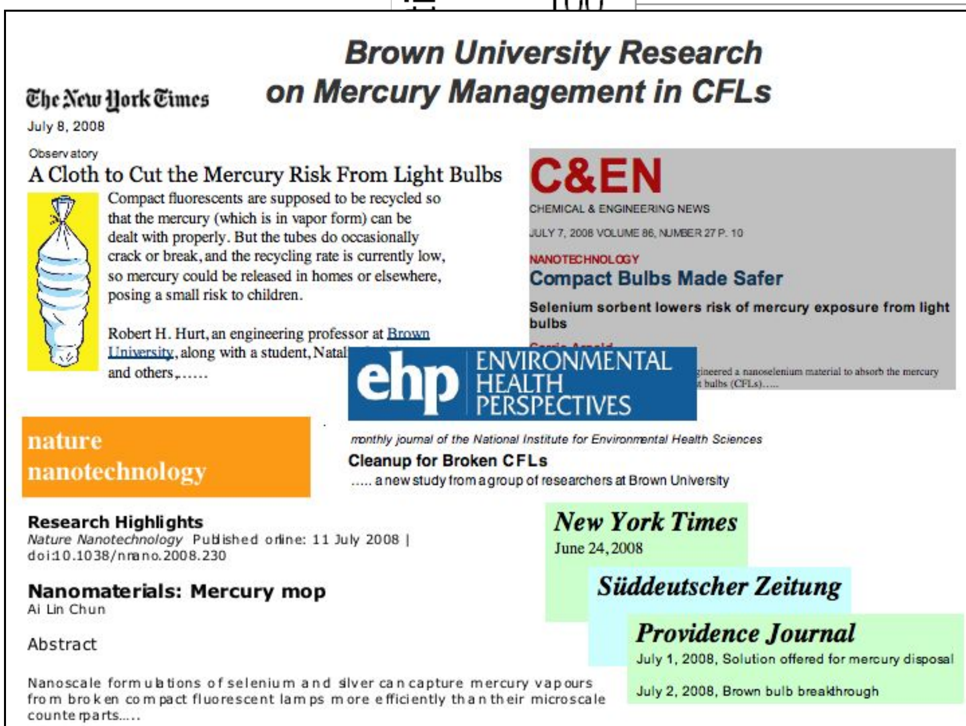
capillary uptake into porous medium

drying

Case Study: Nano-enabled Hg capture

Uncoated nano-Se is 70 x more active than the best commercial sorbent !





Financial support

NCIAA – National Collegiate Inventors and Innovators Alliance

NSF STTR – Small Business Technology Transfer

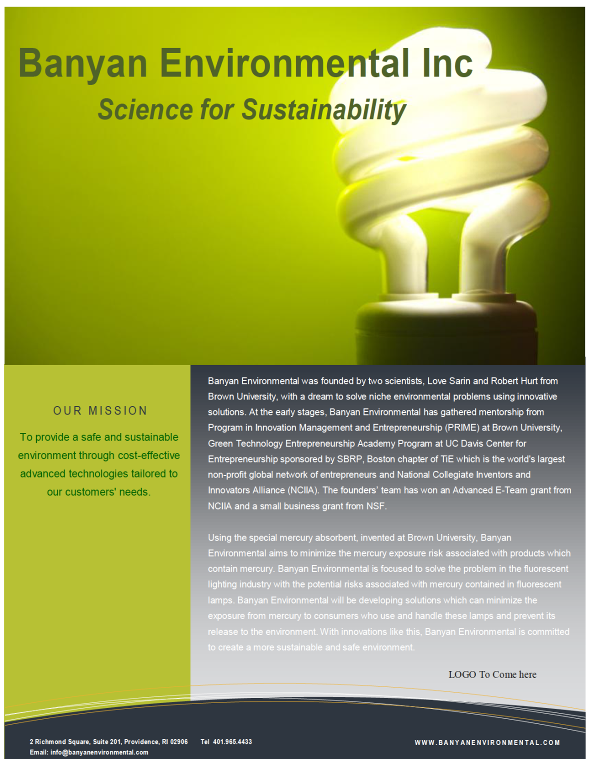
STAC – Rhode Island Science and Technology Council

Banyan Environmental
– a SRP spin-off technology start-up

Dr. Love Sarin
CEO
(former SRP trainee)

Ruben Spitz-Steinberg
R&D engineer

John Moorhead
Finance, Business Developm’t



Banyan Environmental Inc

Science for Sustainability

OUR MISSION

To provide a safe and sustainable environment through cost-effective advanced technologies tailored to our customers' needs.

Banyan Environmental was founded by two scientists, Love Sarin and Robert Hurt from Brown University, with a dream to solve niche environmental problems using innovative solutions. At the early stages, Banyan Environmental has gathered mentorship from Program in Innovation Management and Entrepreneurship (PRIME) at Brown University, Green Technology Entrepreneurship Academy Program at UC Davis Center for Entrepreneurship sponsored by SBRP, Boston chapter of TiE which is the world's largest non-profit global network of entrepreneurs and National Collegiate Inventors and Innovators Alliance (NCIIA). The founders’ team has won an Advanced E-Team grant from NCIIA and a small business grant from NSF.

Using the special mercury absorbent, invented at Brown University, Banyan Environmental aims to minimize the mercury exposure risk associated with products which contain mercury. Banyan Environmental is focused to solve the problem in the fluorescent lighting industry with the potential risks associated with mercury contained in fluorescent lamps. Banyan Environmental will be developing solutions which can minimize the exposure from mercury to consumers who use and handle these lamps and prevent its release to the environment. With innovations like this, Banyan Environmental is committed to create a more sustainable and safe environment.

LOGO To Come here

2 Richmond Square, Suite 201, Providence, RI 02906 Tel 401.965.4433
Email: info@banyanenvironmental.com

WWW.BANYANENVIRONMENTAL.COM

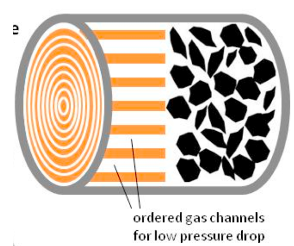
Smart boxes, bags for safe recycling

Retail drop-off boxes

Nanoselenium as a Platform Technology

Technologies for permanent Hg sequestration

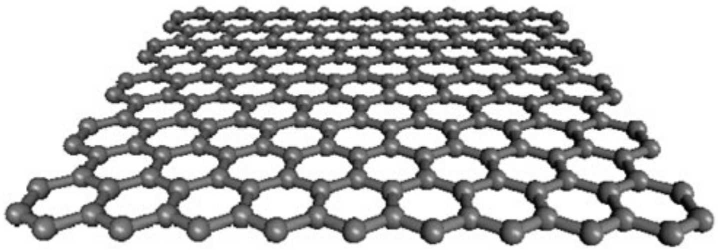
Power plant flue gas capture



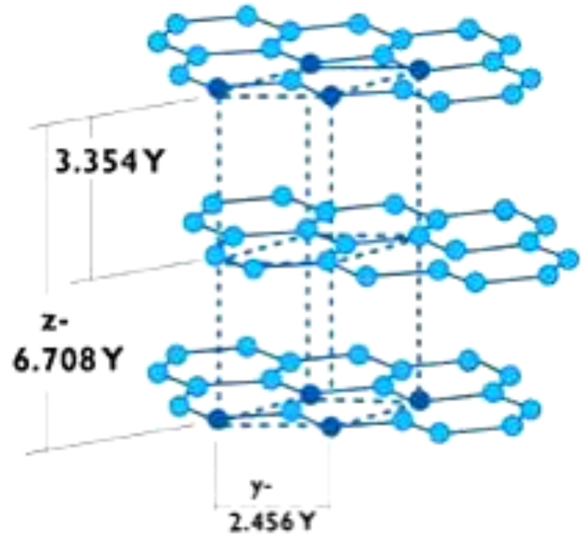
Cartridge-based air-cleaning for NASA spaceflights

Consumer spill and disposal kits

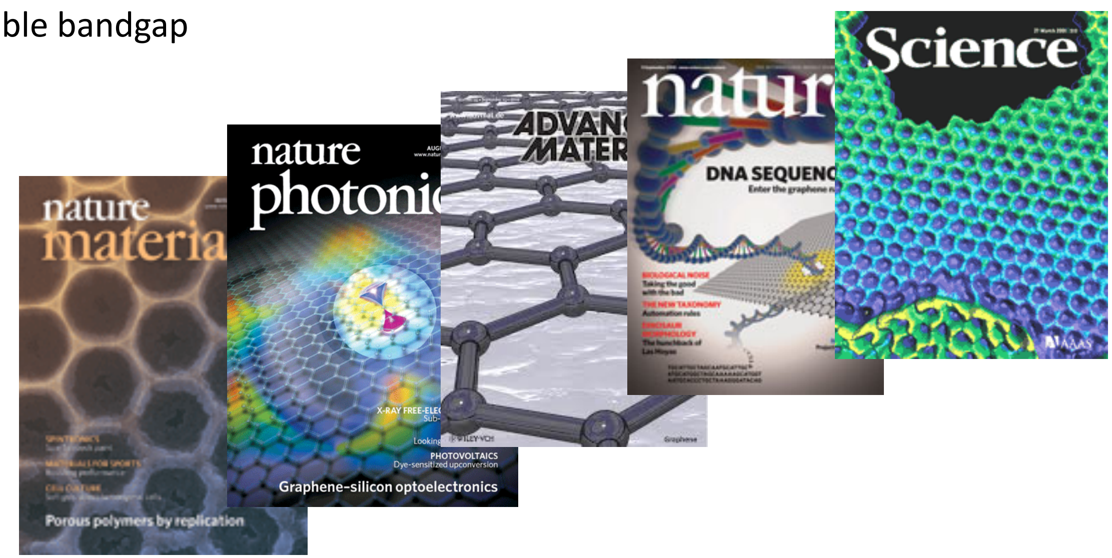
Case Study: Graphene-based Environmental Barriers



- first observed in 1962 (HP Boehm)
- first isolated in 2004 (Geim, Novoselov)
- led to the Nobel Prize, 2010 (Geim, Novoselov)



Exhibits: atomic thinness; high electron mobility;
high conductivity, optical transparency
tunable bandgap

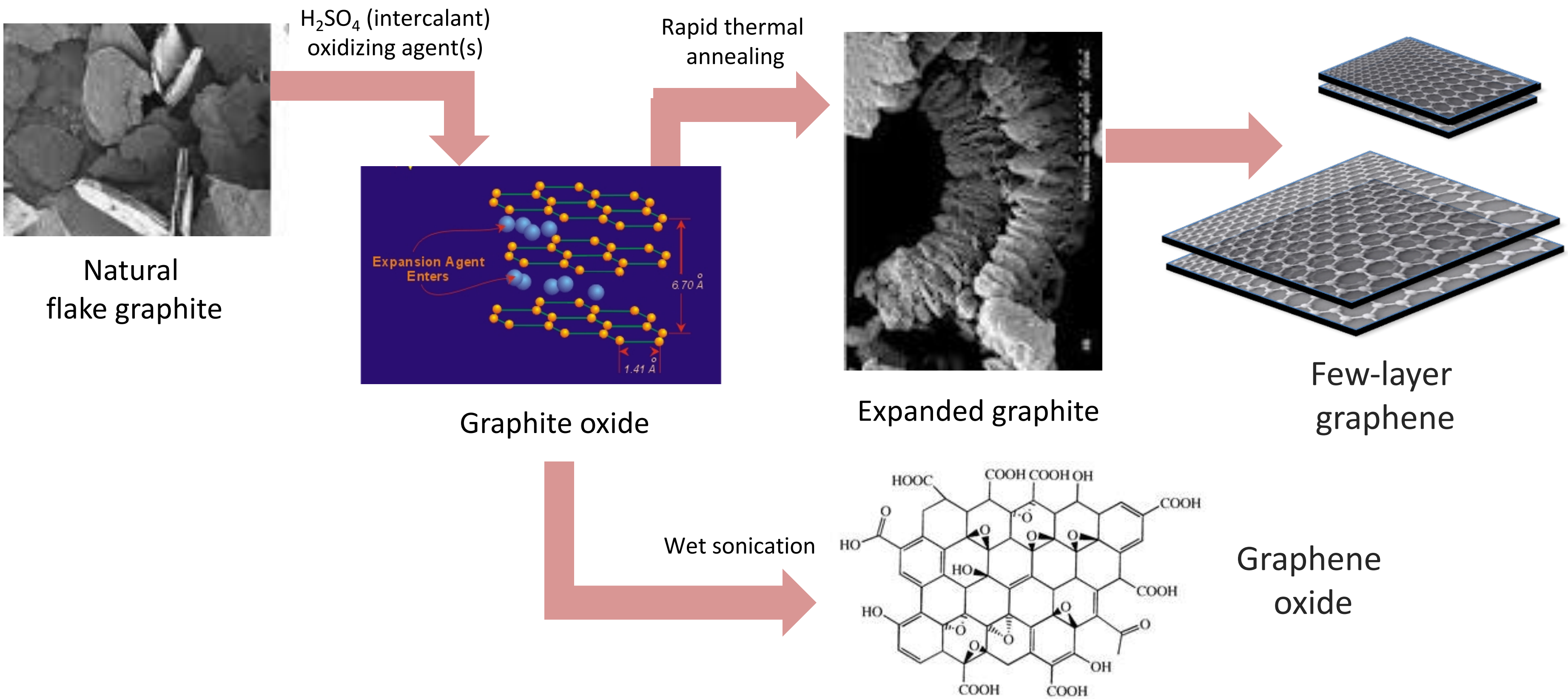


Pristine monolayer graphene is typically fabricated by:

- mechanical exfoliation, or
- chemical vapor deposition

and used on substrates for electronic applications

High-Volume-Production Graphene-Based Materials



Environmental Barrier Technologies

Many environmental technologies are based on *containment*

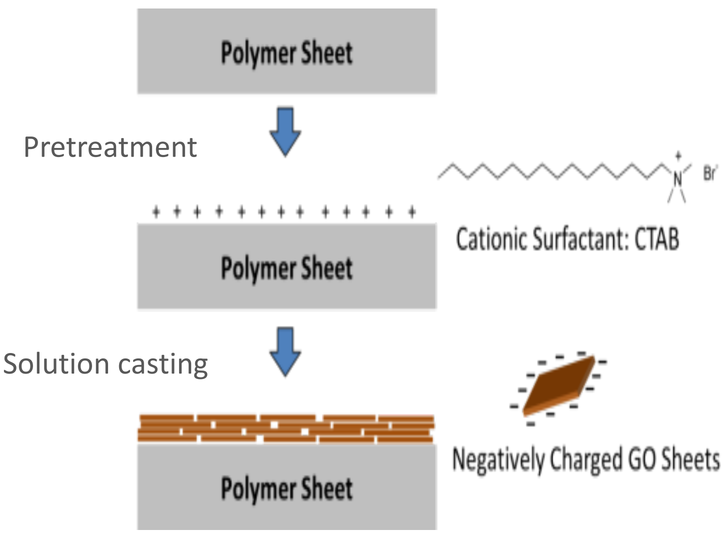
Engineered barriers are used to prevent toxicant release or transport to zones where human exposure is likely

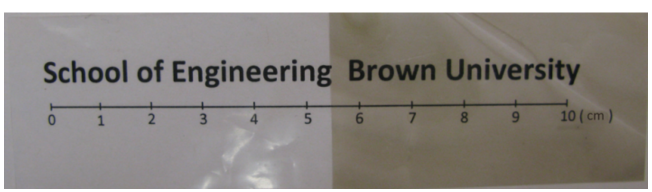
<u>Environmental barriers include:</u>

- geomembranes for landfill liners and caps [Rowe 2004]
- shipping and recycling of wastes containing volatile mercury [Johnson, 2008; Lee, 2009]
- barriers to “leachables and extractables” in food, beverage, and pharmacy products
- vertical subsurface barriers, horizontal vapor intrusion barriers
- functional layers in personal protective equipment
  for hazmat workers or military personnel

Graphene-Based Vapor Barriers

[Guo, Hurt et al., ES&T, 2012]

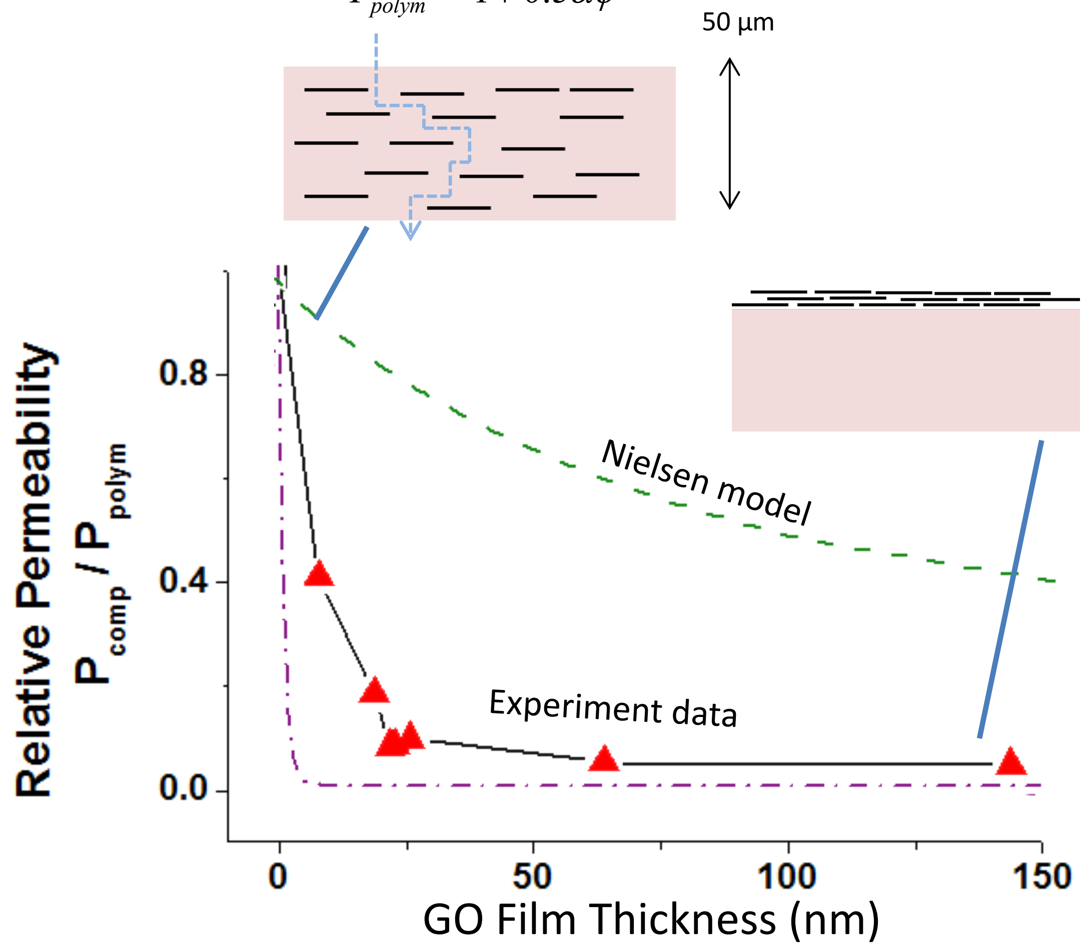




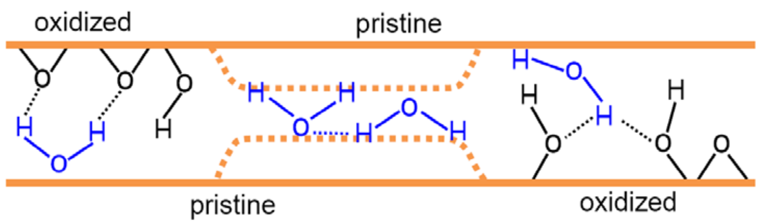
Without GO coating *With GO coating*

Data for Hg vapor

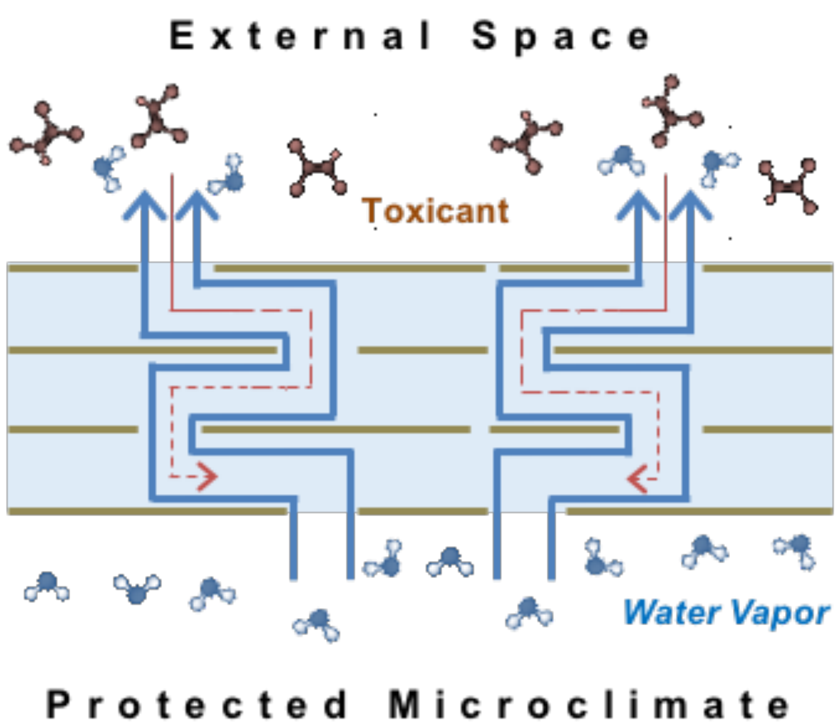
$$\frac{P_{comp}}{P_{polym}} = \frac{1-\phi}{1+0.5\alpha\phi}$$



Water permeates "unimpeded" through graphene oxide films



(Nair *et al.*, Science, 2012)



Breathable toxicant barriers based on multilayer graphene oxide films

- In dry state, graphene oxide films reject <u>all</u> molecules (incl. He)

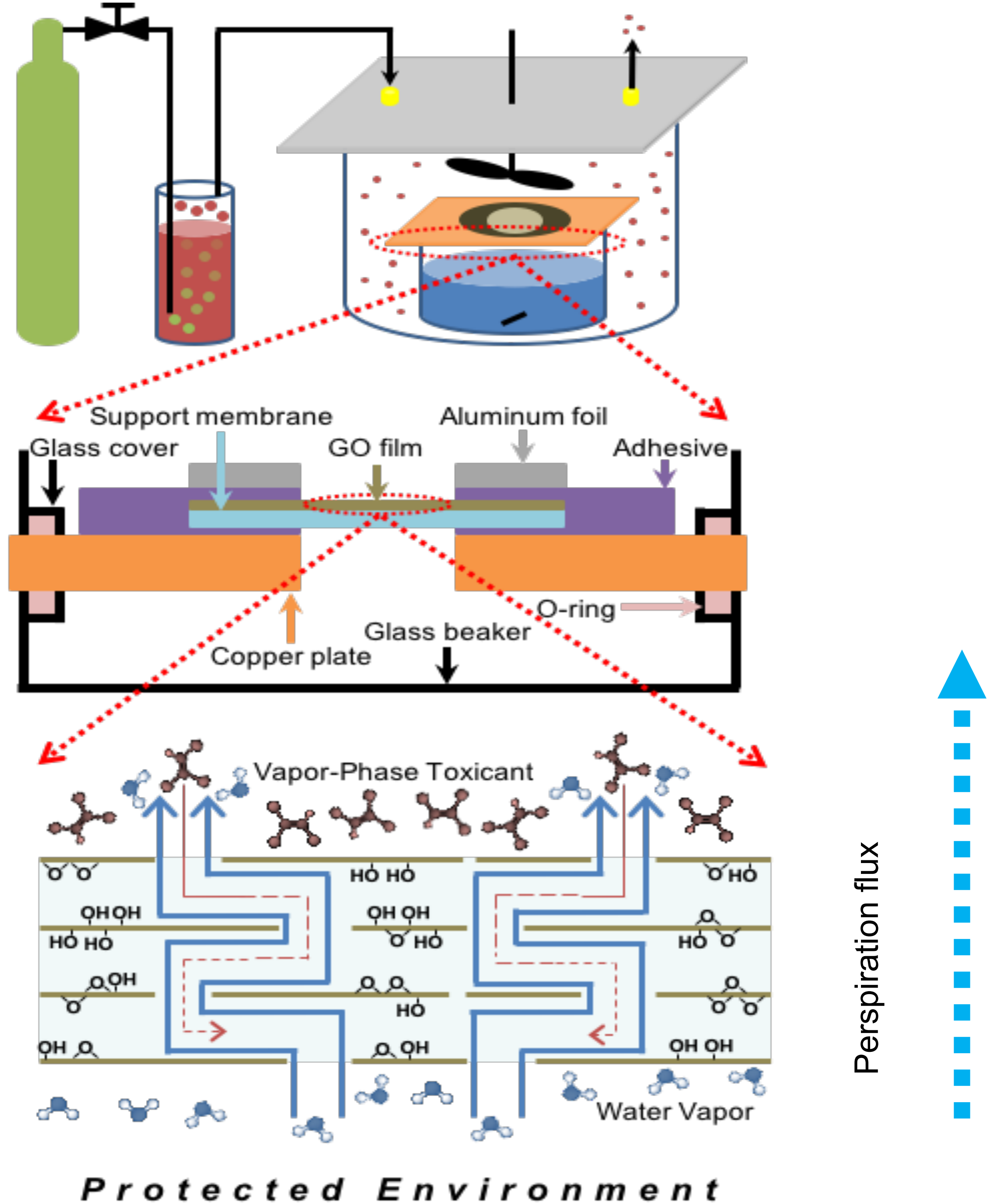
- In wet state, graphene oxide films reject molecules / substances with hydrated diameter > 9 A

<u>Open questions</u>

- Barrier performance against small molecule toxicants
- Barrier performance during active water flow
- Practical suitability in breathable fabrics

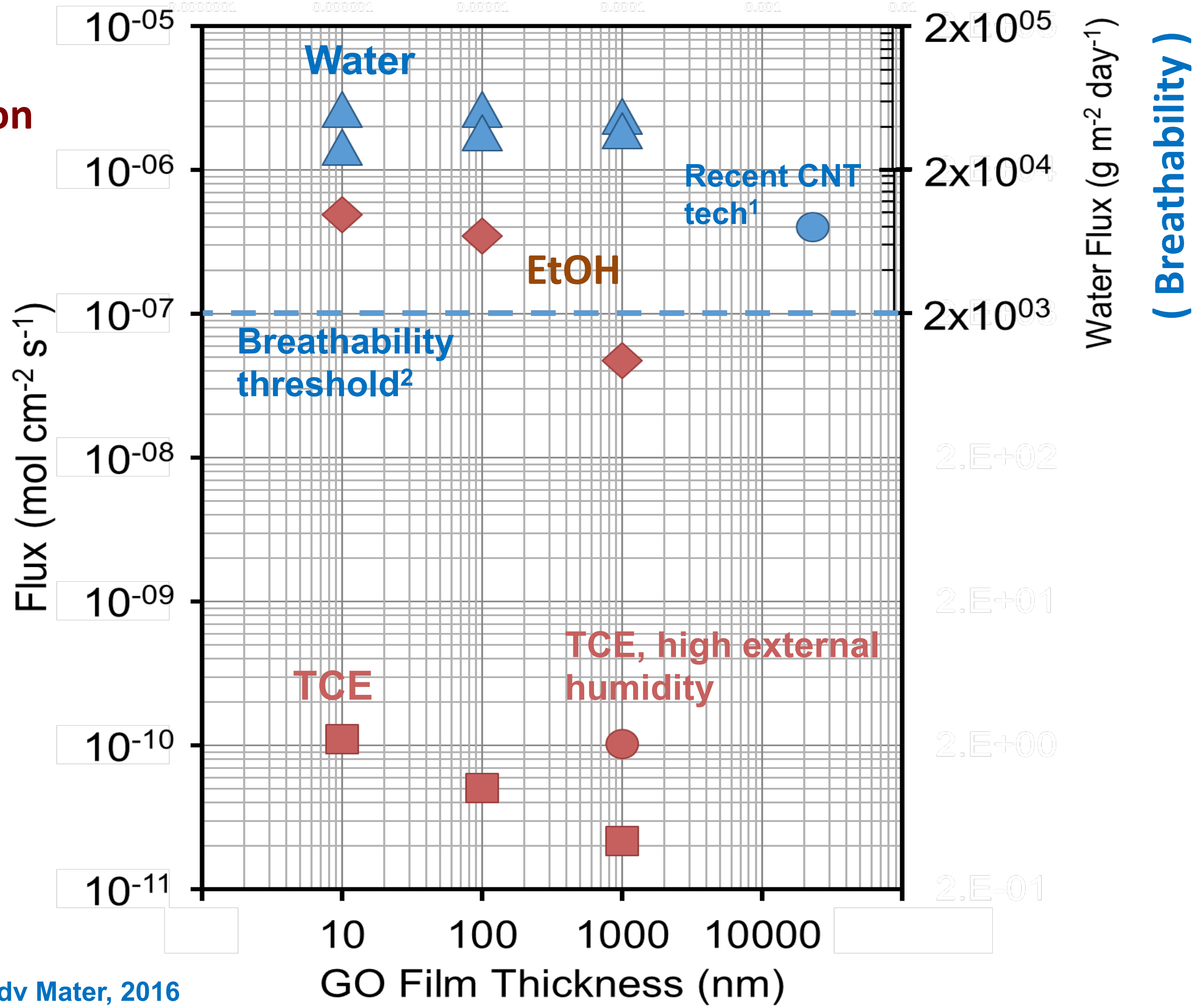
Ruben Spitz
SRP Trainee
PhD Program, Brown

- Developed custom device for membrane testing with active water flux
- Selected TCE and ethanol as models of small molecule toxicants



Results:

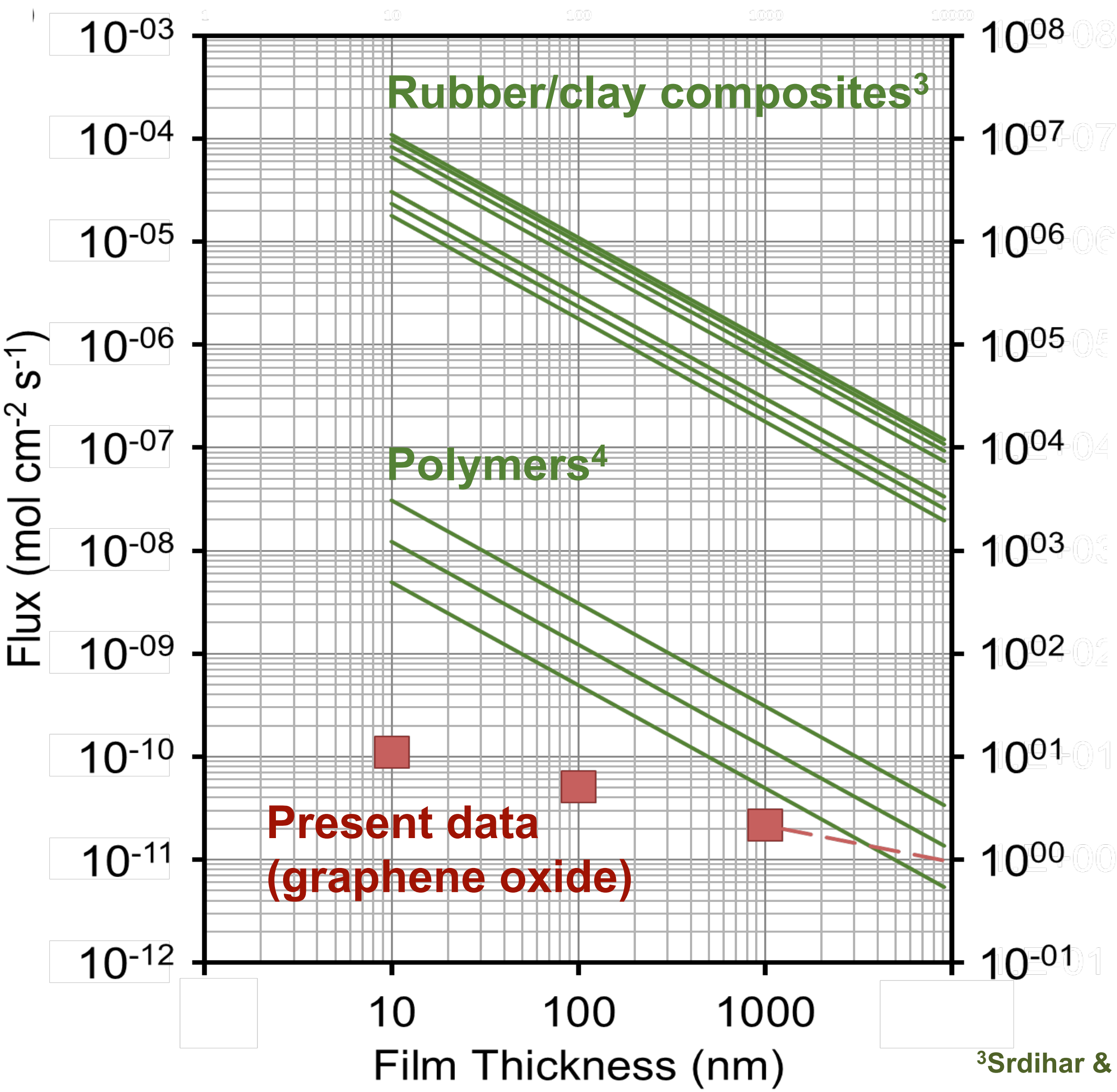
Breathability and Toxicant Permeation



[1]Bui *et al*, Adv Mater, 2016

[2] Wartell *et al*, 1999

Results: TCE permeation performance relative to other materials



Graphene oxide films are promising barriers (for TCE), especially in ultrathin/light applications

[3] Srdihar & Tripathy, J Appl Polym Sci, 2006

[4] McWatters & Rowe, J Geotech Geoenv Eng, 2010

Modelling: What toxicant and film properties govern permeation?

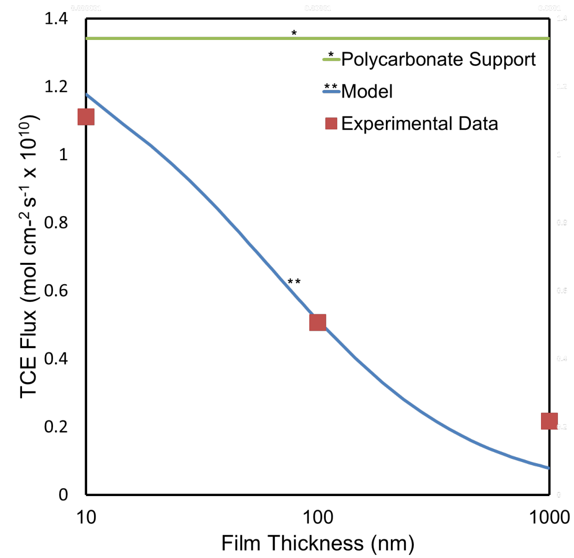
Generation 1 model

$$(VC_A)_x + \left(-D\frac{dC_A}{dx}\right)_{x+\Delta x} = (VC_A)_{x+\Delta x} + \left(-D\frac{dC_A}{dx}\right)_x$$

$$\dot{N}_A = K_{total}\Delta C_A$$

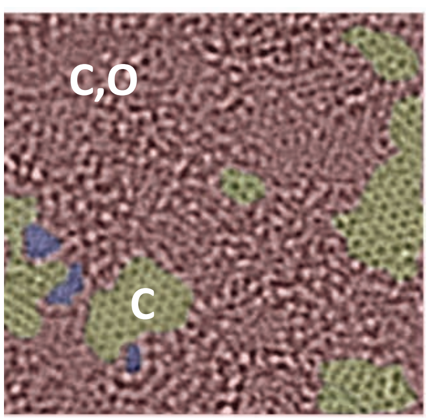
$$where:\ \frac{1}{K_{total}} = \frac{1}{K_{baseline}} + \frac{1}{K_{gallery} + K_{pore}}$$

Predicts no back-diffusion
of TCE against water flux (??)

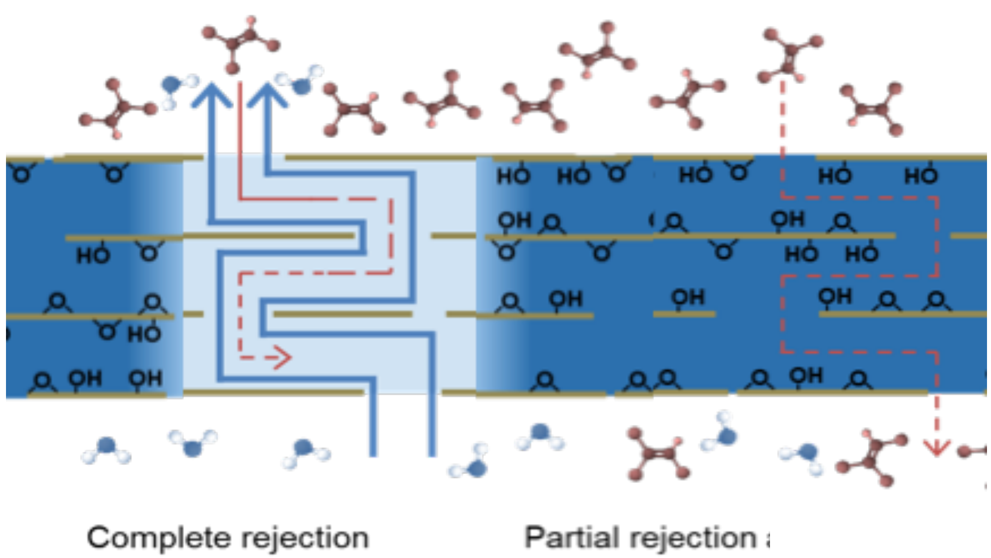


Generation 2 model

GO: oxidized and pristine domains



Erickson et al., Adv Mat



Graphene Environmental Barriers: Summary

> The ideal graphene sheet is a perfect molecular barrier

> Commodity graphene nanosheets can be practical barriers as multilayers (> 10).
Most attractive for ultrathin/light applications

> Graphene <u>oxide</u> films have enlarged intersheet “gallery” spaces and show
complex behaviors in wet conditions

> Graphene oxide films show ultra-high “breathability” (water permeation),
and exclude agents larger than 0.9 nm (bacteria, viruses, particles, most molecules)

> Barrier performance against small molecule toxicants depends on water solubility
(effective for TCE, less effective for EtOH)

> Graphene oxide offers promise as an active layer in breathable
protective technologies, but more work is needed

National Institute of
Environmental Health Sciences
Superfund Research Program