Exploring Ion-Conducting Polymer Membranes for Renewable Energy Technologies

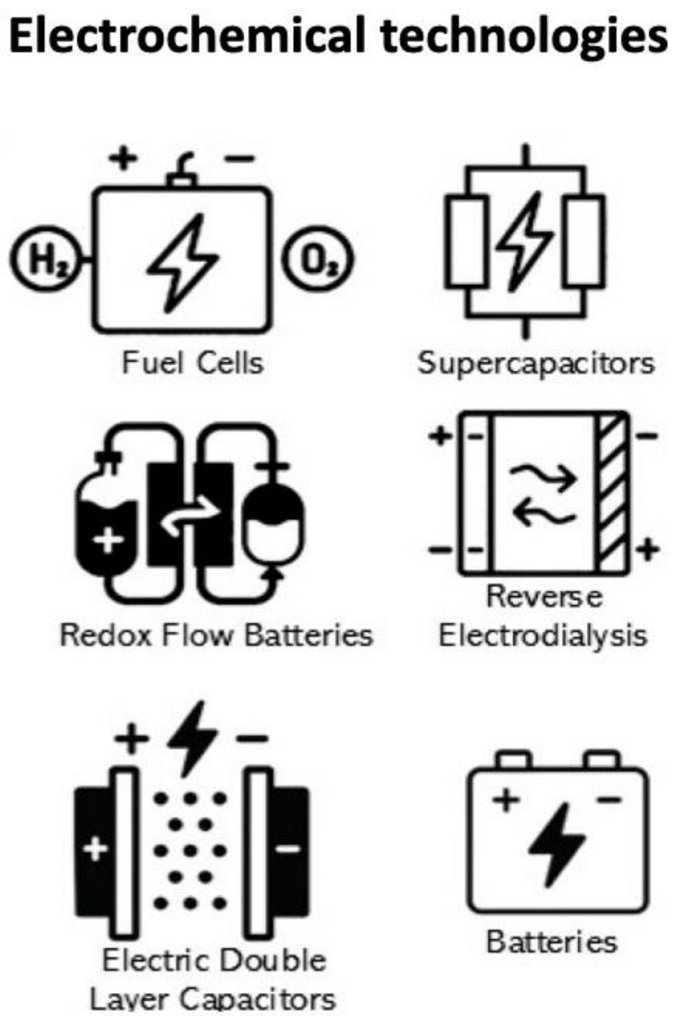
Mia Delja, Karen Acurio, and Shudipto Konika Dishari

Nanomaterials Lab, Department of Chemical and Biomolecular Engineering University of Nebraska – Lincoln

NCMN

National Nanotechnology Coordinated Infrastructure

Motivation

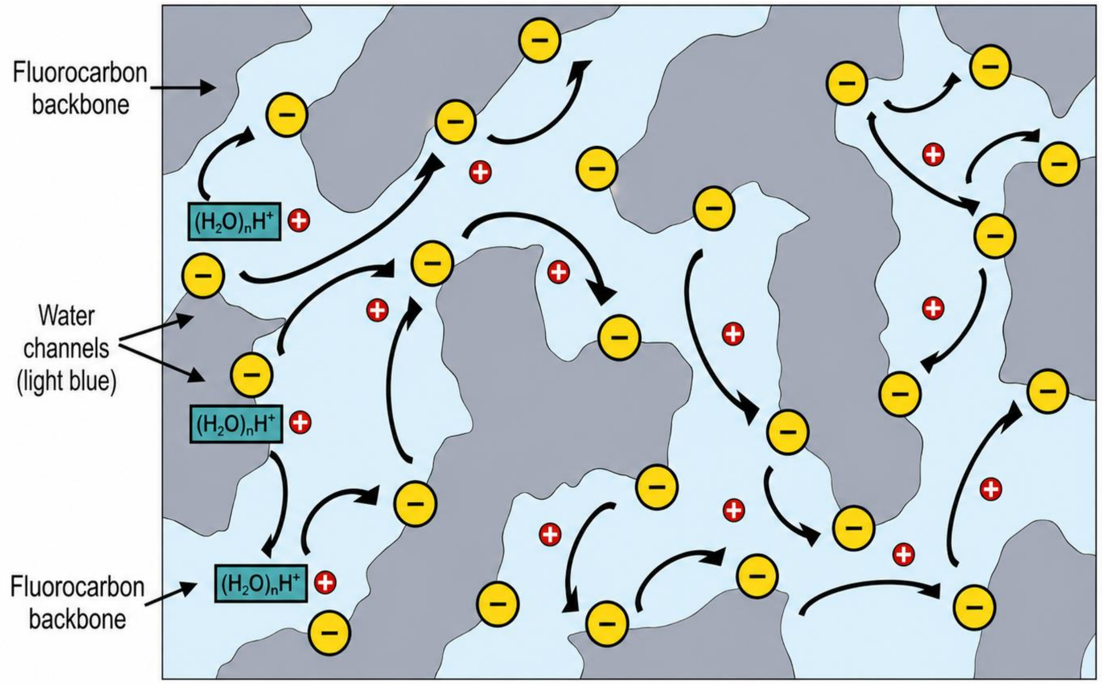


Why Does This Matter?

- Fuel cells require efficient proton-conducting membranes.
- Nafion is the industry standard proton exchange membrane.
- Improving proton transport can increase fuel cell efficiency.
- Composite membranes may improve conductivity while maintaining stability.

Current limitation: pathway disorder limits conductivity

Current Understanding of Proton Transport in Nafion Membranes

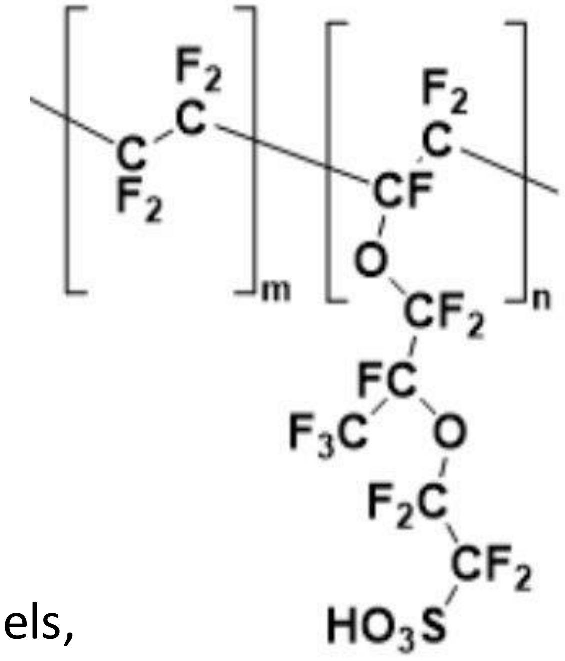


Proton Transport in Nafion

- Fluorinated backbone provides mechanical stability.
- Sulfonic acid groups form hydrophilic channels.
- Protons move through interconnected water channels.

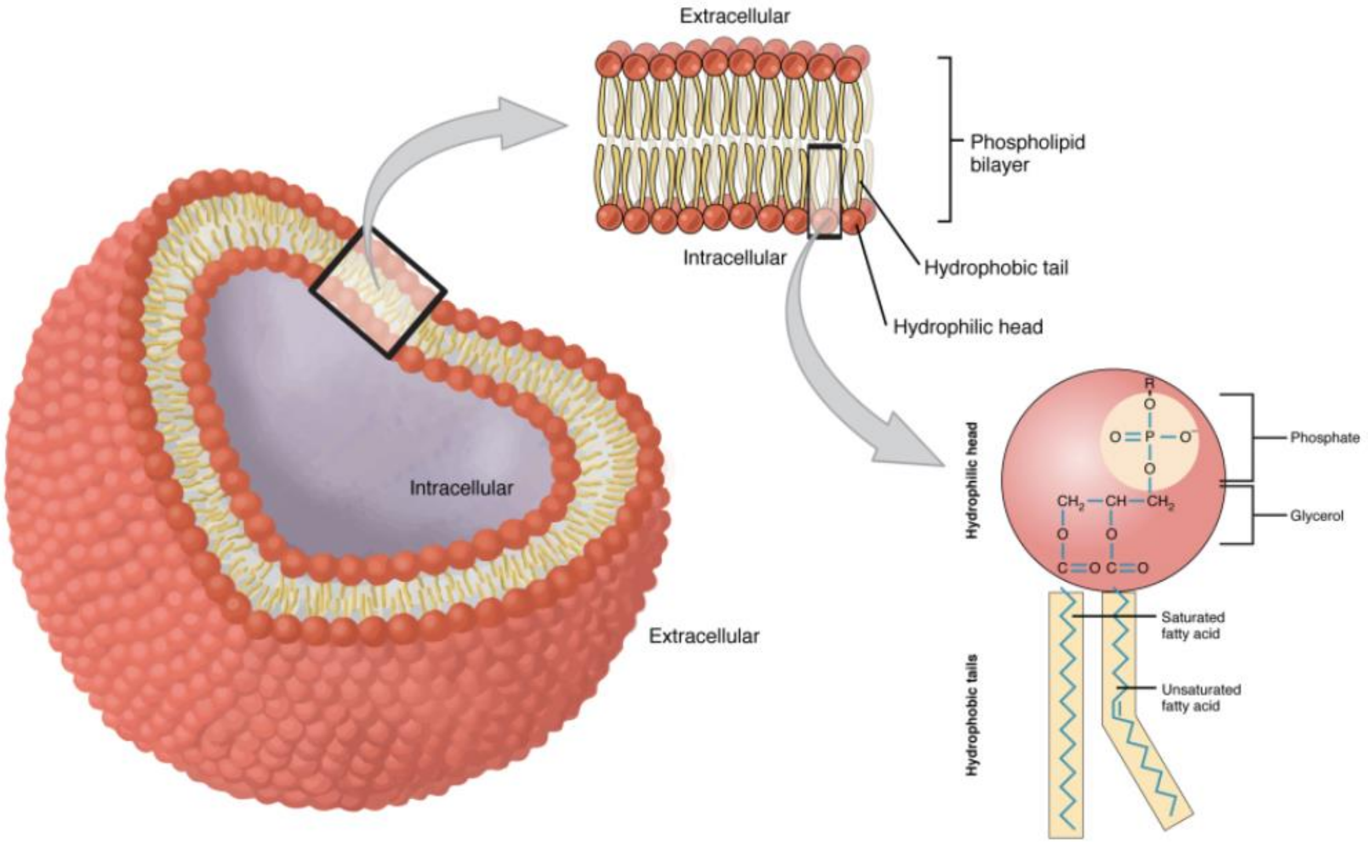
Current Nafion relies on naturally formed ionic channels, but there is still potential to create more efficient proton transport pathways.

Ionomers



Nafion
IEC ~0.91 meq/g

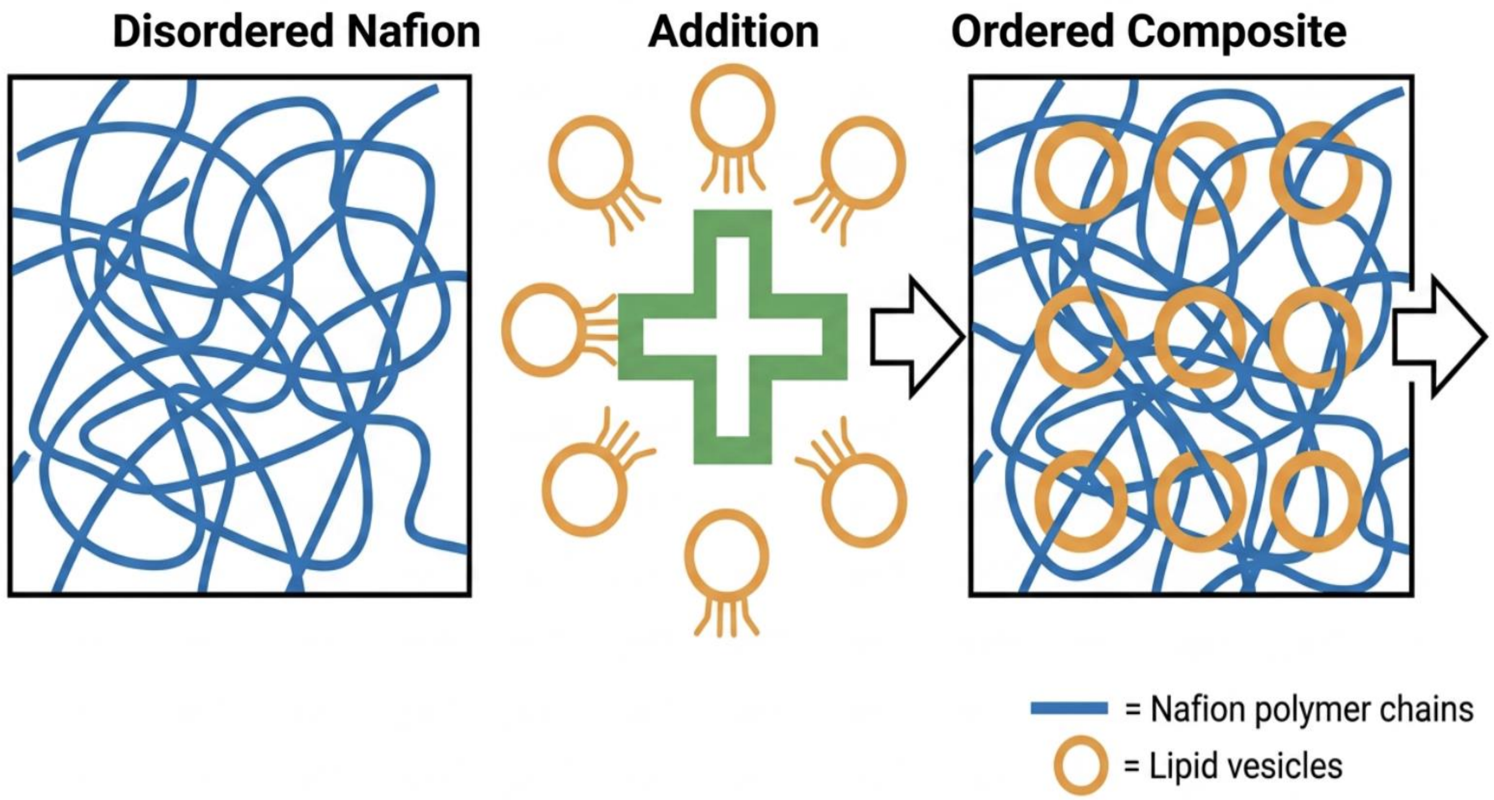
Ordered Lipid Structures Naturally Found



Examples in Nature

- Cell membranes are composed of lipid bilayers.
- Phospholipid head groups self-assemble into highly ordered structures.
- This organization enables efficient and selective transport of molecules and ions.

Optimizing Lipid Vesicles and Current Understanding of Nafion

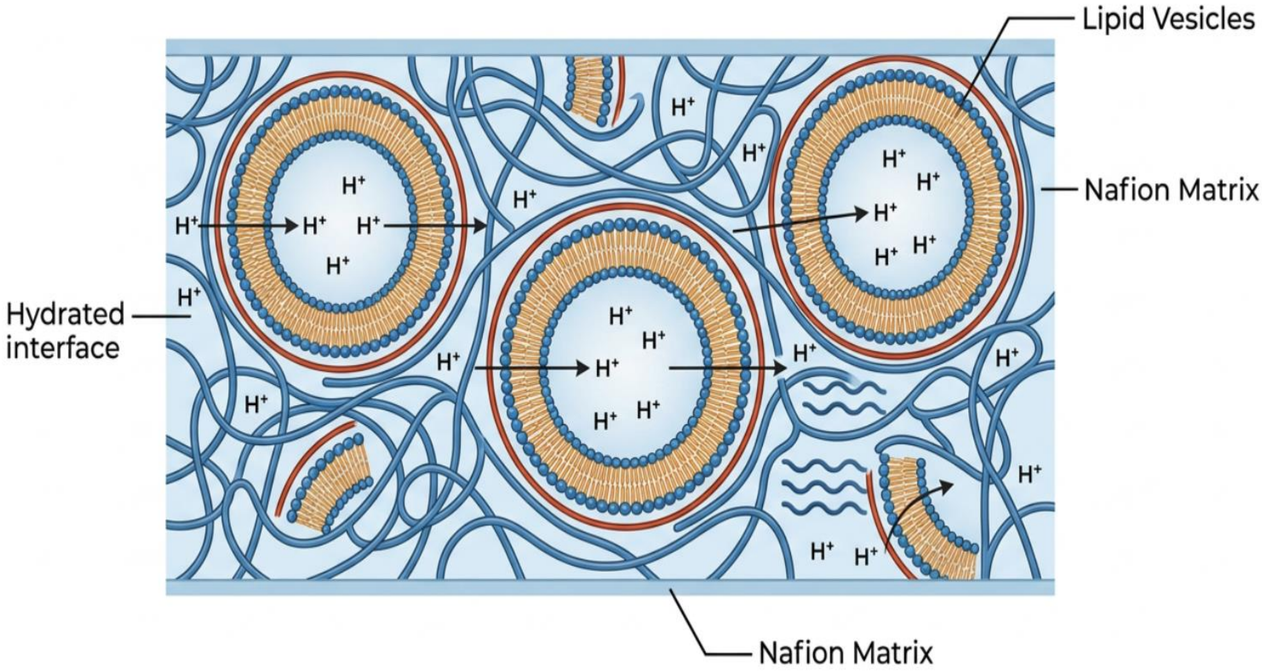


Our Idea:
Introduce lipid vesicles into Nafion.

- Increase nanoscale organization within the membrane.
- Create more continuous proton-conducting pathways.
- Improve proton conductivity by having more ordered proton conducting pathways.

Research Question

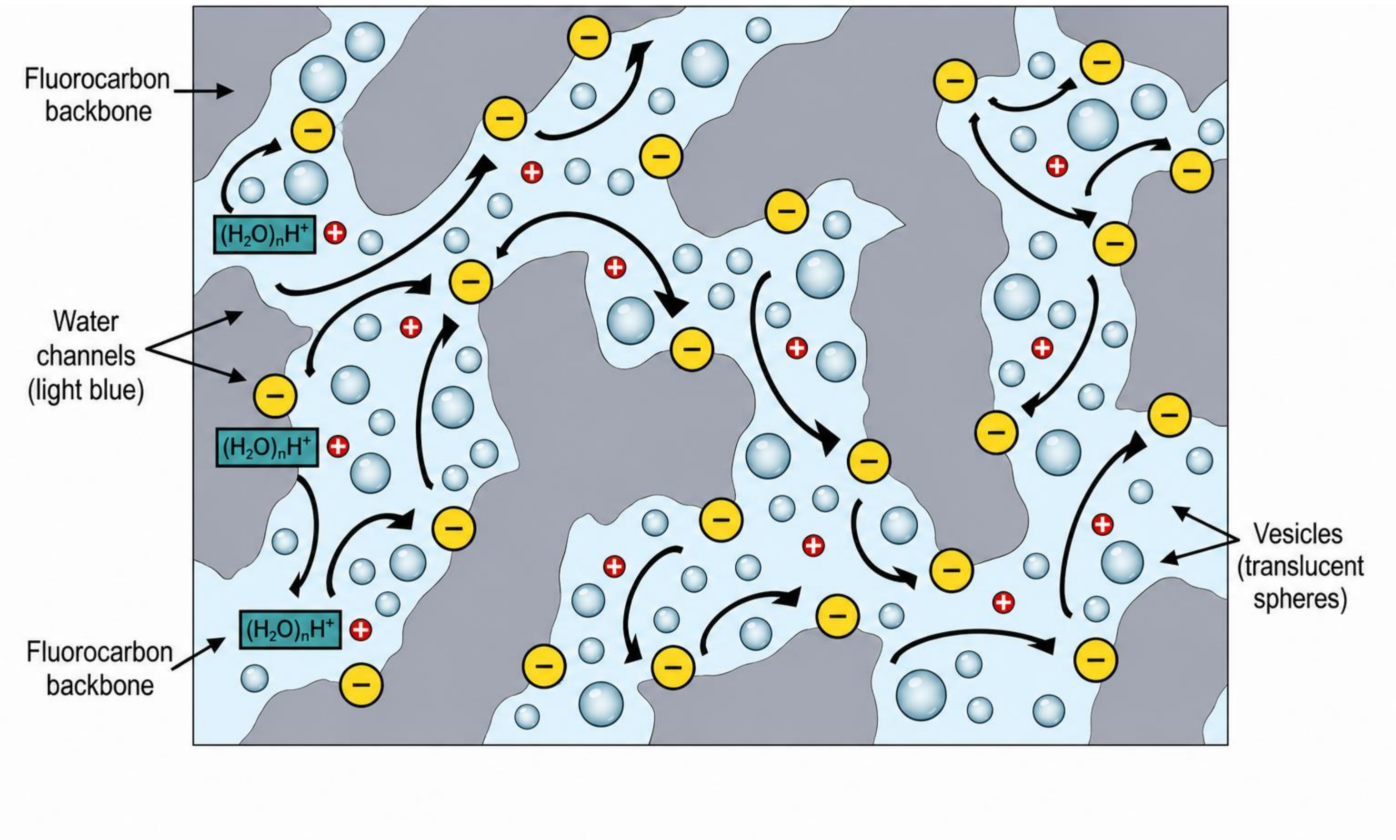
Can lipid vesicles improve proton conductivity in Nafion membranes while maintaining membrane integrity?



Hypothesis

Lipid vesicles can enhance proton transport.

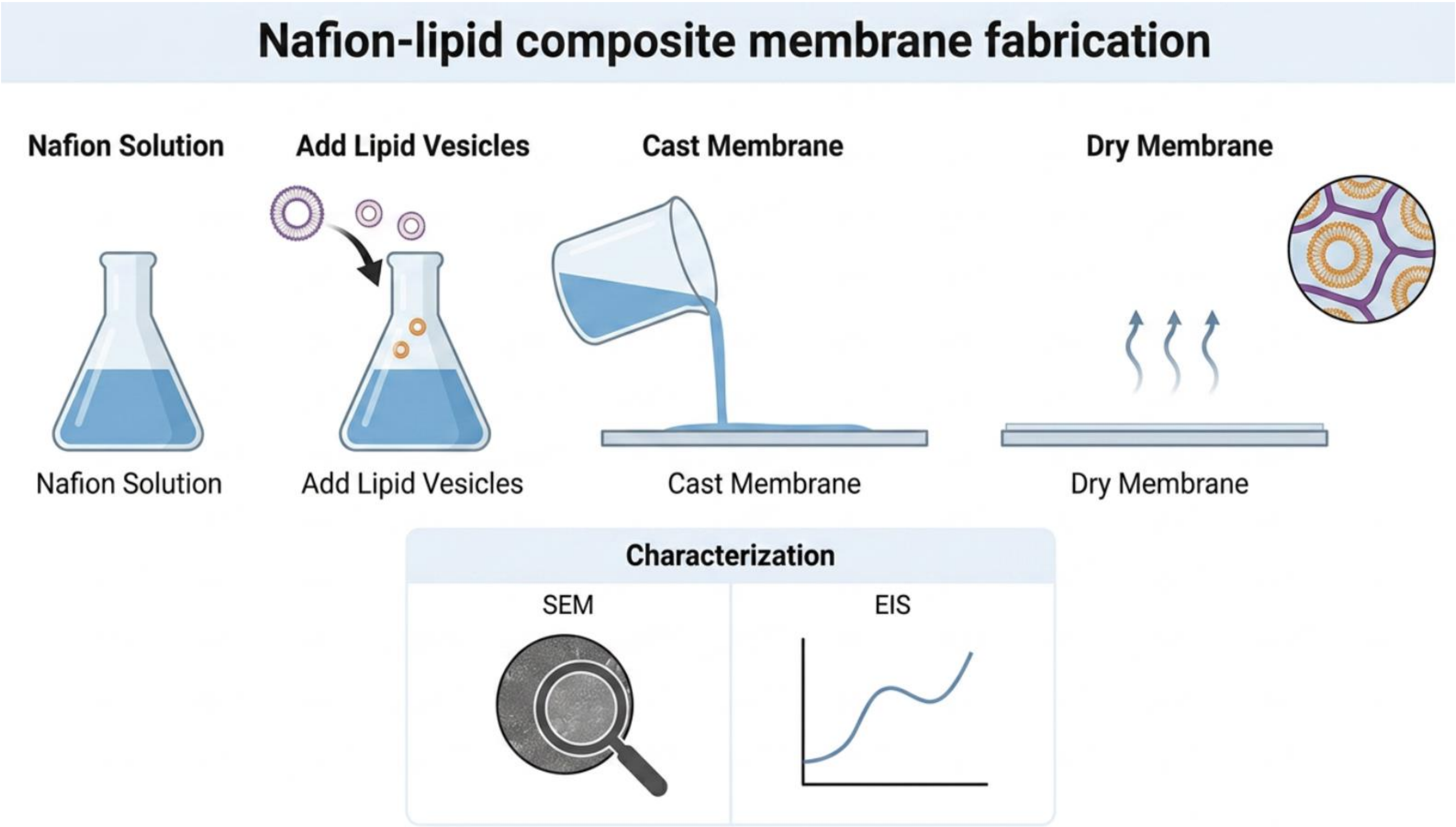
How Nafion Conducts Protons With Lipid Vesicles



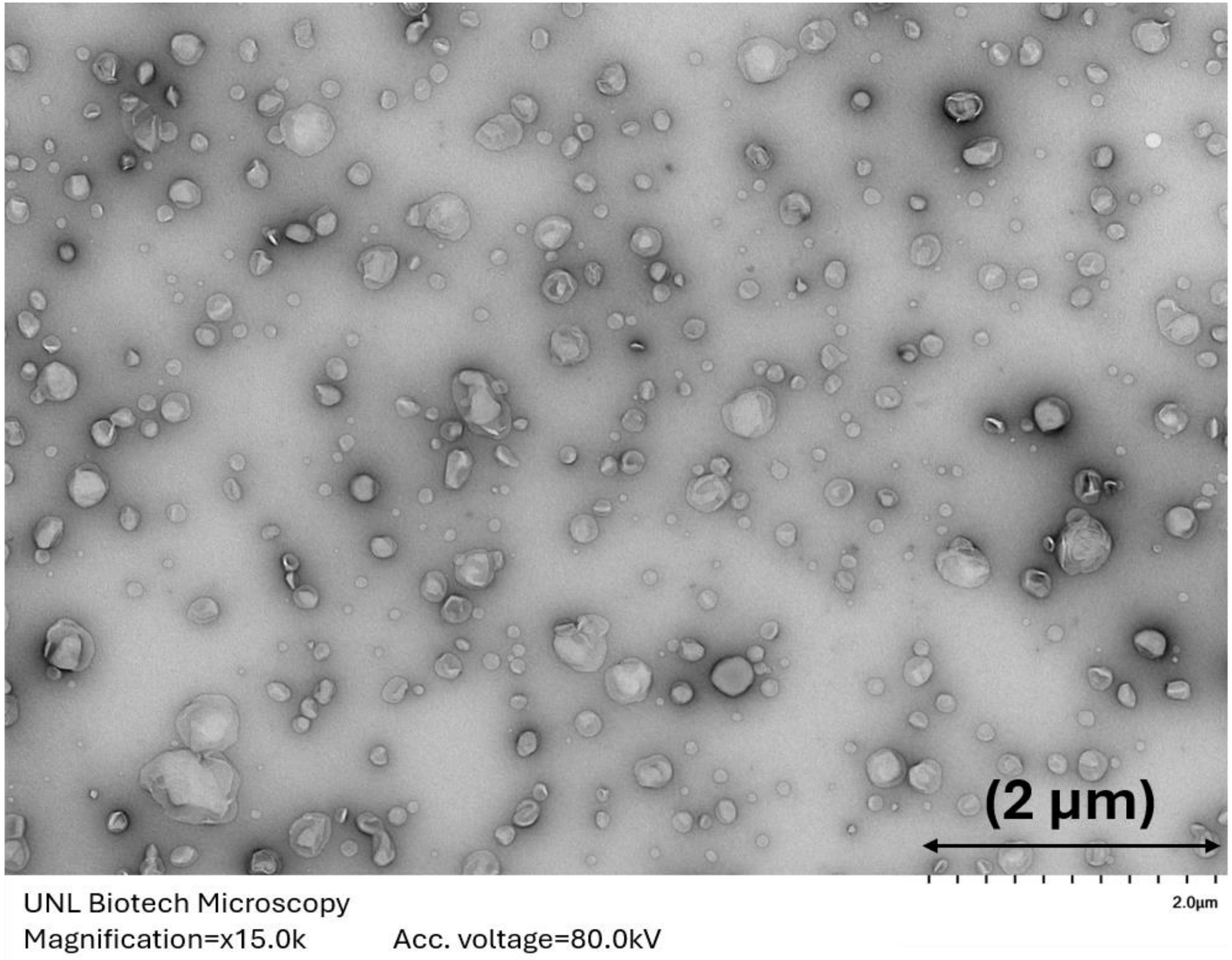
- Lipid vesicles are added directly into the existing water-channel network.
- Their ordered phospholipid structure may create additional proton pathway.
- Vesicles supplement Nafion's native transport mechanism rather than replace it.

Goal: more continuous, ordered pathways → higher conductivity

Experimental Methods



Results: Morphology TEM Image



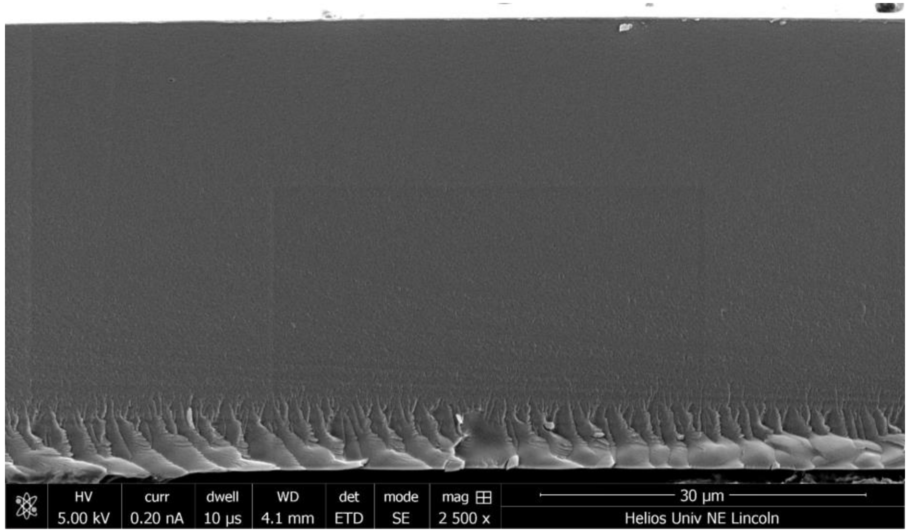
Key Findings

- lipid vesicles were successfully synthesized.
- Vesicles were spherical and well dispersed.
- Vesicle sizes were in the expected range.
- TEM confirmed successful vesicle formation prior to membrane fabrication.
- Approximately 50–500 nm in diameter, with most vesicles around 100–250 nm.

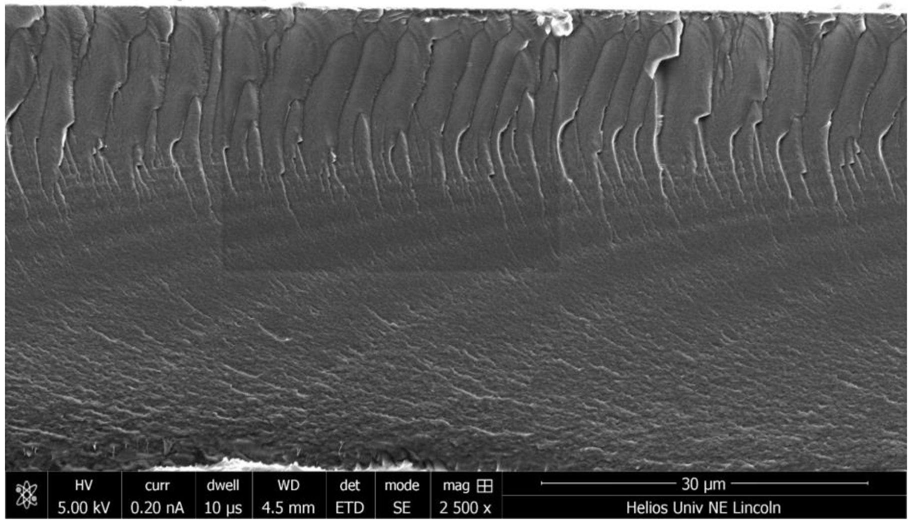
Takeaway:
TEM verified the formation of lipid vesicles used to prepare the composite membranes.

Results: Morphology SEM Images

Pristine Nafion Membrane



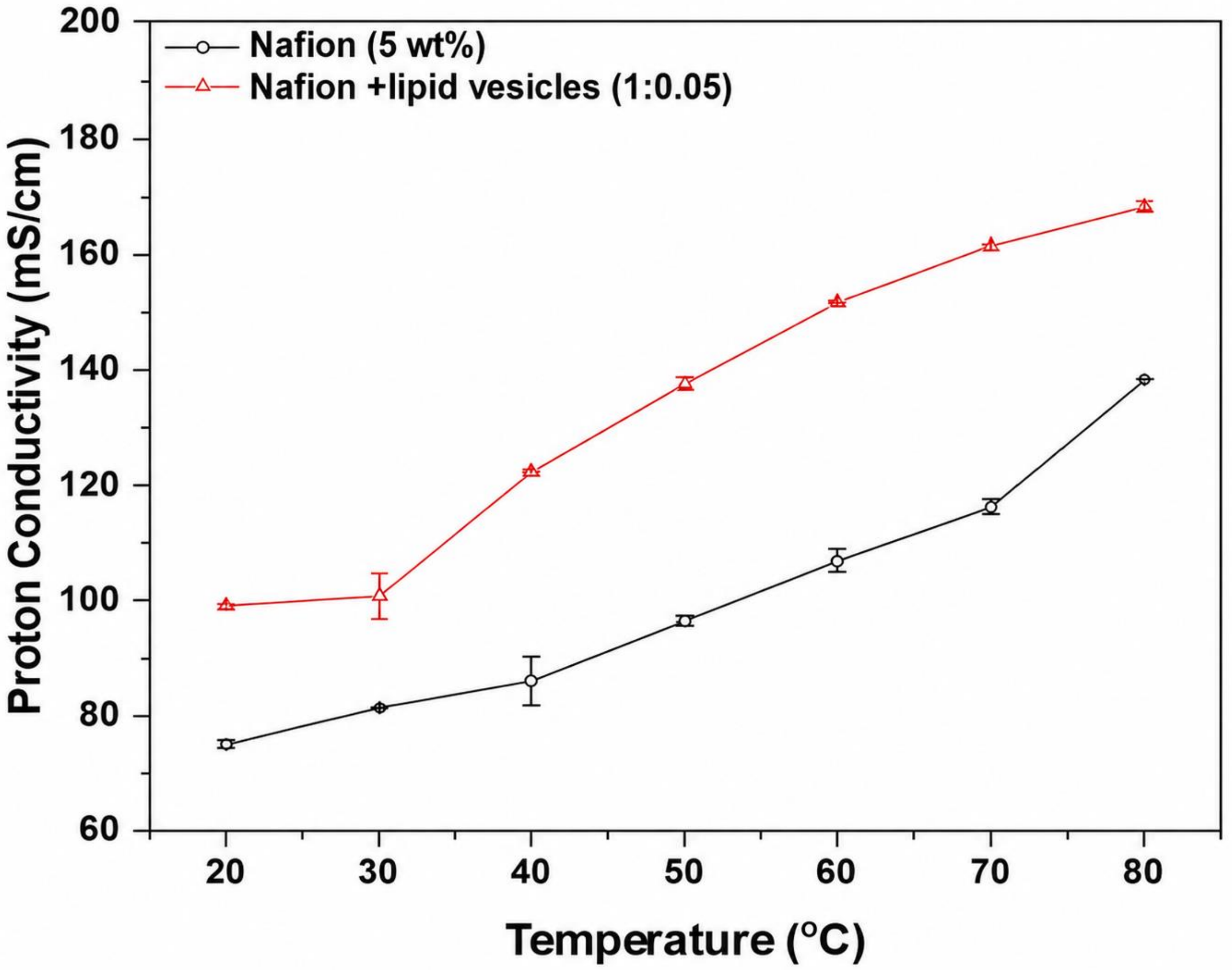
Lipid-Vesicle Nafion Composite Membrane



Key Findings

- Membrane morphology remained intact after lipid vesicle incorporation.
- No major cracks, defects, or phase separation were observed.
- Visible vertical features and increased texture throughout the cross-section suggests that the lipid vesicles influenced the internal organization.

Results: Proton Conductivity



Key Findings

- Incorporation of lipids improved conductivity
- Composite membranes showed higher proton conductivity.
- Conductivity increased across the measured temperatures.
- Results suggest additional proton transport pathways.

Conclusions

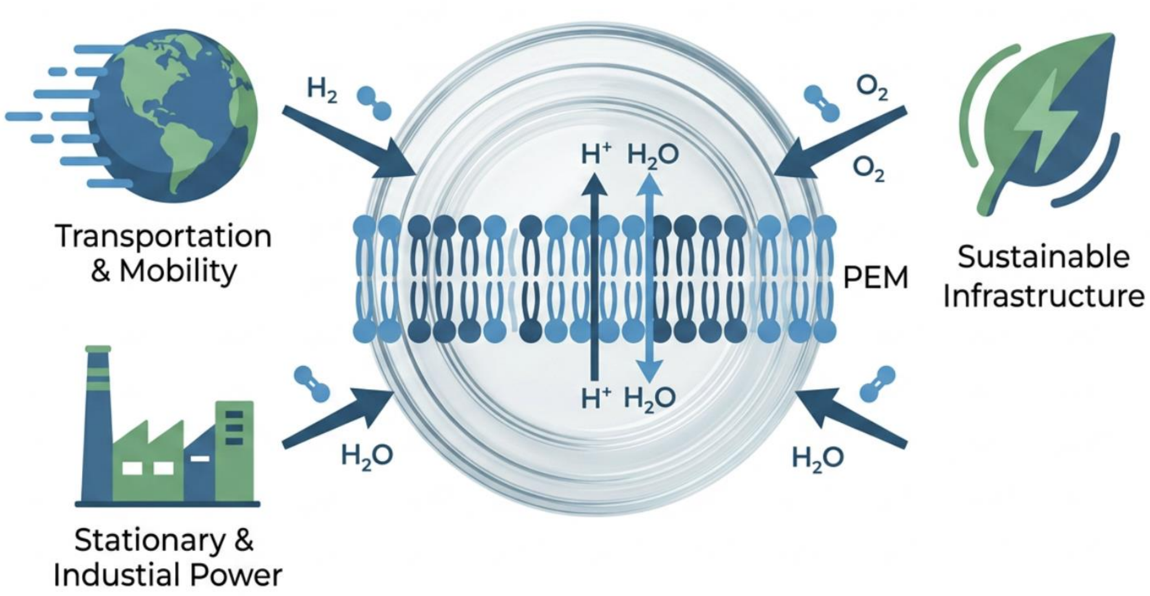
✓ Membrane composition influences proton transport.

✓ Lipid vesicles improved proton conductivity.

✓ Membrane morphology was preserved after the addition of lipids.

✓ Composite membranes show promise for renewable energy applications.

Future Work



- Optimize membrane composition.
- Evaluate long-term mechanical stability.
- Test under fuel cell operating conditions.
- Investigate structure–property relationships.
- Scale up membrane fabrication for practical applications.

Goal: Develop high-performance proton exchange membranes for next-generation energy technologies.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant Nos. 1950137 and NSF-DMR #2520078, and by the Voelte Keegan Bioengineering Support Grant. I thank the Nanomaterials Lab, Department of Chemical and Biomolecular Engineering, University of Nebraska–Lincoln, for providing laboratory space and resources. I also thank Dr. Shudipto K. Dishari for her guidance and mentorship throughout this project, and Dr. Karen Acurio-Cerda for her thoughtful teaching and continued support.

References

[1] Roy, A.; *et al. Chem. Commun.* 2024, *60*, 13114–13117.

[2] Dishari, S. K.; *et al. Macromolecules* 2018.

[3] Cerda, K. A.; *et al. ACS Appl. Mater. Interfaces* 2022, *14*.

[4] LMU Pressbooks, *Human Physiology – The Cell Membrane*.

Thank You