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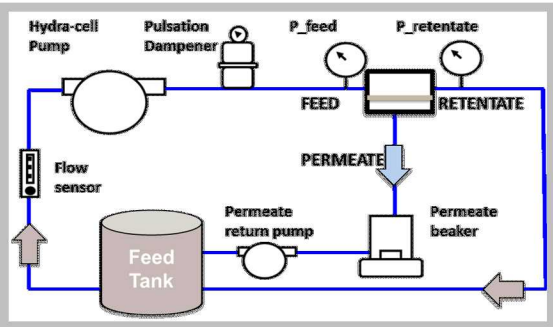

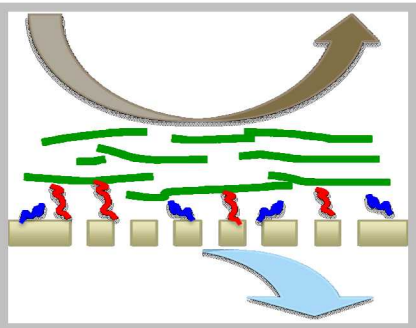

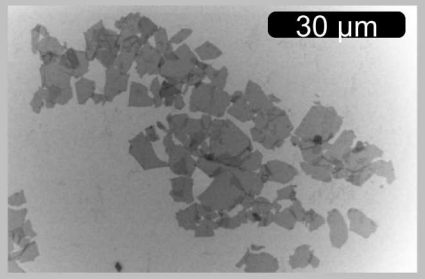

Supported Graphene Oxide (GO) Membranes for Cleaner Water - Characterization, Performance, and Advantages

Curtis Mowry, Laura Biedermann, Michael Hibbs, Victor Pinon, Adam Pimentel, Craig Stewart, Kevin Zavadil

Sandia National Laboratories

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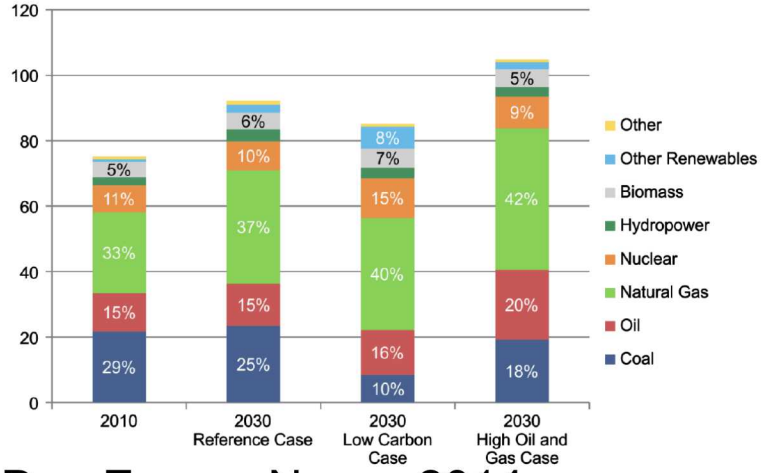
Who needs clean water?

- Wide array of users: filtration = materials AND energy cost
- Others: water OR energy limited

NETL.DOE.GOV



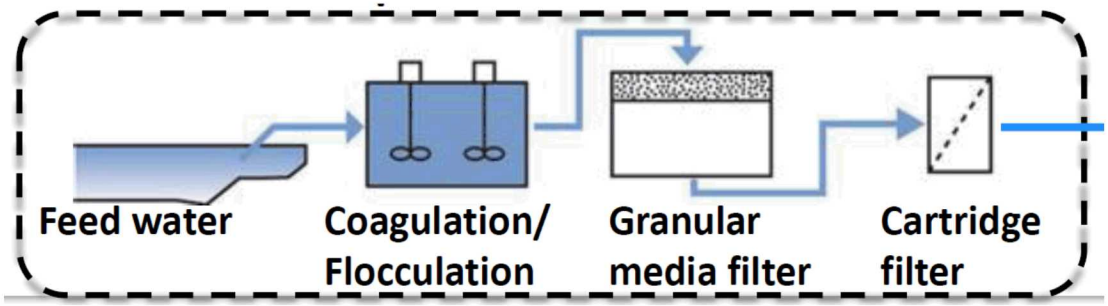
Doe Energy Nexus 2014

US Army photo of a 3000 gallon water bladder in Pakistan

How do we get clean water now?

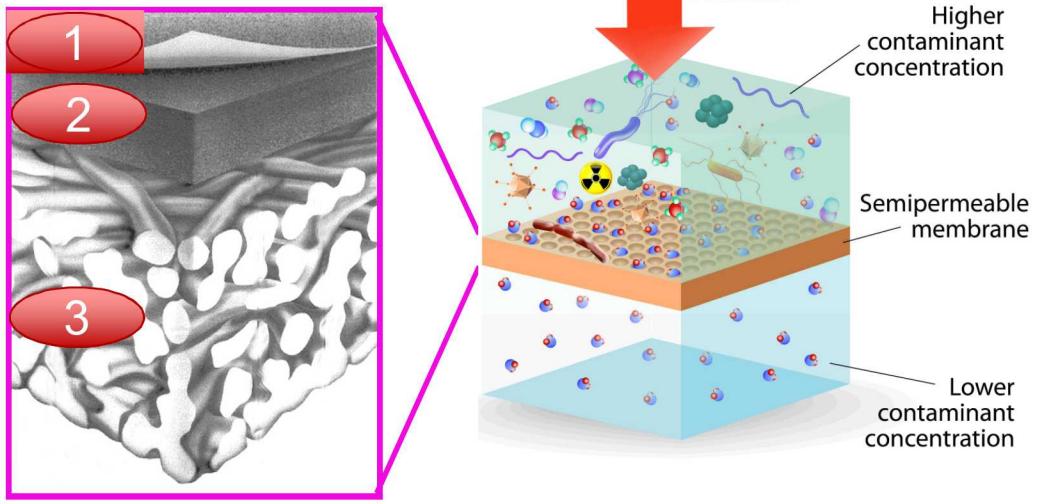
Sandia National Laboratories

Drinking: multi-stage



Desalination: Reverse Osmosis

1. 100-200 nm Polyamide Layer
2. Polysulfone support
3. Fabric support



permeance ~ 1 liter/m^2/hour/bar

rejection > 98%

https://www.advancedwaterinc.com/how-reverse-osmosis-works/ https://www.abcwua.org/education/28_H20_Delivered.html

Is cleanup really important?

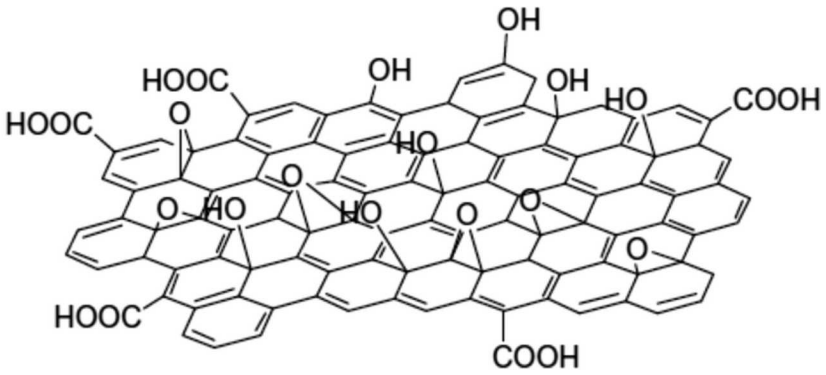
Area	drinking	drinking	Waste
Contaminate	Pb, perchlorate	CECs	CECs
Problem	Cancer, brain damage	unknown	Animals, Fish, environment

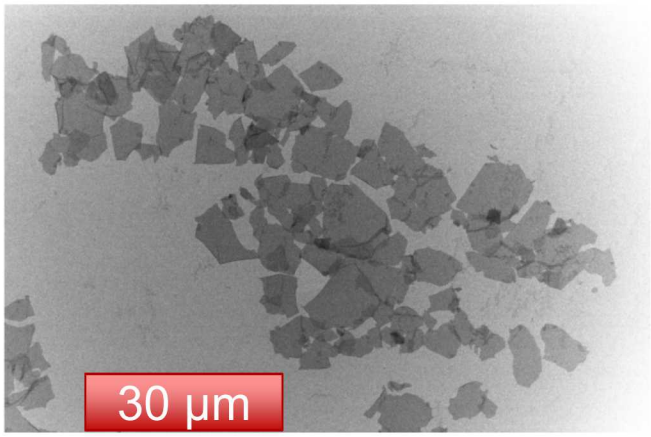
Analyte	MCL	Detected	"x" times higher
chromium-6	0.03	1.3	43.3
chromium-6	0.03	1.1	36.7
vanadium	0.2	6.3	31.5
chromium-6	0.03	0.78	26.0
chromium-6	0.03	0.65	21.7
vanadium	0.2	3	15.0
vanadium	0.2	2.9	14.5
chromium	0.2	1.1	5.5
chromium	0.2	0.92	4.6
chlorate	20	90.1	4.5
chlorate	20	87.3	4.4

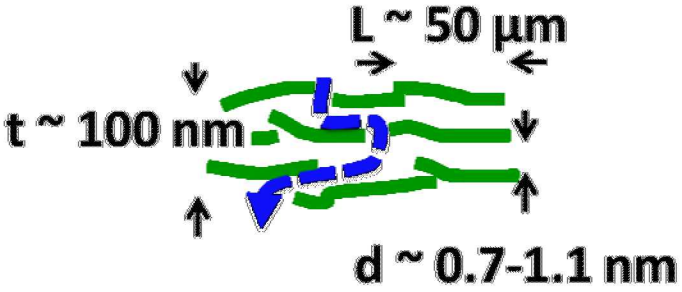
Detected UCMR-4 analytes: Albuquerque 2015 (subset of full data)

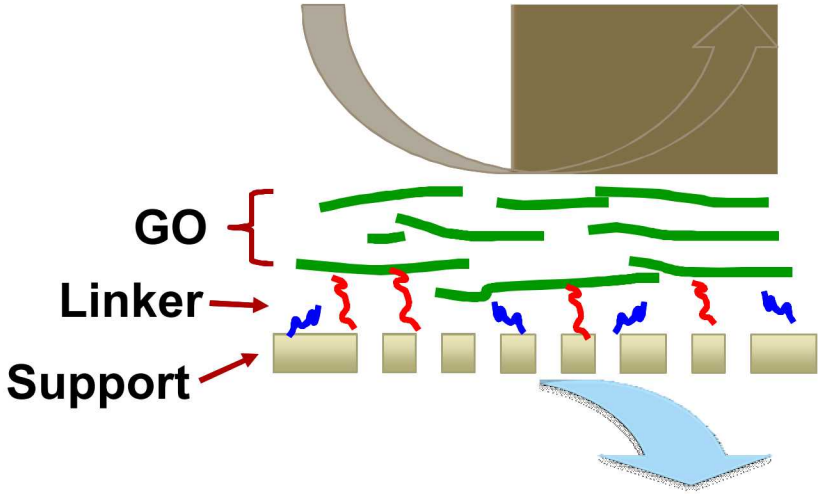
UCMR: unregulated contaminant monitoring rule

What is GO? How does it filter?



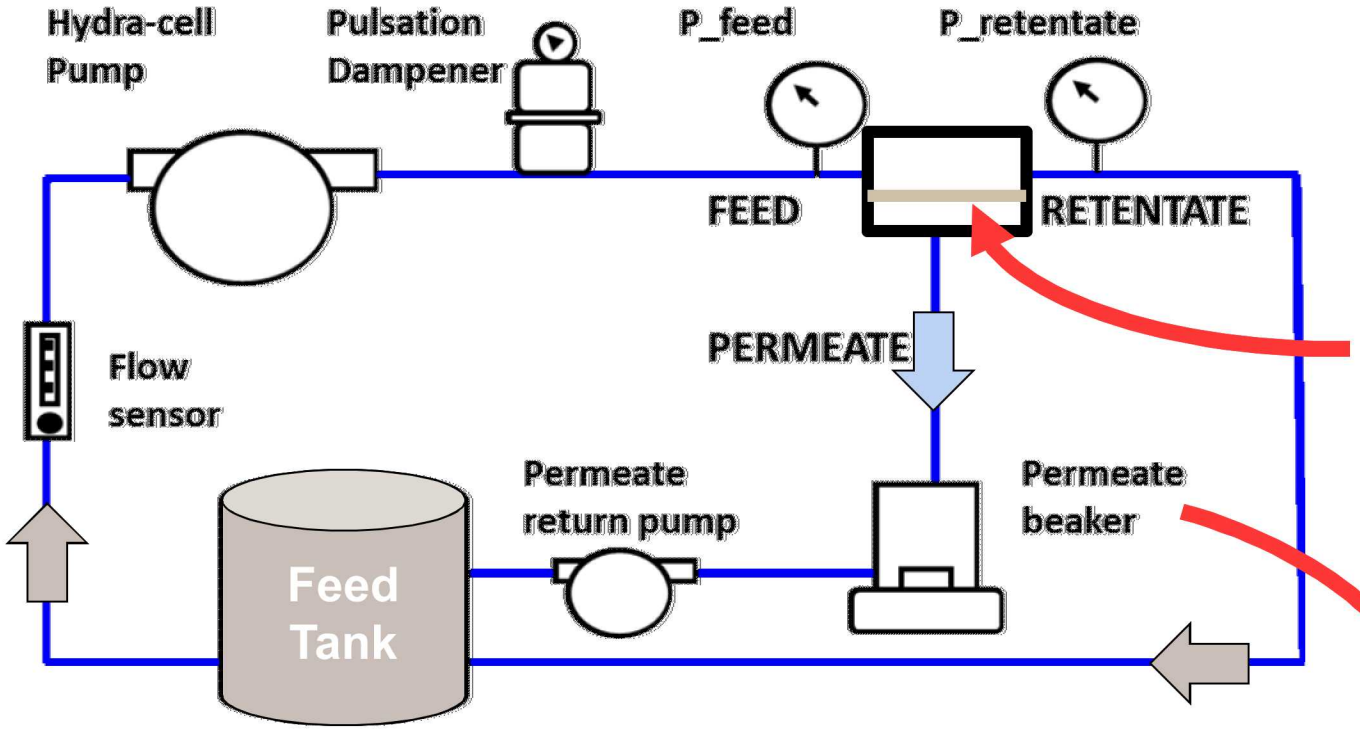






Material cost: \$0.10/m^2 for a 100-monolayer GO membrane

How is the performance tested?



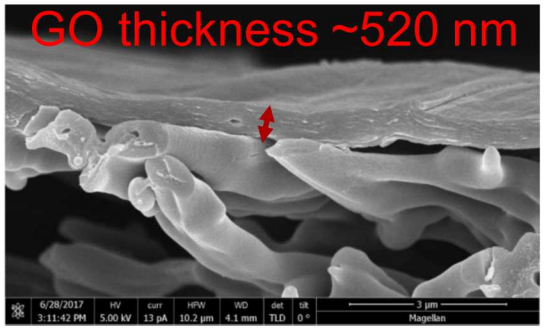
~2” x 4” membrane (after testing)

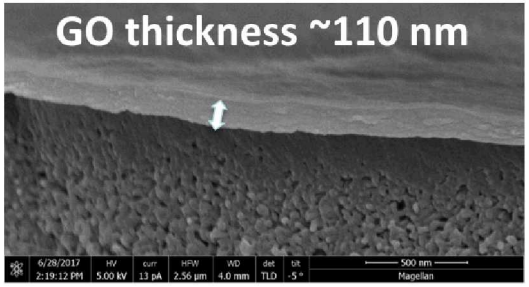
Measure salts organics

Measure flow (permeance) pressure

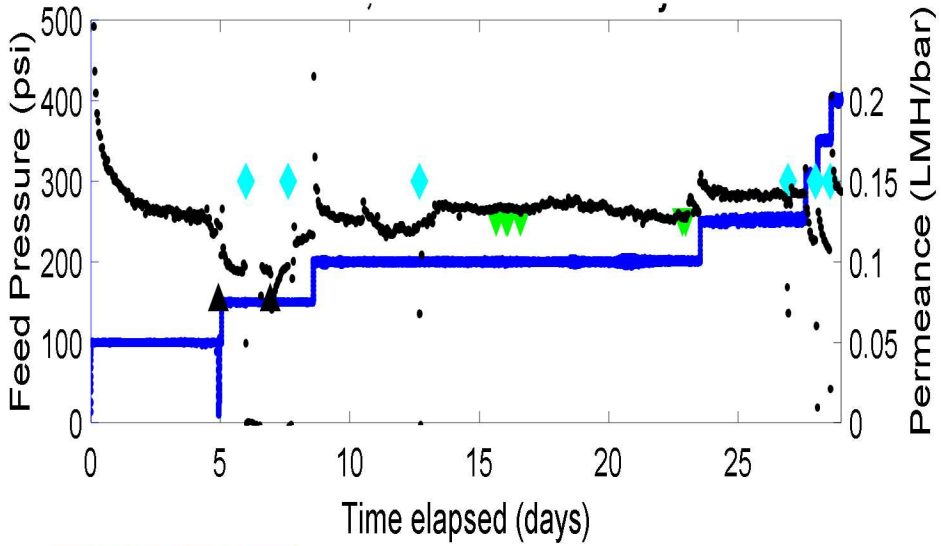
Measure salts organics

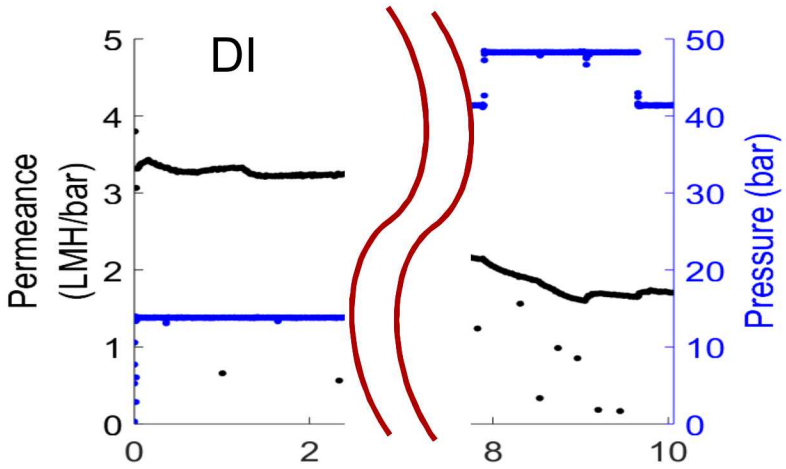
Permeance improvements made.





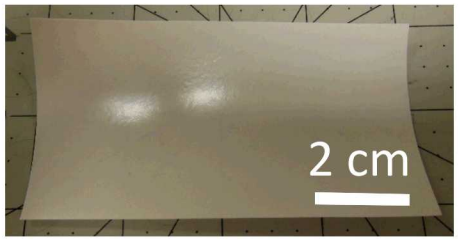
20-50 nm membrane tested w/ seawater TDS ~35,000 ppm





Net rejection maximized at 82%.

1.8” dia.

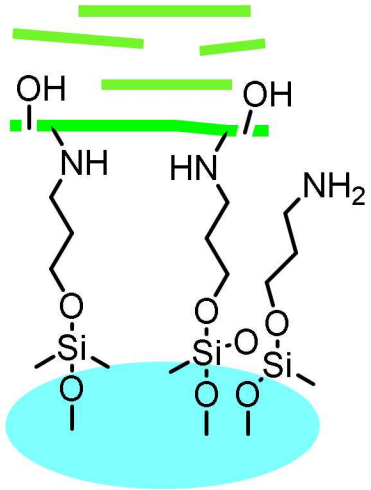


2” x 4”

TDS= total dissolved solids

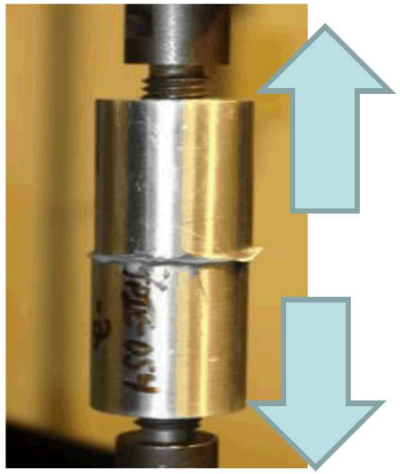
What other metrics are important?

- GO adhesion to support
- Support strength
- Support permeability
- Chlorine tolerance
- Organics rejection
- Biofouling



Graphene oxide bound to surface

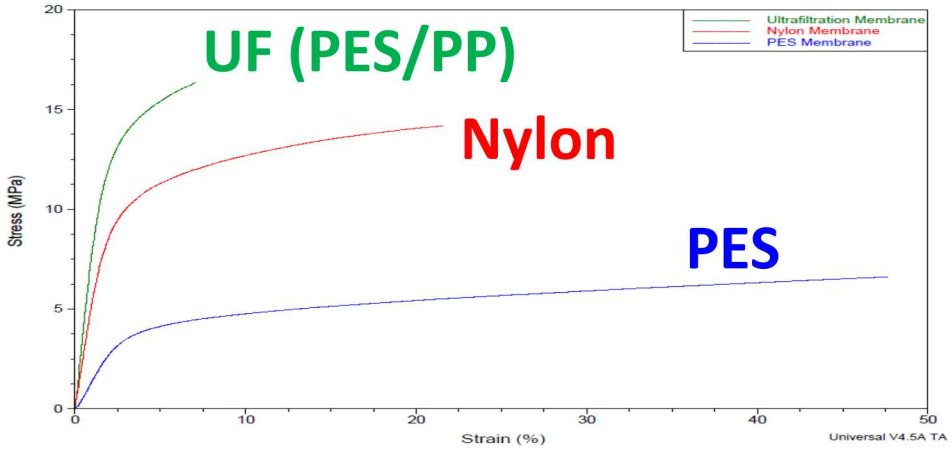
GO adhesion and support strength



No adhesion promoter

Advanced promoter, 50-100 nm

400 psi
Pull at fail

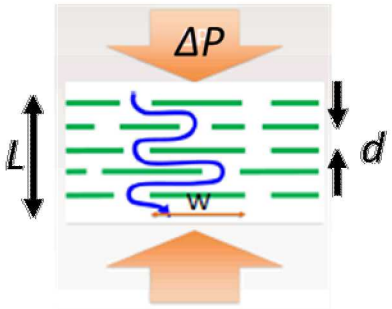


Nylon-difficult to functionalize for bonding to GO

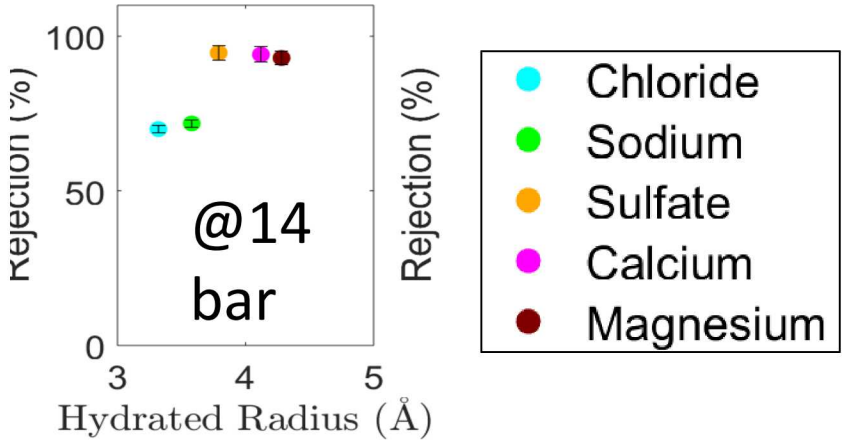
UF=ultrafiltration = polyethersulfone on polypropylene

PES = polyethersulfone

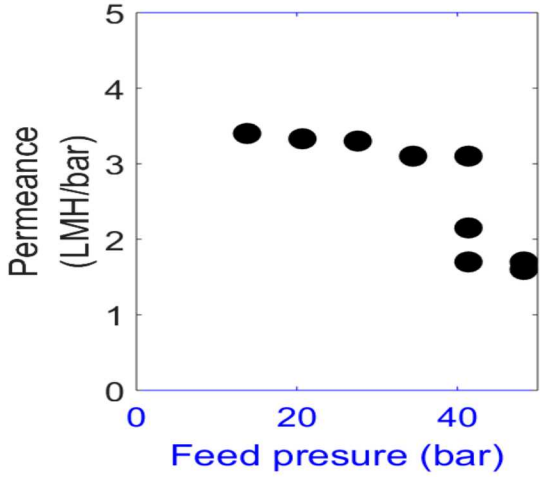
Interlayer spacing affects performance



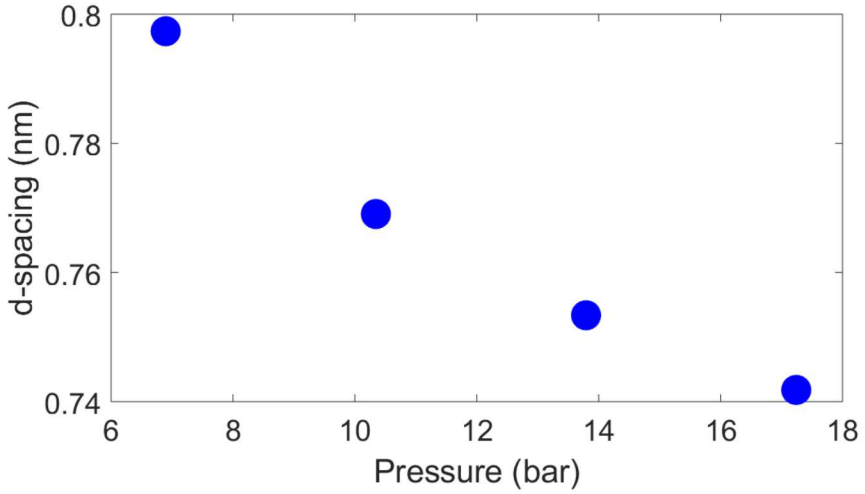
W ~ 5-10 μm GO flake diameter
d ~ 0.7 - 1.2 nm interlayer spacing



Observed change in permeance



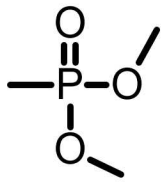
BNL synchrotron XRD experiments confirm GO compression

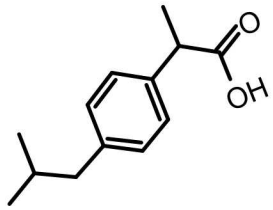


Organics rejection

Est. 60-nm thick GO layers; permeance = 0.4 LMH/bar

	Rejection at 300 psi (%)
DMMP	94.6%
Ibuprofen	98.9%
Chlorate	86.2%
Nitrate	100%
Phosphate	96.9%
Sulfate	98.7%





Chlorate is on EPA contaminate candidate list (CCL-4)

Phosphates, **nitrates** from agriculture run-off

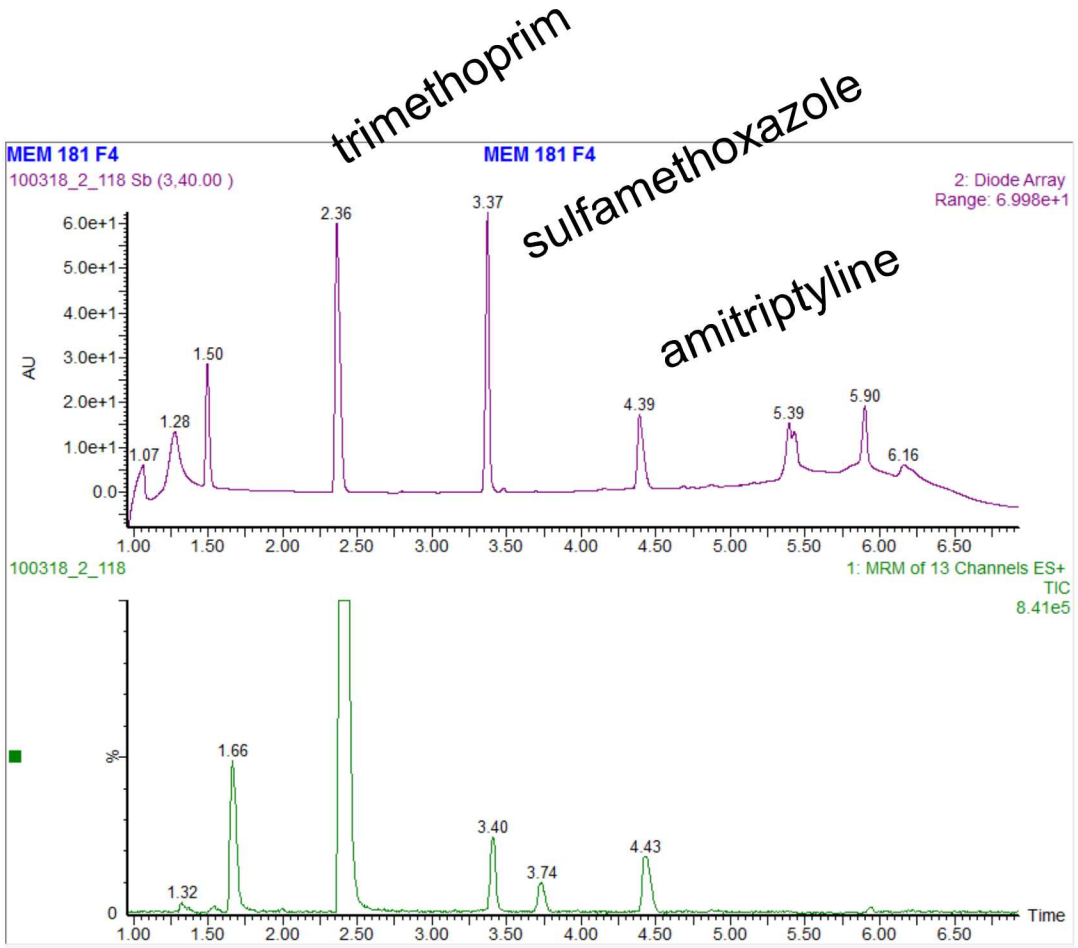
Results show wide-ranging applications are possible

Additional CEC challenge

- Test completed, evaluation of performance underway

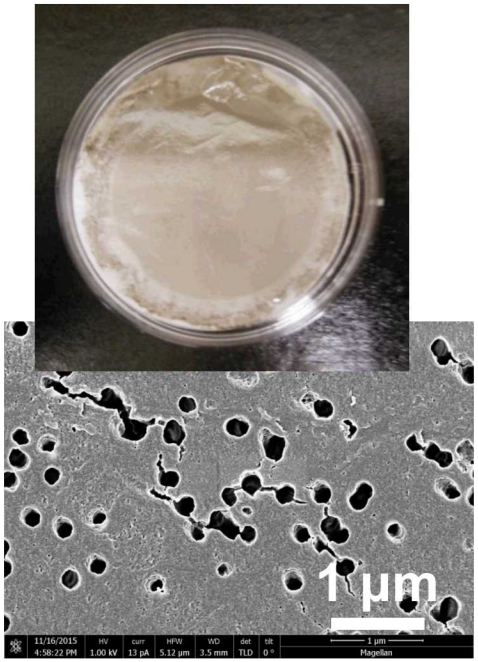
Uv/vis signal

Mass spectrometer signal

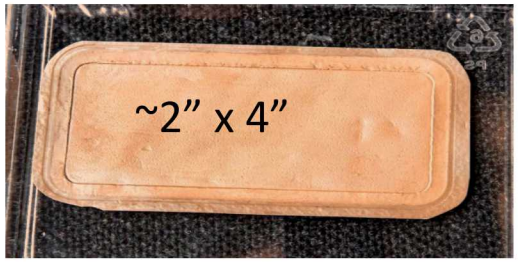


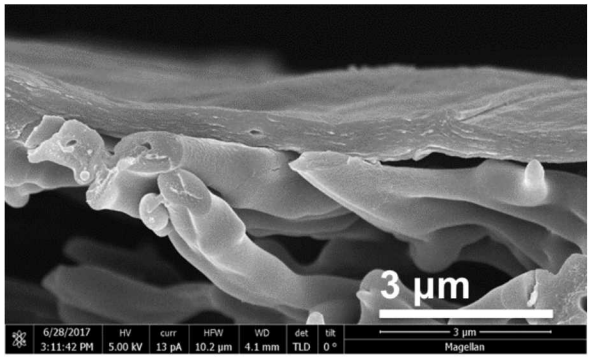
Summary of GO-membrane evolution

47-mm polyester, isocyanate linkers

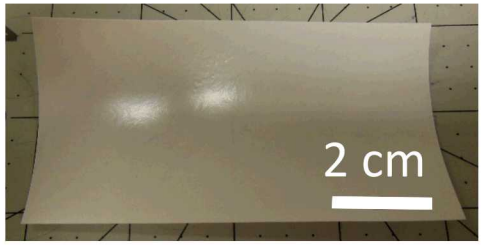


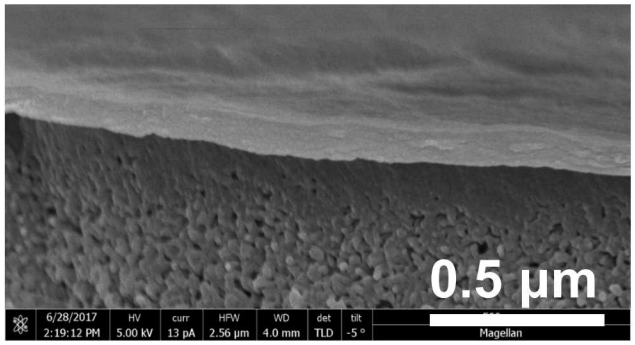
polyethersulfone support APTMOS and PEG linkers





ultrafiltration supports APTMOS and PEG linkers (aq.)





Increased strength, permeance, and rejection

Conclusions and Future Work

Sandia National Laboratories

- We created supported-GO water filtration membranes
  - Permeance scales inversely with GO thickness
- Improvements have increased robustness and permeation
  - crosslinking and supports
- Tests show
  - Months-long robustness
  - Chlorine tolerance > 1 ppm
  - Minimal scaling
  - 99% sulfate rejection
  - High organics rejection
- Membrane process ready for scale-up

Acknowledgements

Sandia Colleagues

Bryan Carson, biofouling lead

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Mike Kent, Susan Altman, Tom Stewart; generous gift of space and equipment

Sandia's water community

- **Brookhaven National Laboratories's National Synchrotron Light Source II, Beamline 28-ID-2**
- Eric Dooryhee, Mohamed Elbakhshwan, Simerjeet Gill