# Amphiphilic Titanium Porous Transport Layers for Highly Effective Low-Temperature Reversible Fuel Cell

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DOE Hydrogen Program
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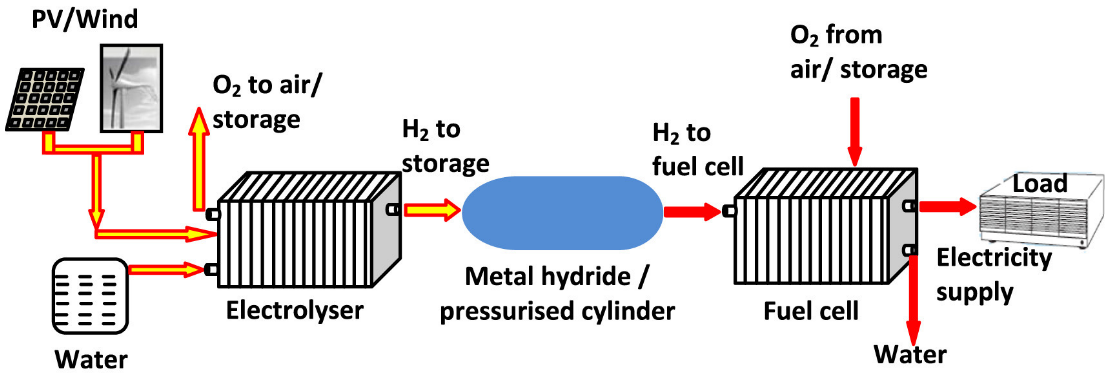
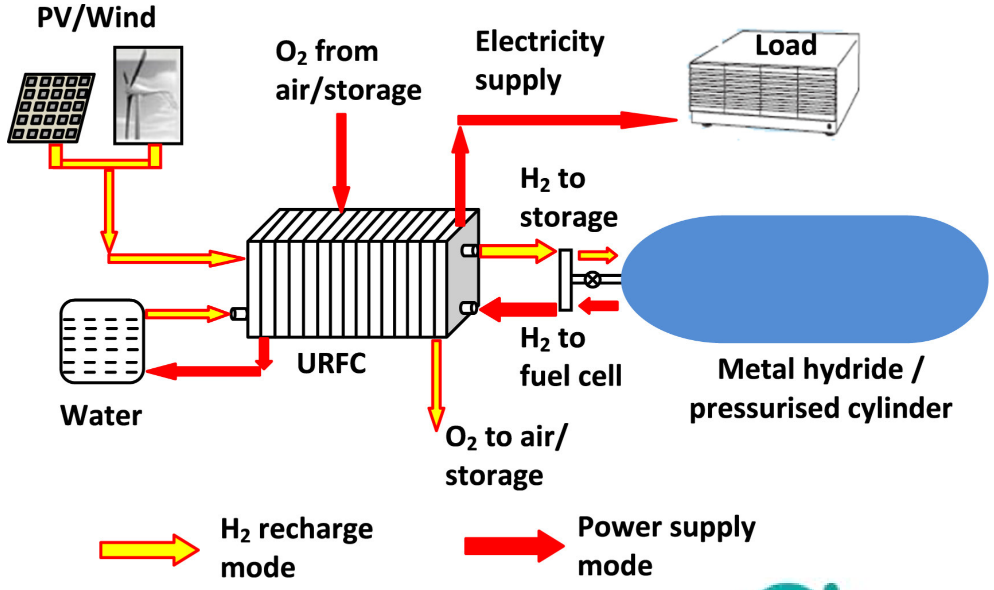
AMR Project ID: MNF-BIL008

# Impact of reversible fuel cell

- Addressing the challenge of aligning energy supply with demand
- Proposing a promising technology for large-scale energy storage and conversion
- Offering high theoretical specific energy density with $H_2/O_2$ gas tanks
- Minimizing capital costs by integrating fuel cell and electrolyzer functionalities into a compact single-device

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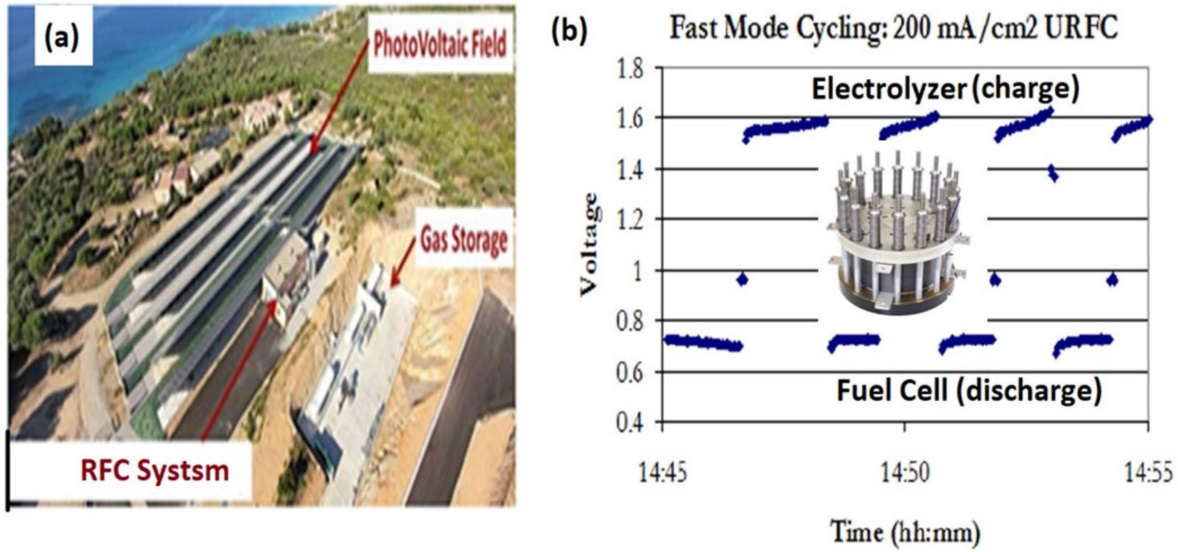
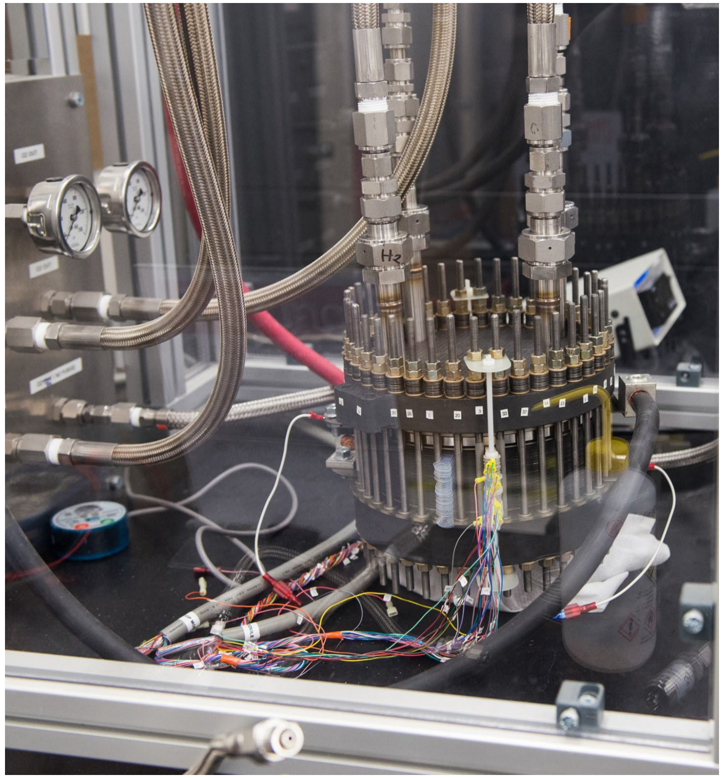
# Giner’s successful history




(a) Giner 50-kW RFC system integrated with a solar panel

(b) Giner demonstrated RFC charge-discharge behavior



Giner’s advanced fuel cell & electrolyzer development

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# Project Goal

- Design a 5 $cm^2$ compact reversible fuel cell unit by incorporating Ti-based amphiphilic porous transport layers and high-performance catalyst-coated membranes.
- Enhance the cost-effectiveness of the reversible fuel cell unit by increasing its round trip efficiency to over 52% at significant current densities (500 $mA/cm^2$ in fuel cell mode and 1000 $mA/cm^2$ in electrolyzer mode).
- Perform simulations to determine optimal operating conditions for both fuel cell and electrolyzer modes.

# Overview

## Timeline

- Project Start Date: 7/10/2023
- Project End Date: 5/9/2024

## Budget

- Total Project Budget: $ 206,500
  - Total DOE Share: $ 206,500
  - Total Cost Share: $ 0
  - Total DOE Funds Spent: $ 204,492
  - Total Cost Share Funds Spent: N/A

## Partners

- Co-PI: Yun Wang
- Partner Organization and role: University of California, Irvine, Full Professor

## Barriers

Technology validation:

- Reproducible fabricating amphiphilic PTLs at 5 $cm^2$ scale
- Achieved >52% round-trip efficiency at 500 $mA/cm^2$ in fuel cell mode and 1 $A/cm^2$ in electrolyzer mode

Simulation:

- Created a 3D model for the fuel cell and electrolyzer and figured out the optimal working conditions.

# Relevant to DOE Goals

| | |
|---|---|
| Lower greenhouse gas emissions and pollutants | Accelerate the deployment of URFC technology for renewable energy storage. Hit the new URFC milestone of over 52% round-trip efficiency. |
| Build clean energy infrastructure | The optimal URFC operation environment is studied; amphiphilic PTLs have been developed; bench-top URFC has been validated; the design is ready to be scaled up. |
| Strengthen U.S. manufacturing | The fabrication of amphiphilic PTL utilizes advanced manufacturing technologies, which could stimulate the manufacturing industry improvement. |
| Create Good-paying jobs in the US | The deployment of URFC technology needs experienced operation engineers, advanced manufacturing engineers, stack assembly engineers, which are all good-paying positions. |

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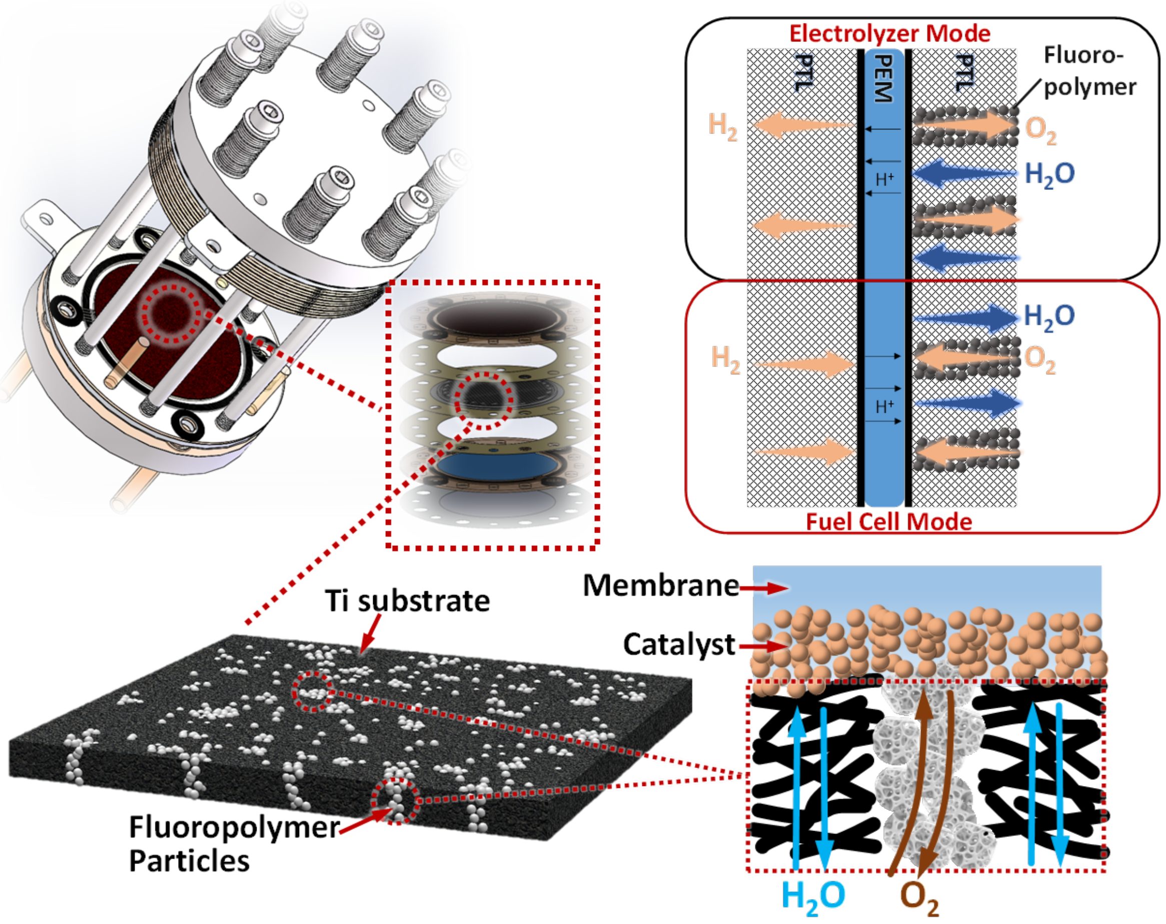
# Approach




- **Technical approach**: Develop amphiphilic PTLs; the hydrophobic area ensures $O_2$ transport in fuel cell mode, and the hydrophilic area facilitates water transport in electrolyzer mode.
- **Uniqueness**: regions of distinct features are united on the same piece of PTL using reproducible way.
- **Critical barriers**: 1) fabricate micrometer-scale fluoropolymer particles with macroporous structure. 2) Fabricate Ti substrate with uniform pore distribution.
- **Strategy to address**: laser technology.
- **Integrate with HFTO R&D projects**: The strategy of making Ti substrate hydrophobic can be applied to carbon substrate to benefit fuel cell projects.

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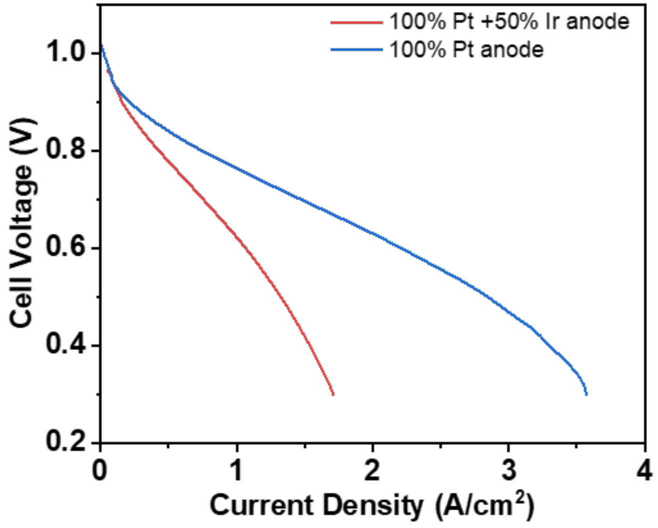
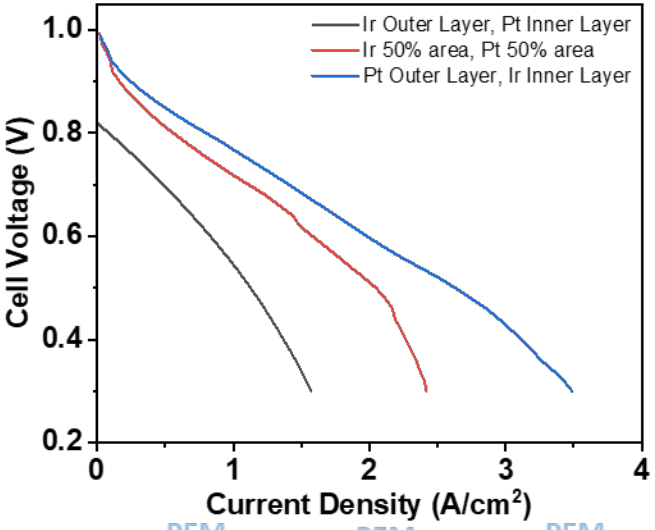
# Approach: Safety Planning and Culture

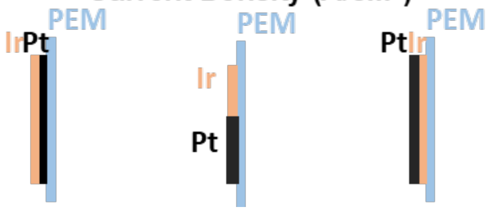
- The test of the fuel cell was delayed in order to install safeties on the Scribner stations. We discovered a scenario in which a leak path allowed $H_2$ gas to flow into the $N_2$ line. When gas pressure was lost in the $N_2$ line because the cylinder was empty, the internal valve allowed $H_2$ to leak into the $N_2$ plumbing. We installed a pressure switch and solenoid valve on the $N_2$ inlet line to prevent it.
- We leak check and use the $H_2$ sniffer during start up to ensure there are no leaks of $H_2$ into the lab.
- We made a shield for the cell when installed on the Scribner station to prevent accidental contact.

# Accomplishments and Progress – Fuel cell mode



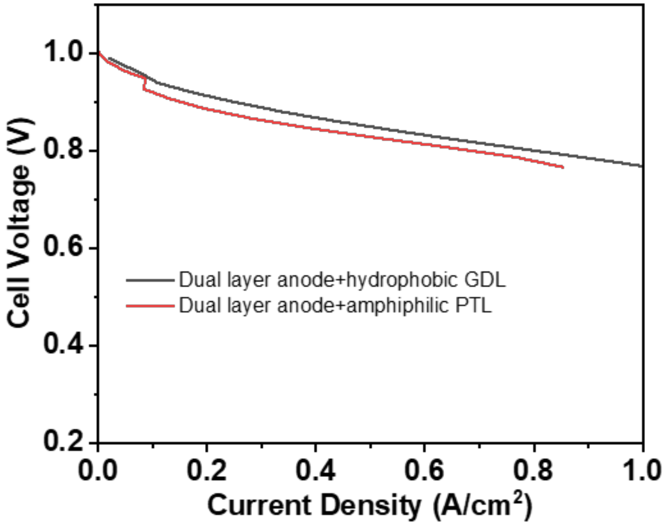

Ir may be harmful for the ORR activity on Pt.




Pt & Ir are deposited into two layers.

Pt at the outer layer, Ir at the inner layer shows then best performance




Amphiphilic PTL shows very similar performance with hydrophobic GDL in fuel cell mode

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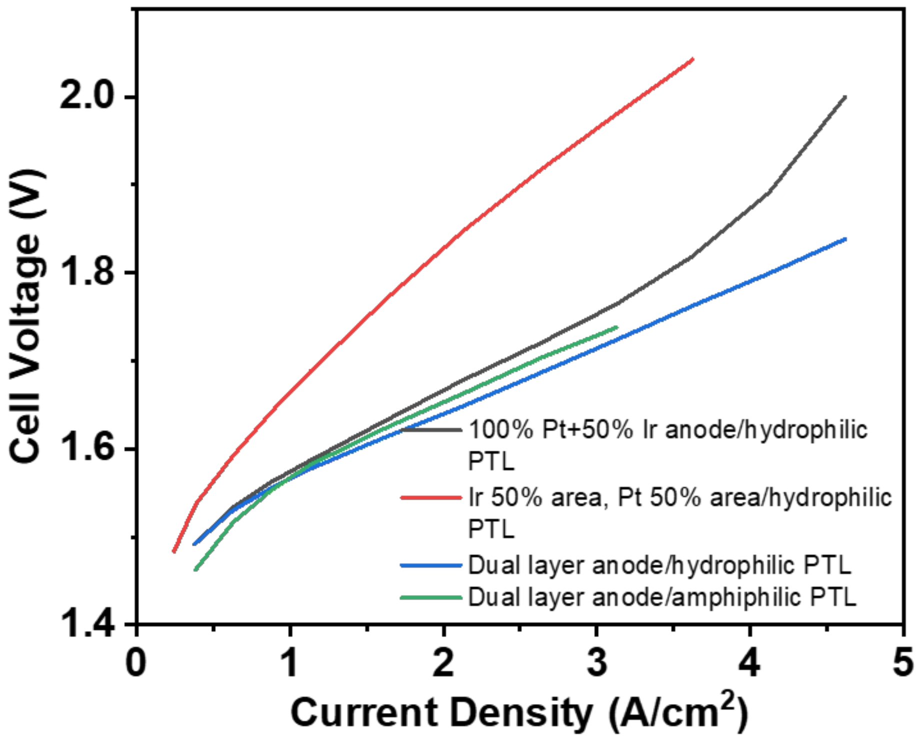
# Accomplishments and Progress – Electrolyzer mode




Pt & Ir split to different areas and 50% for each shows the worst performance.

Dual layer catalyst layer design shows excellent performance in both fuel cell and electrolyzer mode.

Amphiphilic PTL shows very similar performance with hydrophilic PTL in electrolyzer mode

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# Collaboration and Coordination

| Collaborators | Role |
|---|---|
| University of California, Irvine (Subcontractor) | Computational fluid dynamics modeling for better understanding the structure-performance relationship of PTLs. Machine learning and forecasting the fuel cell and electrolyzer performance under different operation conditions. |
| 3M (Vendor) | Supply the low-loading, high surface area catalyst and catalyst-coated membrane to demonstrate better performance. |

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# Technology transfer activities

- Full patent application number: No. 63/352,040
- Giner is primarily a technology development company and is not market facing. We sell or license technologies that we have developed under federal funding to more established companies.
- Successful examples include the sale of a transdermal alcohol sensor that we developed under NIAAA funding and the sale of Giner ELX to Plug Power.

# Community Benefits Plans and Activities

- Two women of color were hired and made great contributions to the fuel cell testing and PTLs fabrication.
- We have a DEI committee looking for opportunities to recruit from demographics that are underrepresented in STEM.
- Giner has conducted employee surveys specifically about the topic of TEI to guage employees' views on the culture at Giner.
- Giner provided paid summer internships for 2 women and 1 man of color and they made great contributions to the project.

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# Remaining Challenges

- The project's main objective of >52% round-trip efficiency has been achieved.
- **Challenges for future projects:**
- Scale the fabrication of amphiphilic PTLs from 5 $cm^2$ to 50 $cm^2$ and bigger scales while maintaining the uniformity of fluoropolymer distribution.
- Stabilize the fluoropolymer to reduce the erosion of turbulent water flow.

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# Proposed Future Work

**Proposed work during the rest of this year:**

- Test the low-loading catalyst with amphiphilic PTLs.

**Future work:**

- Scale up the reversible fuel cell to a 5-cell stack with 50 $cm^2$ per cell.
- Improve the amphiphilic PTL design to be more uniformly according to the simulation results.
- Work with 3M to integrate the amphiphilic PTLs with 3M CCM.
- Identify alternative, cheaper manufacturing methods.
- Optimize heat management for reversible fuel cell stack.

# Summary

- Over 52% round-trip efficiency was achieved based on amphiphilic PTLs and double catalyst layer CCM design.
- The amphiphilic PTL was made by embedding porous fluoropolymer particles into Ti sinter, which is reproducibly made at 5 $cm^2$ scale.
- Simulation results indicates that a uniform mixture of hydrophilic and hydrophobic area is the best PTL design, which guides our next step research.