

METALLIC: The Minerals to Materials Supply Chain Research Facility

Center 2: Extractions and Separations



METALLIC Industry Event
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Meet the Team: METALLIC Center 2 – Extractions & Separations



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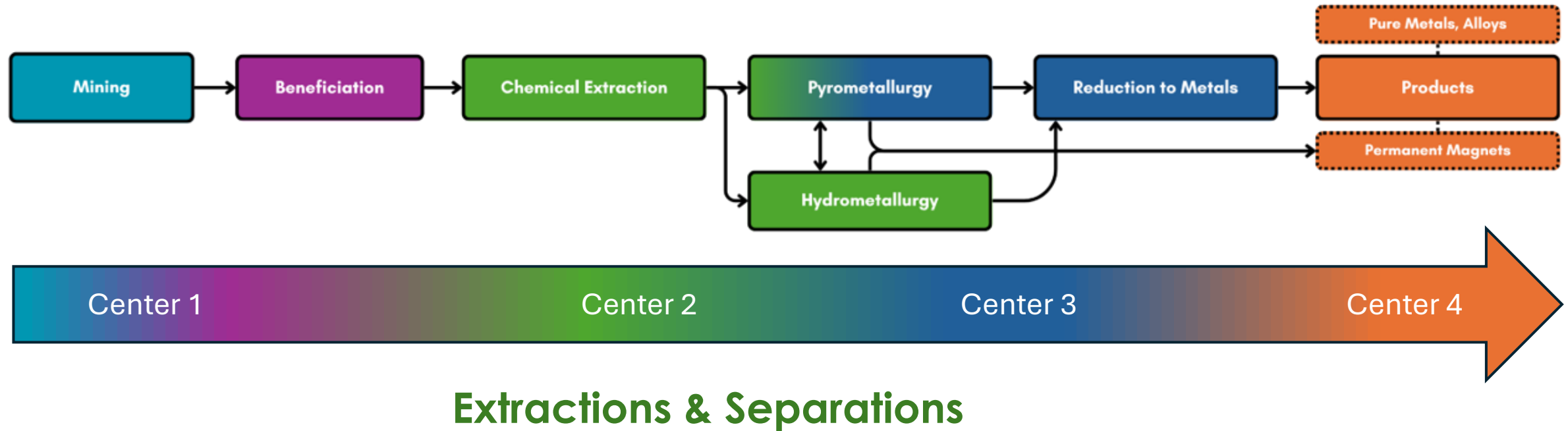
**Aaron Wilson
(INL)**
Center 2 Co-Lead

How Center 2 (Extractions & Separations) fits into METALLIC structure



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Building collaborations and workflow across teams



Rapidly validating and maturing new technologies and pathways to achieve low-cost and/or high-purity separation

Extractions and Separations (Center 2)

Concentration, purification, and transformation of critical materials

Flagship Activities:

1. Testbed for Novel Unit Operations
2. Solvent Extraction Testbed
3. AI-Guided Autonomous Chemistry Testbed

Outcomes:

- Develop improved, cost-effective, and environmentally sustainable unit operations
- De-risk new technologies and process flows at scale (TRL 4-6)
- Rapid identification of optimal operating parameters for processing



Flagship # 1: Testbed for Novel Unit Operations

Configurable Unit Operations for Maximum Flexibility

What METALLIC Offers

- Advanced extraction & separation methods and validation from lab- to pilot-scale
- Addresses large gap at the “mid-scale” (1-500 gallons)
- Integrate with digital twins, process modeling, and cost analysis

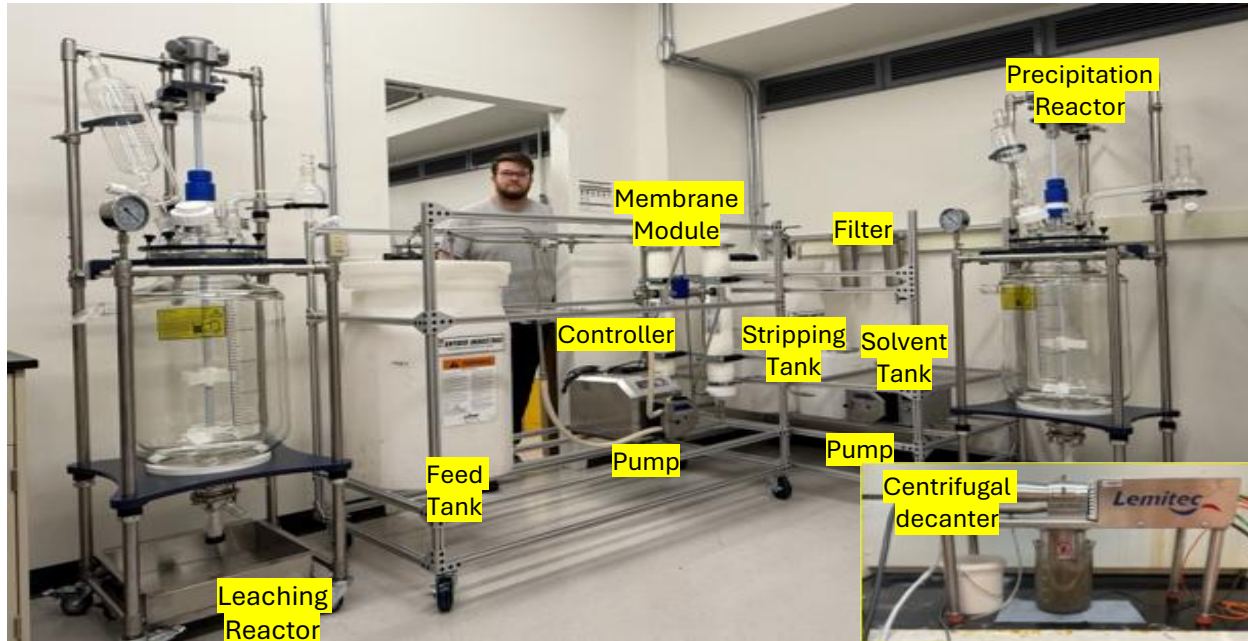
Existing Capabilities:

- Batch, column, moving bed, and continuous processing methods for CMM recovery
- Multi-Phase Transport Evaluation Loops (M-TEL; M-TEL X) for handling high volumes of slurries
- Ion-exchange and electrodialysis systems (bench-scale, pre-pilot, and pilot scale)
- Dimethyl Ether (DME)-based dewatering and crystallization technologies
- Testbeds that can handle radiological materials

New Capabilities:

- Ion exchange pilot and microwave system for advanced extraction and separation
- Simultaneous calorimetry system integrated with Fourier-Transform Infrared (FTIR) spectroscopy, mass spectrometry (MS), and gas chromatography (GC)

mTEL-X, MSX and Ion Exchange



Modular, configurable, instrumented test loops that can handle slurries and complex fluids to scale up new technologies for novel beneficiation, separations, process handling and monitoring to a higher TRL.

Pilot Scale

- Initial design is 6 columns that are 6 inches by 4 feet
- Fully PLC controlled system
 - Ability to run any number of columns
 - Automated extraction and stripping
 - Real time measurement and recording of pH, conductivity, temperature, and pressures



Flagship #2: Solvent Extraction (SX)

What METALLIC Offers

- Solvent extraction (SX) platforms for CMM separations, circuit design, SX ligand validation, HREE/LREE separation, high-value co-product recovery, and membrane testing
- Test conventional and unconventional feedstocks with minimized waste, reduced chemical usage, and lower water consumption

Existing Capabilities:

- Bench-scale SX platforms, including Membrane Solvent Extraction (MSX)
- Two industrial-scale membrane modules with a total surface area of 40 m² have been integration into an MSX system
- Membrane characterization platform to understand and mitigate membrane fouling

New Capabilities:

- Nanofiltration systems upgraded for separations
- Membrane development and extrusion technologies
- Pre-pilot SX and MSX systems for CMM recovery

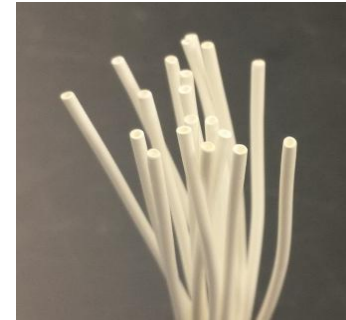
Membrane Solvent Extraction



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Membrane Selection Criteria

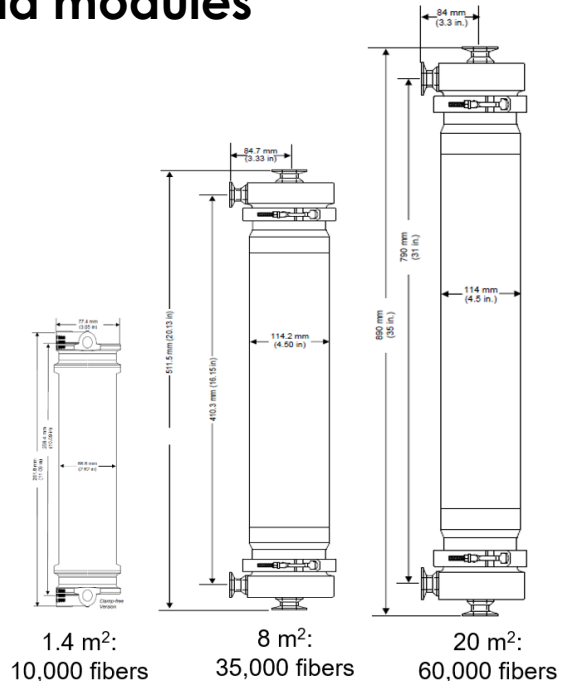
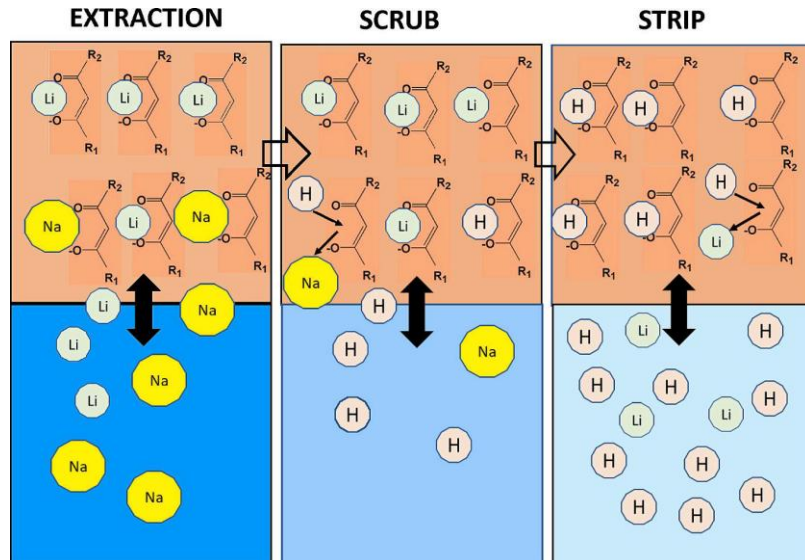
- Hydrophobic
- Highly stable in strong mineral acids
- Low-cost, commercially available
- Pore structure
- High surface area with low footprint



Polypropylene hollow fibers



PVDF hollow membrane and modules



Recovery of Lithium from Brines by Solvent Extraction

Evans et al. <https://doi.org/ornl.idm.oclc.org/10.1016/j.susmat.2025.e01724>

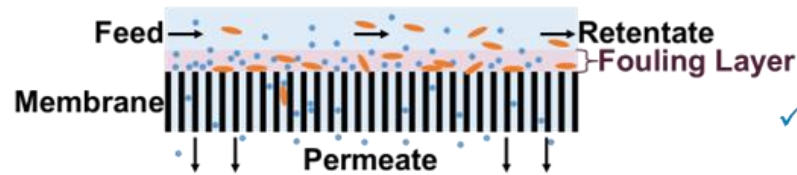
Membrane Separation Platform to Understand and Mitigate Fouling



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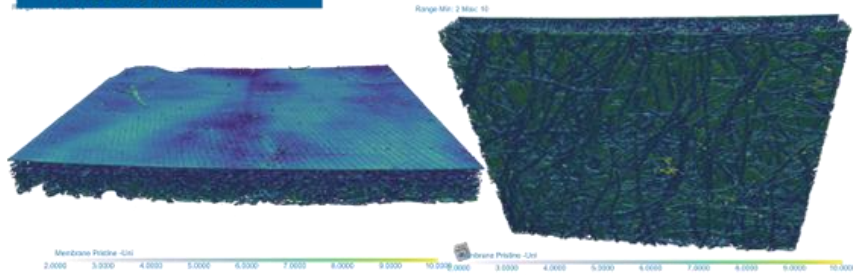
Advanced Photon Source: Membrane characterization in a cross-flow system to quantify membrane degradation and fouling to improve separation efficiencies and membrane lifetime

In-Situ Cross-Flow Membrane System

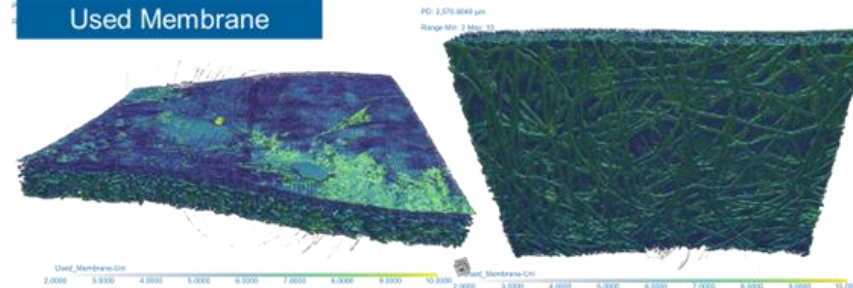


Microtomography at 7BM

Pristine Membrane



Used Membrane



3D Imaging:

- ✓ Fouling layer formation
- ✓ Support layer compression
- ✓ Small Angle X-Ray Diffraction: Nano porosity changes due to clogging mechanisms

Spectroscopy:

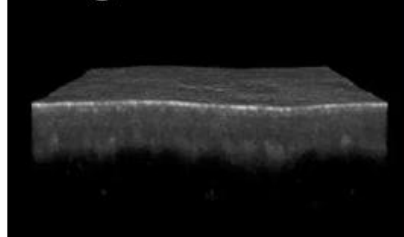
- ✓ Elemental concentration for selectivity
- ✓ Oxidation state

Optical Coherence Tomography Microscopy

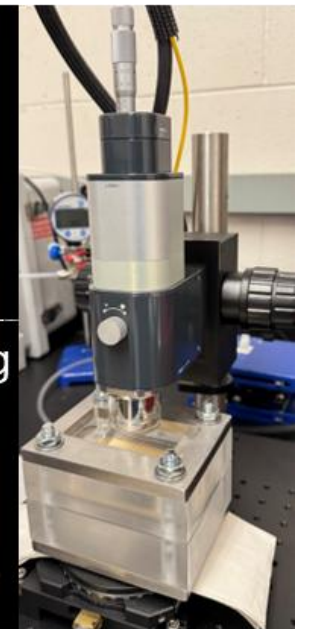
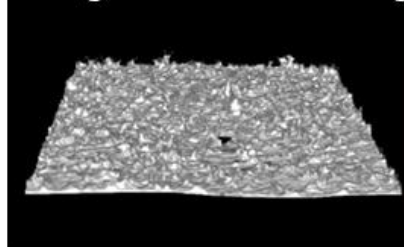
- Cell Development
- In-lab Monitoring

Fermentation Broth Fouling

Original TIF



Segmented Fouling



What METALLIC Offers

- **AI-guided autonomous chemistry lab** to test novel extractants and ion-exchange sorbent/adsorbents and identify optimum process conditions
- **Real-time process monitoring, data streaming, on-the-fly data analysis and simulation for AI enabled feedback** for chemical analysis instruments
- **Data analysis** and down selection of the highest performing **extractants/adsorbents**

Existing Capabilities:

- **Liquid-liquid separation** robotic platform (JKem)
- **AI/ML continuous flow chemistry** with multi- and tandem analytical instrumentation
- **Chemspeed Technologies SwingXL** platform for liquid and solid-state reaction
- Automated, rapid **membrane development and testing**

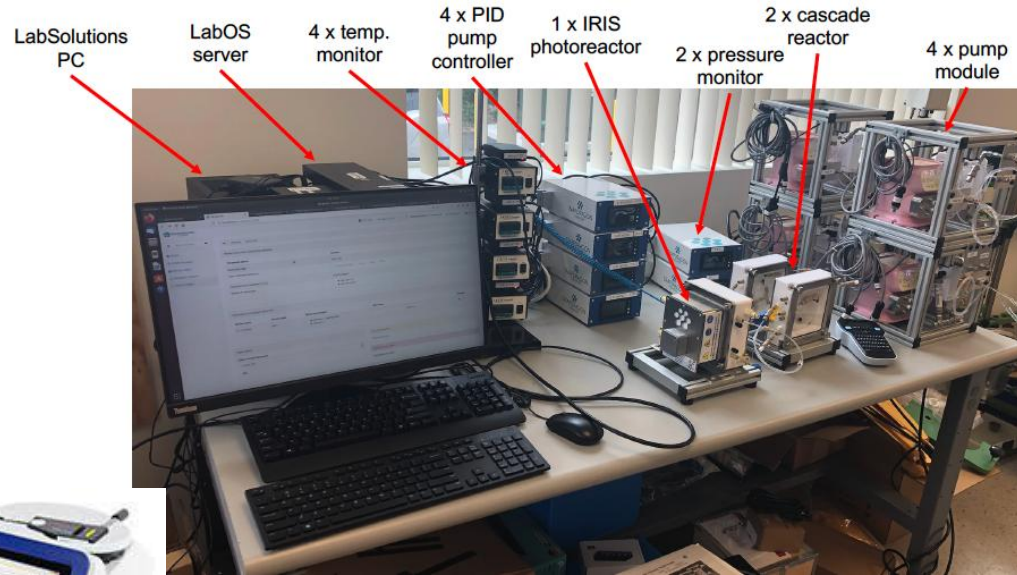
New Capabilities:

- **Custom Raman testing station** with Wasatch Photonics laser source and detector



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AutoFlowS



NMR



IR/Raman



SPR

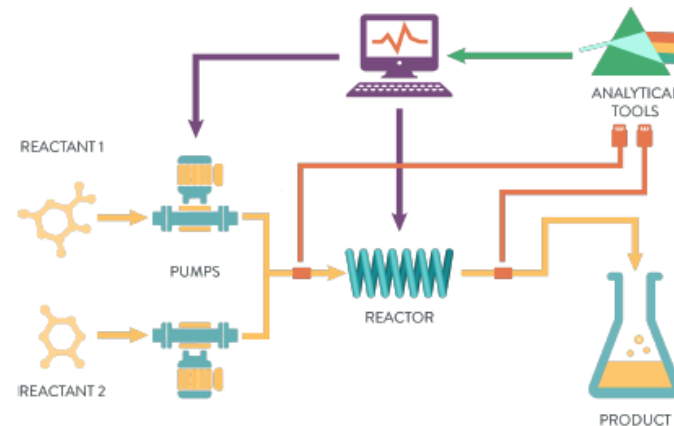


ESR



Fluorescence

Auxiliary Flow Reactor (ThalesNano Syrris, Vapourtec): Instrument/Sensor Interfacing



Easy Sampler





Testbed for Novel Unit Operations can support:

- Validate, mature, and optimize extraction and separations technologies and new flowsheets at industry-relevant scales

Scale: 1-100 gpm, kg/h

AI-Guided Autonomous Chemistry Testbed can support:

- Leveraging autonomous and ML-driven experiments to identify operating regimes (reducing experiments and time) and user-provided materials

Scale: Grams to Kg

Solvent Extraction (SX) can support:

- Accelerate further advances in SX by validating new extractants, process configurations, and contactor types (e.g. MSX)

Scale: up to 100s of liters

**OUR GOAL IS TO DRIVE INNOVATION
IN EXTRACTIONS AND SEPARATIONS**

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