WASTE STREAM REUSE STRATEGIES

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With
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Date 18January2022

FOUR KEY QUESTIONS

- What kind of resource can be significant? Concentrations, Specific
- Composition, Total Size, ...?
- Where might it be found with respect to infrastructure?
- What would be required to produce this resource?
- How can carbon management and environmental safeguard imperatives be met?

WASTE STREAM REUSE STRATEGIES

- In the context of the above four questions, what processing steps need to be accomplished at what locations?
  - Initial mining (selective segregation according to REE content or other valuable or waste minerals…)
  - Separation of mined material into streams according to required next steps (REE rich minerals, carbon rich ore, content of other critical materials, waste material)
  - Chemical/physical extraction of REE and other CM from host minerals
  - Onsite acid recovery and water treatment

WASTE STREAMS

- What waste streams are created at each step, and what will be the local management strategy for these materials?
- Solid mineralogical materials.
- Waste/process waters.
- Natural precipitation drainage and runoff waters.
- Air born waste streams (NOx, SOx, particulates, unburned hydrocarbons, CO_2,…)
- Processing chemicals.

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WASTE STREAMS
(CONTINUED)

- Extraction of materials of added value?
- Long term safe storage of materials with potential future value?
- Long term storage in an environmentally secure way.

- Initial focus on recovery of trace REE concentrations and alternative uses and storage of CO2.
- Encouraging results of earlier work with graphene membrane filtration/separation and biological extraction

LIQUID WASTE STREAMS

Primary waste streams

- Coal mining (current)
- Graphite mining (future)

Secondary waste streams

- Hard rock mining
- Oil and Gas produced water
- Refinery resids

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STATE OF THE ART- SOLVENT EXTRACTION

Bastnesite concentrate

↓

Calcination

↓

Leaching

↓

D2EHPA → Solvent extraction → Raffinate (La, Ce, Pr, Nd) → Solvent extraction circuit 1

↓ Eu, Sm

Iron precipitation

↓

D2EHPA → Solvent extraction → Raffinate → Solvent extraction circuit 2

↓

Reduction / precipitation → Strip solution → Solvent extraction circuit 3

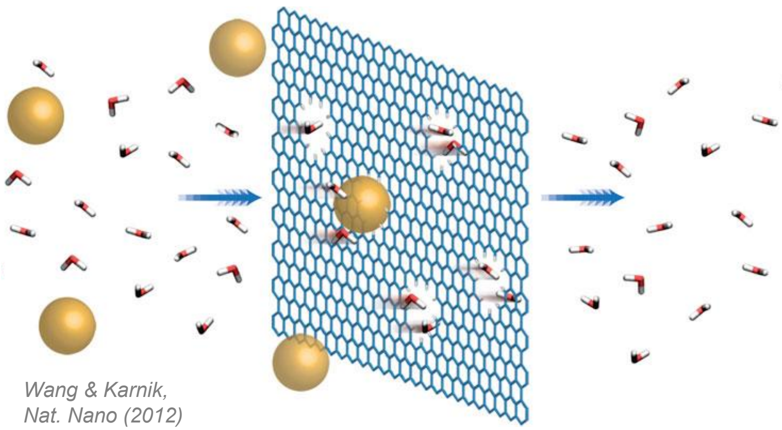
↓

Eu sulfate solution

Image source: tenova.com

Modified from - minerals Engineering 56 (2014) 10-28

OUR INNOVATION: NANOPOROUS ATOMICALLY THIN GRAPHENE MEMBRANE



Wang & Karnik, Nat. Nano (2012)

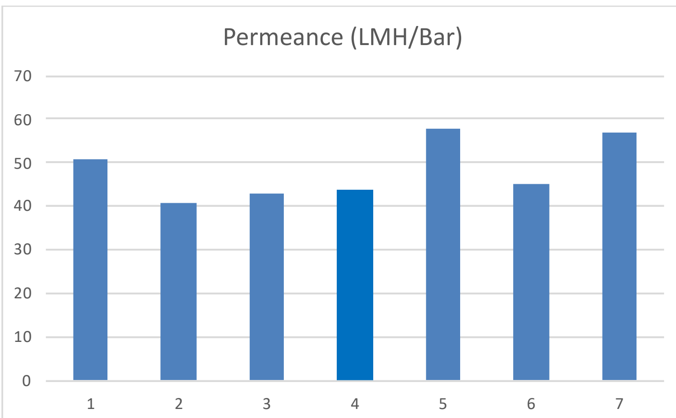
Well-defined pores in an atomically thin graphene layer enable rapid, size-selective transport of molecules

- Applications for CORE-CM Recovery
  - Replace solvent extraction
  - Reclaim acids for onsite recycle
  - Energy efficient separation of hydrocarbons
  - Onsite water management

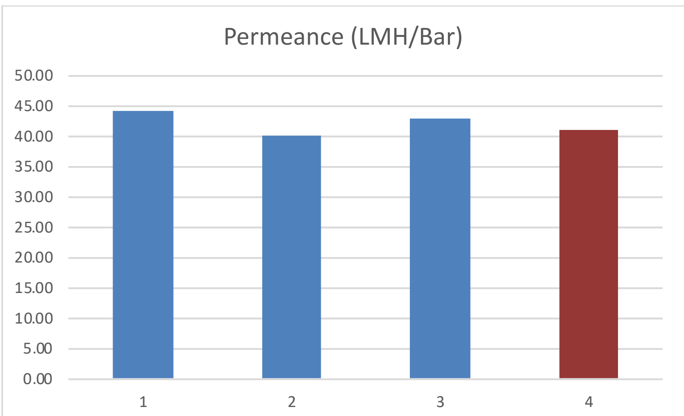
- **Thin:** Rapid transport enabling compact, energy-efficient separations especially for dilute process streams and offshore/decentralized uses
- **Strong:** Separate high-salinity or high-concentration solutions, high product recovery
- **Rigid/defined pores:** Rejection of molecules above a certain size, regardless of type of solute and solvent
- **Chemically resistant:** Better cleaning, use with organic solvents and aggressive solutions
- **'Designable':** Pore structure can be directly related to transport properties, enabling rational design for different applications
- **Scalable:** Amenable to roll-to-roll manufacture

Wang et al. Nat. Nano (2017)

Test results: Permeance with model brines



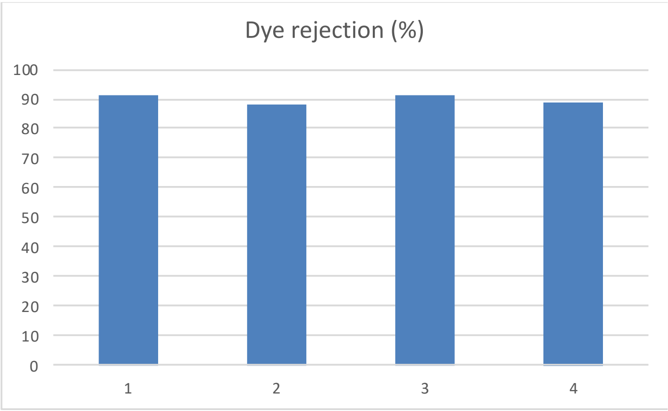
Time on stream per run: 24 hours, Permeance range 41-58 LMH/bar)



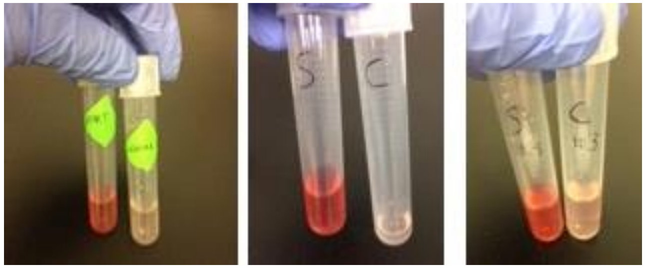
Membrane robustness – runs 1,2 and 3 used the same membrane, 24 hours each, separated by days, run 4 is a new sample

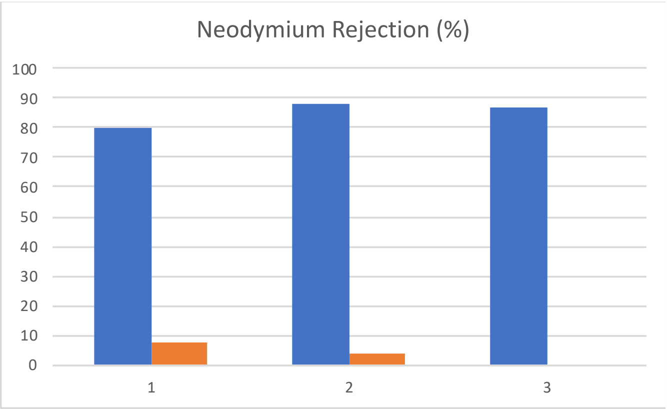
Comparison: Conventional polyamides: 1 LMH/Bar

Test results: Separations from Model Brines



Time on stream per run: 24 hours, runs 1 and 3 use the same membrane





Sample 1: 1.24 ppm in 23.2 ppm NaCl

Sample 2: 1.24 ppm in 22.4 ppm NaCl

Sample 3: 2.46 ppm in DI water

NaCl rejection: 4% and 7% respectively in runs 1 and 2 (negligible)

Summary of accomplishments

- Developed novel experimental and analysis procedure based on inductively coupled plasma mass spectrometry (ICP-MS) to examine ***simultaneous*** ion transport across nanoporous graphene membranes
- Demonstrated graphene membranes' potential to selectively separate REE from monovalent ions
  - ***Two orders of magnitude ionic distinction*** between Neodymium and sodium
  - ***Complexation agents*** (e.g. phosphate) selectively modulate REE ion size to achieve selectivity
- Demonstrated permeance of 41-58 L/m^2/hr/bar (LMH/bar) (compared to conventional polyamide membranes at 1 LMH/bar)
- Single stage Neodymium separation of 80-88% at very low concentrations (Equates to >99% separation with 3 stages)

ACKNOWLEDGEMENT

Rohit Karnik (MIT)

Efficiency Improvements and Component Integration for Rare Earth Element (REE) Recovery from Coal-Based Resources Using Environmentally Benign Bio-weathering

Brandon Briggs, University of Alaska Anchorage

Technology Summary

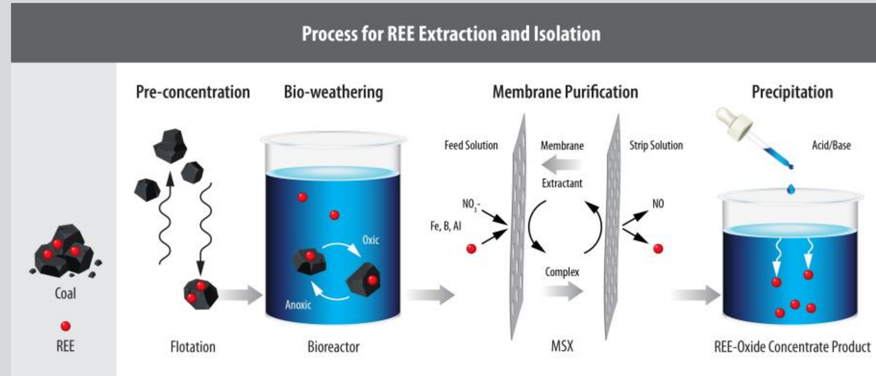
- *REE are used in consumer products and are critical in defense and healthcare industries.*
- *Bio-weathering can overcome economic issues with current technologies and be environmentally friendly.*

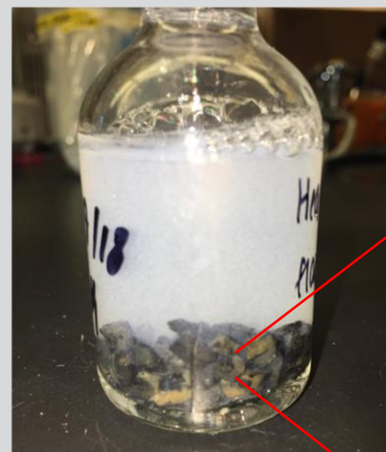
Technology Impact

Produce a novel system that can produce REOs from coal.
Reduce cost of REO production from low concentration feedstocks by 40%.
Remove safety and environmental hazards associated with acid baking and leaching.

Proposed Targets

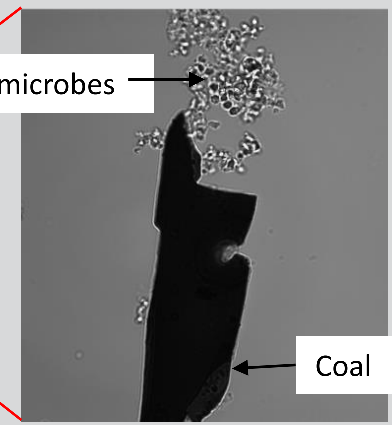
Metric	State of the Art	Proposed
REE recovery	*65%*	*>75%*
Energy balance	27-38GJ/ Tonne	13GJ/ Tonne
Hazardous waste	Strong acids for solvent extractions	<5% waste products with minimal acids





Batch culture of *S. oneidensis* growing on coal. pH= 6.4

S. oneidensis attached to the edge of coal.



Bio-weathering system to produce rare earth oxides from waste streams

- **Microbial bioweathering** is the dissolution process of rocks and mineral substrates through the metabolic activity of microbial entities. This process has happened continuously for billions of years all over the planet, and it is a critical mechanism for the stability of Earth's biogeochemical cycles.

- A byproduct of this mechanism is the release of embedded elements and minerals (**including rare earths**) within the geological matrix undergoing weathering, *without the harsh acid leaching required of standard methods with volatile organic solvents and associated waste streams*.

- Yields can be higher due to extended/indefinite mechanisms-of-action (*as long as the microbial consortia/population remains stable and viable*), as opposed to one-time chemical treatments that are difficult/expensive to replicate and are of limited value on already spent/treated ore material.

Optimizing *S. oneidensis,* and other microbes…

Univ. of Alaska has identified several microbial strains capable of bioweathering coal ore through a novel anoxic-to-oxic cycling methodology that dramatically enhances percent recovery of REE compared to standard microbial acid-leaching processes (figure at right).

The exact biological mechanism is hypothesized to be associated with iron-coupled redox cycles and biological production of chelators that remove metals from the mineral matrix. However, the exact mechanism is not yet fully-understood.

Once the exact biological mechanism is understood at the genomic level, synthetic biology can be leveraged to design and build optimized bio-platforms for even more efficient REE recovery across a range of ore types

For enhanced REE recovery