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Presentation Title: Advanced Copper-MXene Composites for Enhanced Grid Efficiency and Resilience

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Organizations(s): Argonne National Laboratory, NAECCO, Loukus Tech

Advanced Copper-MXene Composites for Enhanced Grid Efficiency and Resilience to Address Next-Generation Transmission Needs

Jianlin Li, Shiba Adhikari, Brian Wyatt, Sixbert Muhoza

Argonne National Laboratory (Prime Lab), NAECO and Loukus Tech (Industry Partners)

DOE OE TRAC Peer Review 2026

PROJECT OVERVIEW

- **Project Description:** This project develops scalable copper (Cu)-MXene composite conductors with enhanced electrical conductivity, mechanical strength, and corrosion resistance for next-generation underground transmission systems. The technology aims to improve grid efficiency, reliability, and capacity while advancing advanced conductor materials toward commercial deployment

- **Period of Performance:** 10/01/2025 to 09/30/2028

- **Award Amount:** $750,000 (Federal) and $575,000 (Cost share)

- **Prime Awardee:** Argonne National Laboratory

- **Partners:** NAECO LLC., Loukus Tech

- **Technology Area:** Advanced Conductors, Busbars, and Dielectric Materials

- **Alignment/Supports strategic pathway:** This project **optimizes** grid performance by reducing transmission losses through advanced high-performance conductors; **grows the grid** by advancing scalable Cu/MXene technology from TRL 3 to TRL 6 toward commercial deployment; and **stabilizes grid infrastructure** by improving conductor strength, durability, and corrosion resistance.

PROJECT DETAILS: PROBLEM STATEMENT

- **Growing electricity demand and grid modernization require transmission conductors with higher efficiency, greater reliability, and improved resilience** to support electrification, renewable energy integration, and expanding underground transmission infrastructure.

- **Conventional copper conductors are approaching their performance limits**, with electrical losses, mechanical degradation, and corrosion contributing to reduced efficiency, higher maintenance costs, and limited-service life.

- **Current reinforcement strategies often improve mechanical strength at the expense of electrical conductivity**, making it difficult to simultaneously achieve the performance required for next-generation grid applications.

- **A scalable conductor material that combines high electrical conductivity, mechanical robustness, corrosion resistance, and manufacturability is needed** to enable future high-performance transmission systems.

PROJECT DETAILS: TECHNICAL APPROACH/INNOVATION

Technical approach:

- Develop high-performance Cu/MXene composites with enhanced conductivity.
- Use ANL developed advanced MXene synthesis and optimize scalable composite processing methods
- Validate wire fabrication / cable performance and perform real-world testing with industry partners

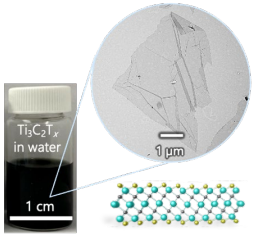


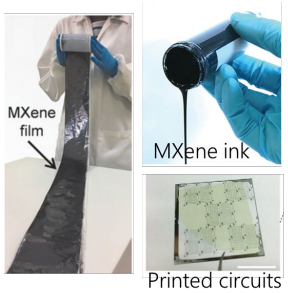
Why Ti_3C_2 MXene

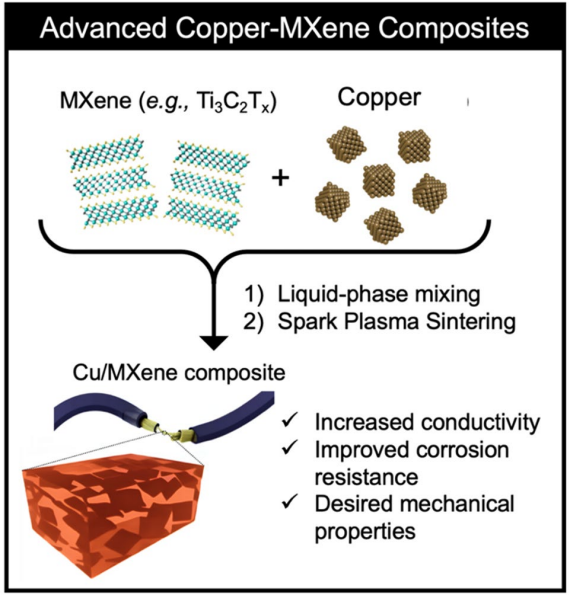
- Scalable synthesis (>1 kg to tonnes)
- Processible in water
- Conformal coatings
- High electrical conductivity (35,000 S/cm)

Mxenes are the largest family of US discovered 2D nanomaterials









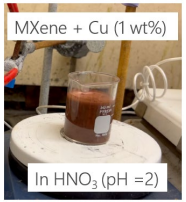
Nature Synthesis, *1*(8), 601-614.

TECHNICAL ACCOMPLISHMENTS

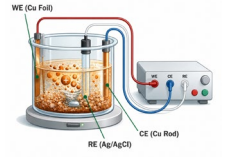
- **Demonstrated scalable MXene synthesis,** successfully producing 100 g batches of high-quality $Ti_3C_2T_x$ MXene to support composite fabrication and future scale-up efforts.



- **Established an initial liquid-phase self-assembly process** using the HNO_3-assisted approach to fabricate Cu/MXene composite powders with successful MXene incorporation onto copper particles.



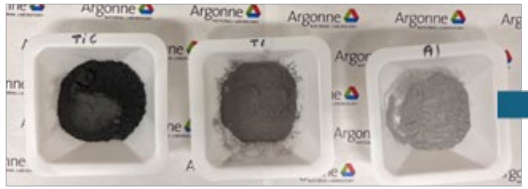
- **Developed an electrochemical self-assembly strategy** to improve the uniformity and interfacial distribution of MXene on Cu particles, with optimization currently underway.



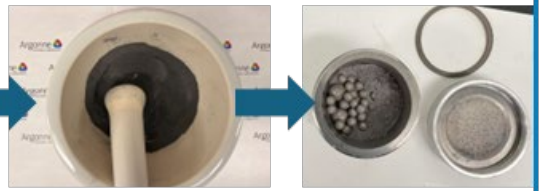
- **Conductivity measurements:** Preliminary data showed **improved conductivity on composite than the pristine Cu.** We also **identified densification as a critical processing parameter**, indicating that higher-density consolidated pellets are required to accurately evaluate the intrinsic electrical performance of Cu/MXene composites.



DEMONSTRATED THE BATCH SCALE SYNTHESIS OF MXENE



Powder samples TiC, Ti, and Al

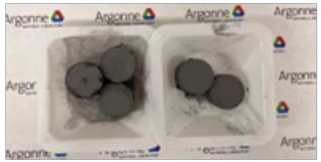


Physical mixing and ball milling





Pelletizing using a die set and pellet press



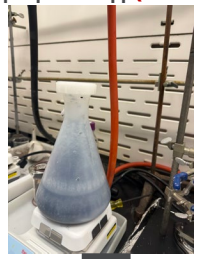


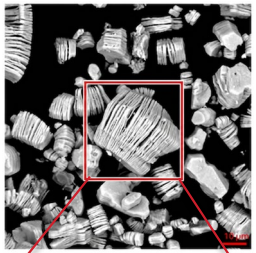
Pellets before sintering



Pellets after sintering

$M_{n+1}AX_n$ (MAX) etching

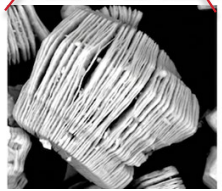








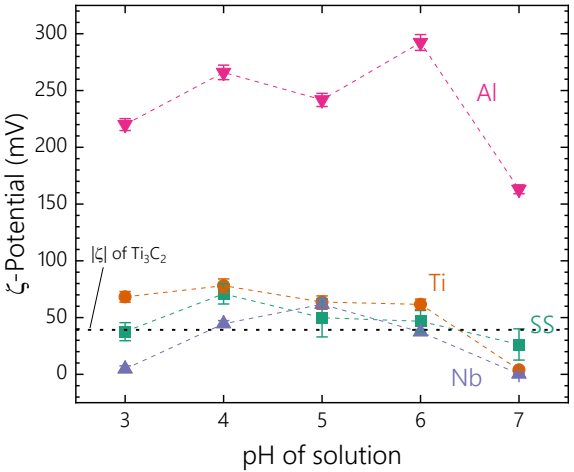
MXene powder after washing and drying under vacuum



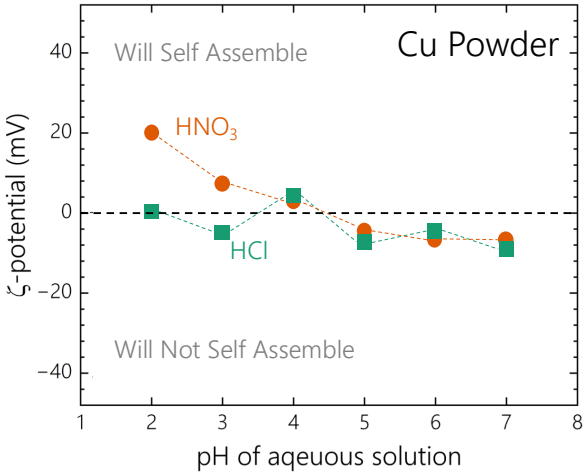
SEM image of the MXene

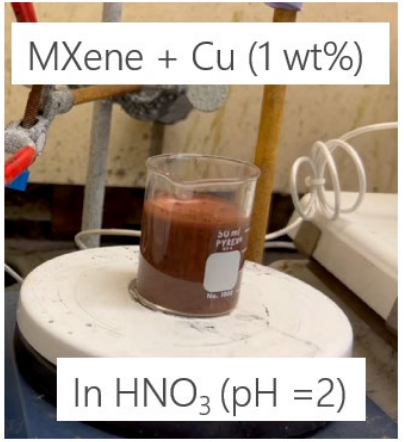
SELF ASSEMBLY APPROACH FOR METAL/MXENE COMPOSITE SYNTHESIS

For most metals



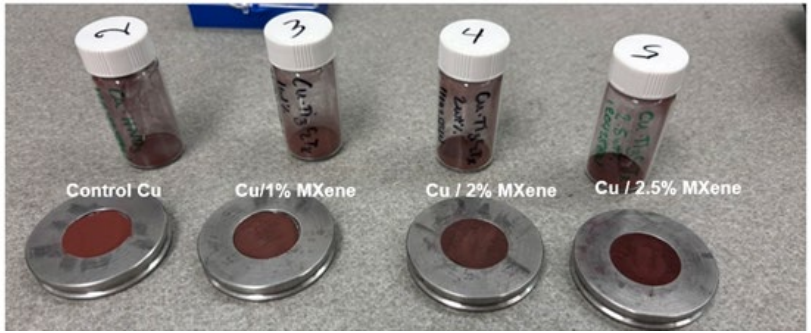
For Copper



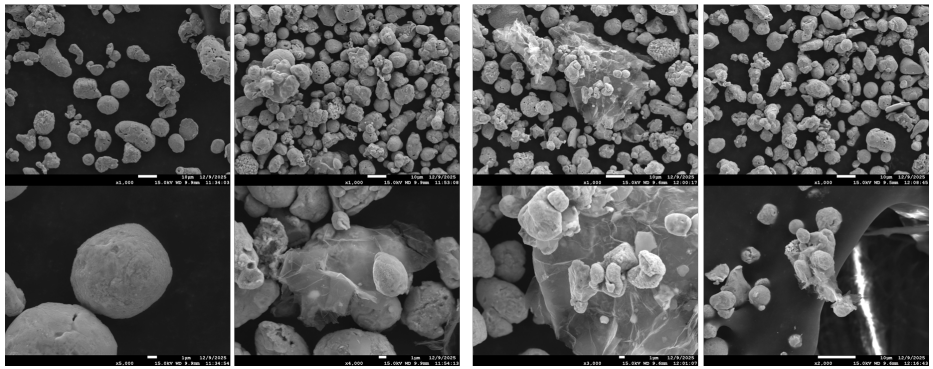


- HCl-modified approach works with many metals, which illustrates its promise to induce self-assembly of negatively charged 2Ds to metals.
- When mixing with HCl, the Cu + HCl was non-reactive, the zeta really didn't go above 0. However, with HNO_3, the Cu powder increased in zeta potential.

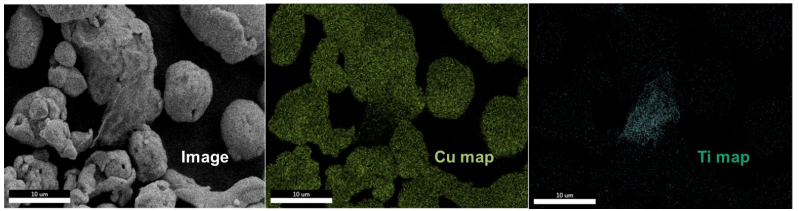
CU/MXENE COMPOSITE FROM NITRIC ACID (HNO_3) SELF ASSEMBLY APPROACH



Cu-HNO_3 treated | 1wt% Ti_3C_2 -Cu | 2wt% Ti_3C_2 -Cu | 2.5wt% Ti_3C_2 -Cu

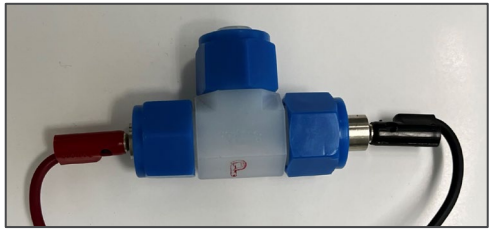


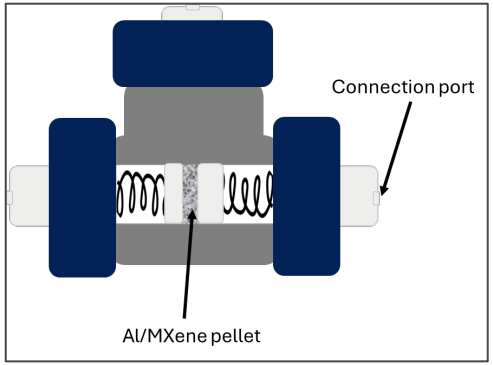
- Control Cu shows no flake-like features, while >1 wt% Ti_3C_2 show presence of single-to-few flake of MXene with Cu.
- EDS mapping confirms that Ti and Cu are separated.
- Although we see somewhat self assembly using HNO_3 approach, optimization through electrochemical approaches being investigated



IMPROVED CONDUCTIVITY OBSERVED WITH MXENE INTEGRATION

2-Terminal Resistance Measurement



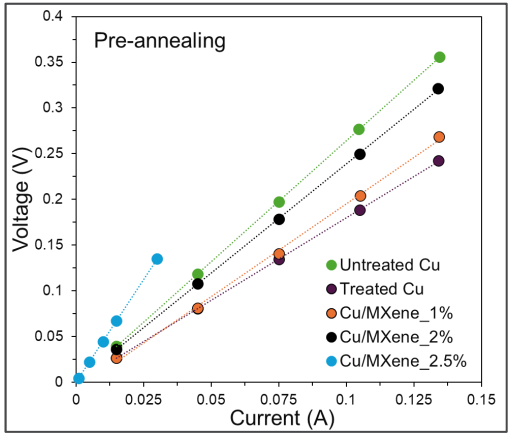


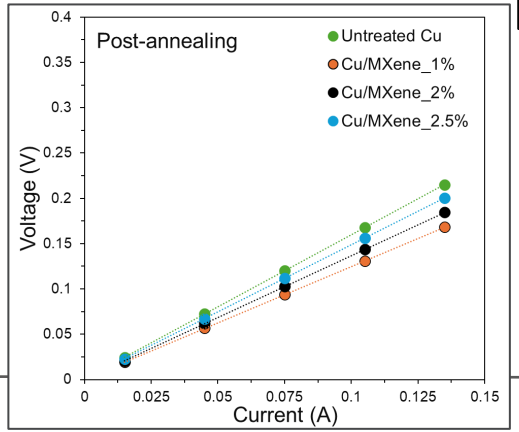
$$R = \frac{V}{I}$$

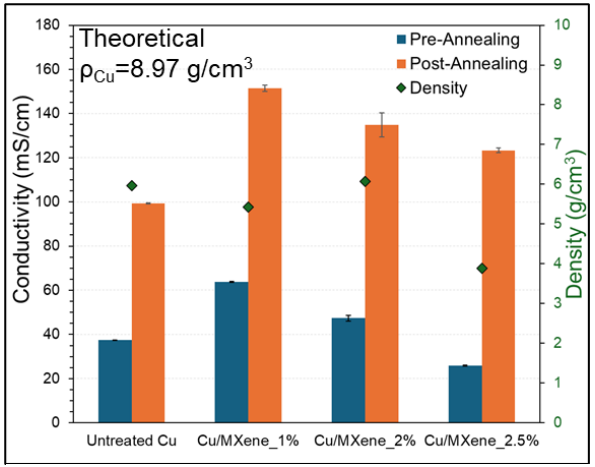
$$\rho = R\,\frac{A}{L}$$

$$\delta = \frac{1}{\rho}$$









- Conductivity measurements conducted with 2-terminal resistance probes.
- All samples exhibited ohmic behavior.
- Optimal conductivity achieved with 1wt% MXene integration.
  - Higher conductivity achieved with annealing (at 550 °C).
  - The density of our pellets was below copper's theoretical value.
  - Further conductivity optimization to focus on density optimization.

OPTIMIZATION OF CONDUCTIVITY TO ACHIEVE THE IACS SCALE VALUES

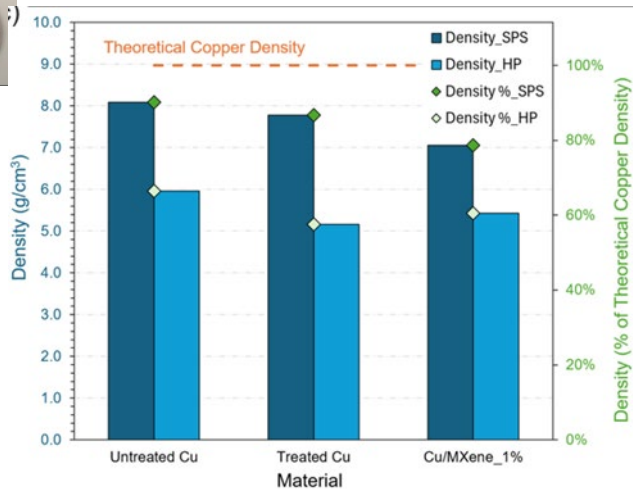
IACS = International Annealed Copper Standard



Hydraulic Press



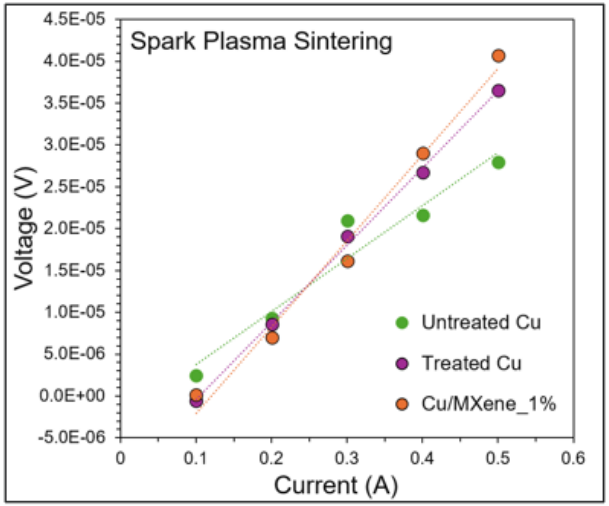
Spark plasma sintering furnace at Argonne
(HP D 25-SI)

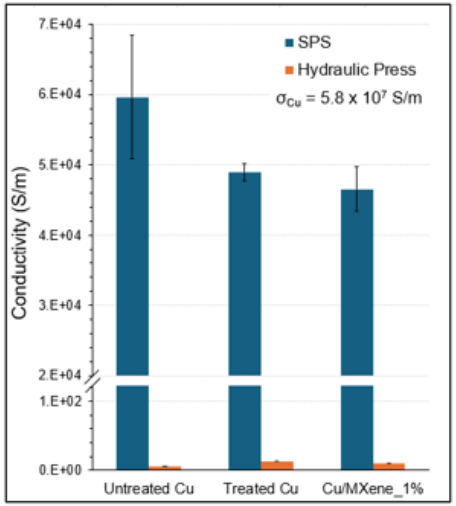


- Spark plasma sintering (SPS) can optimize both annealing (> 800 °C) and density (> 90% of theoretical)
- Observed in improved in density. Further optimization in process.
- This optimization is expected to enable IACS scale conductivity values (58 MS/m)

OPTIMIZATION OF CONDUCTIVITY TO ACHIEVE THE IACS SCALE VALUES

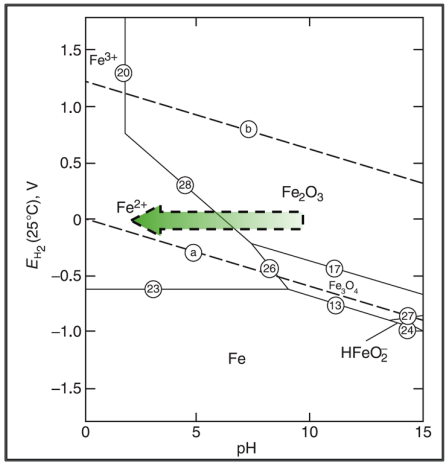


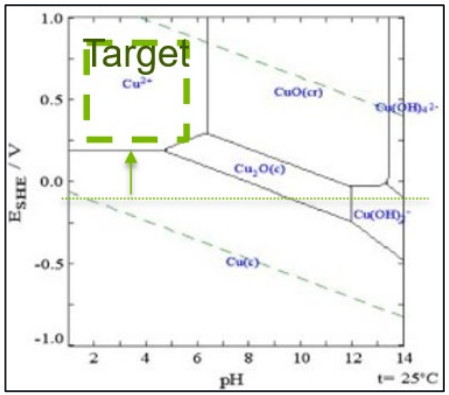


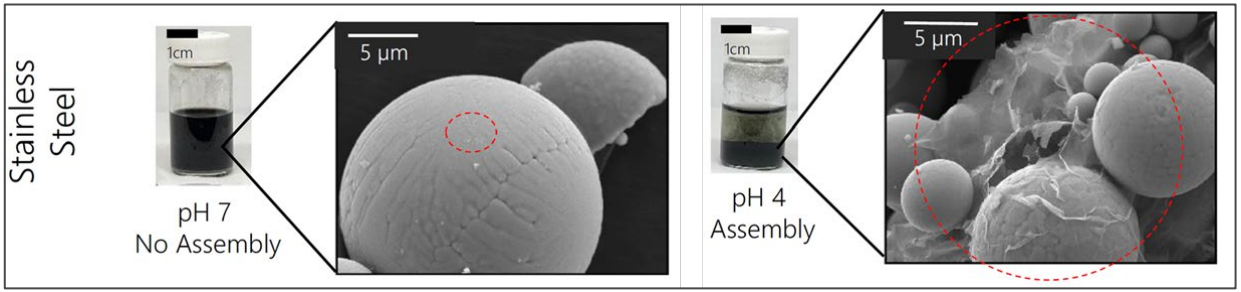


- SPS significantly improved conductivity, highlighting the importance of densification.
- Electrical performance is currently density-limited, not necessarily MXene-limited.
- Next: Optimize densification and electrochemical self-assembly to achieve target conductivity.

OPTIMIZATION OF SELF ASSEMBLY APPROACH USING ELECTROCHEMICAL METHOD

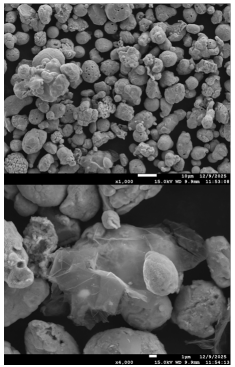






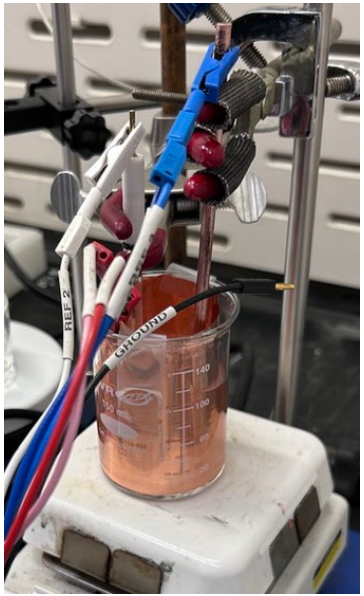
J. Patenaude, B. C. Wyatt, et.al., *MRS Advances*, 2024, 9:551–556

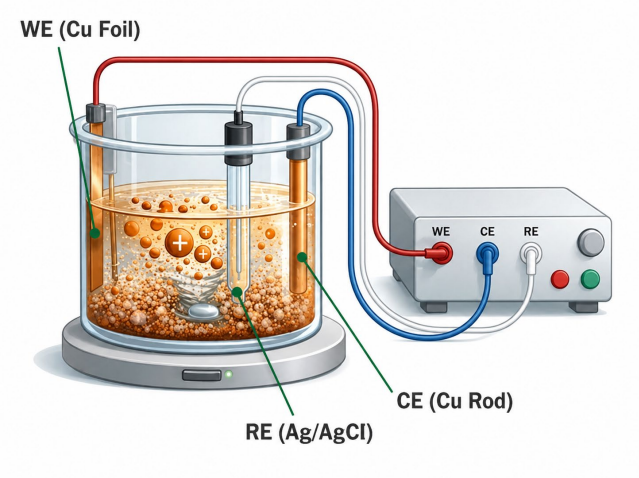
- Pourbaix diagrams provide thermodynamic guidance on electrochemical conditions that favor specific metal phases
- Guided by the Pourbaix diagram of iron, self-assembly of stainless steel with MXenes was achieved as Fe^{2+} is favored at low pH and 0 V vs SHE
  - The same approach is being explored for copper
  - Oxidize Cu (Cu^{2+}) is favored at both low pH and higher potential (≥ 0.25 V vs SHE)

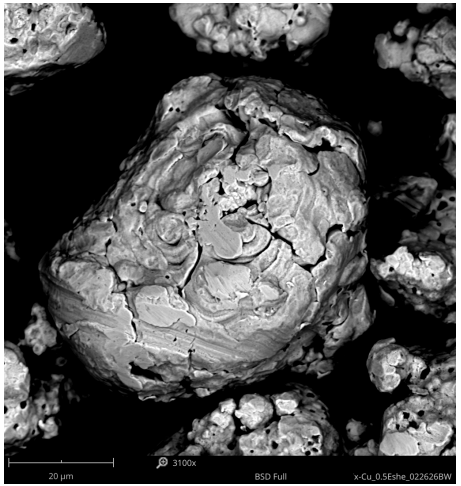


SEM image of the Cu/MXene (1%) from HNO_3 approach

OPTIMIZATION OF SELF ASSEMBLY APPROACH USING ELECTROCHEMICAL METHOD





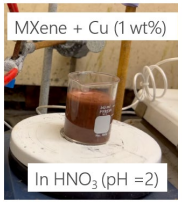


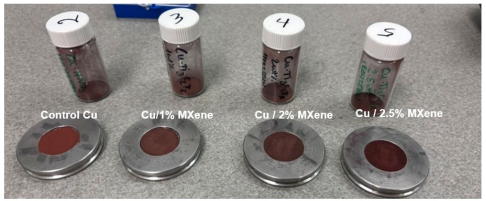
- Preliminary experiments completed: Cu electrodes and an electrolyte comprised of Cu suspended in HCl
- Initial microscopy analysis indicated the requirement of optimization efforts to focus on determining conditions that will induce sufficient surface charge on the copper

CONCLUSION / IMPACT

- **Established scalable synthesis and processing routes** for Cu/MXene composites, including successful **100 g-scale MXene production** and initial composite fabrication.
- **Demonstrated the feasibility of MXene integration with copper** through self-assembly approaches, laying the foundation for improved conductor performance.
- **Identified key processing–structure–property relationships**, with ongoing optimization focused on achieving uniform MXene distribution using electrochemical approach and high-density composite consolidation.
- **Positioned the technology for scalable manufacturing and industrial validation** through partnerships with Loukus Technologies and NAECO, supporting future commercialization.
- **Supports DOE Office of Electricity goals** by advancing next-generation conductor materials that can improve transmission efficiency, reliability, and resilience for a modernized electric grid.

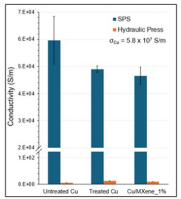


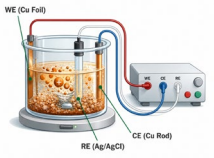












FUTURE DIRECTION/NEXT STEPS

- Expand the electrochemical synthesis approach to get better uniform distribution of MXene over Cu particles
- Densify Cu/MXene composite to improve electrical conductivity
- Continue characterizing the Cu/MXene composite
- Work with industry partner (Loukus) on wire fabrication
- Optimize and Scale Up Synthesis Process
- Application Testing with Industry partner (NAECO)

ACKNOWLEDGEMENTS

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE).



U.S. DEPARTMENT of ENERGY

REFERENCES

1. K.R.G. Lim, M. Shekhirev, B.C. Wyatt, B. Anasori, Y. Gogotsi et al., Fundamentals of MXene synthesis. Nat. Synth **1**(8), 601–614 (2022).

2. S. Adhikari, S Muhoza, Z Hood, Invention report - IN-24-108

3. J Patenaude, BC Wyatt, SK Nemani, B Anasori, A generalized and scalable self-assembly method of 2D carbides to metal powders, MRS Advances 9(9) 551-556 (2024)