IFBF 2025

24-26 JUNE 2025
VIENNA, AUSTRIA
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BioZen Batteries

Development and validation of a flexible, low-cost, small-volume flow cell platform for high-throughput flow battery research, development, and deployment

Redoxino™

Mini Flow Cell Test System

www.redoxino.com

Co-authors: **Maarten A. Rutgers**[1], **Colin L. Hilkemeyer**[2], **Alexander L. Hendin**[2], **Christopher K. Walsh**[2], **Seamus D. Jones**[1,2]

[1] *BioZen Batteries, Inc., Santa Barbara, CA, USA*

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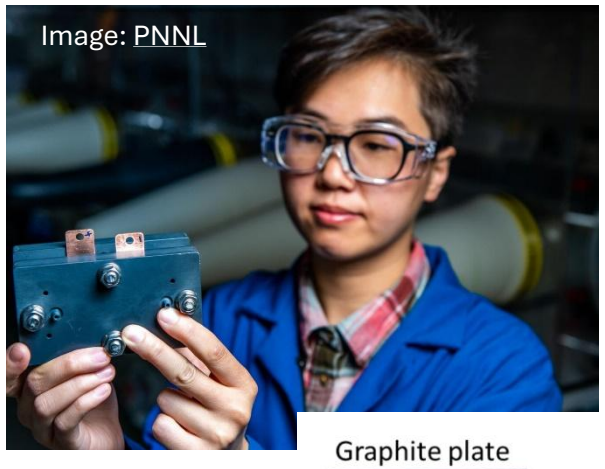
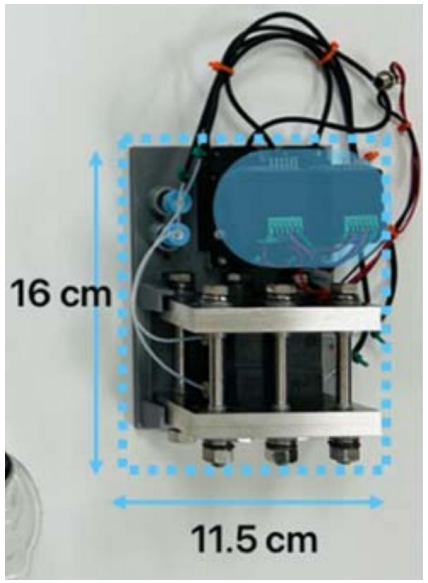
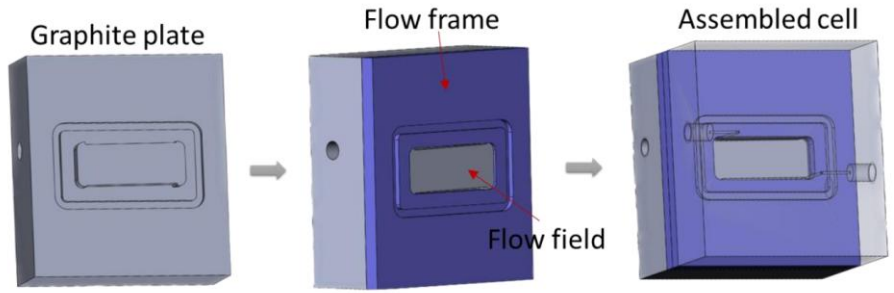
Redoxino™ BioZen Batteries

New mini cells from PNNL and FBRC: Bolted

- Recent and existing small-volume cells use legacy **bolt-together** stack architectures
- They seem to work, but may be **complex**
- **Licenses** required?





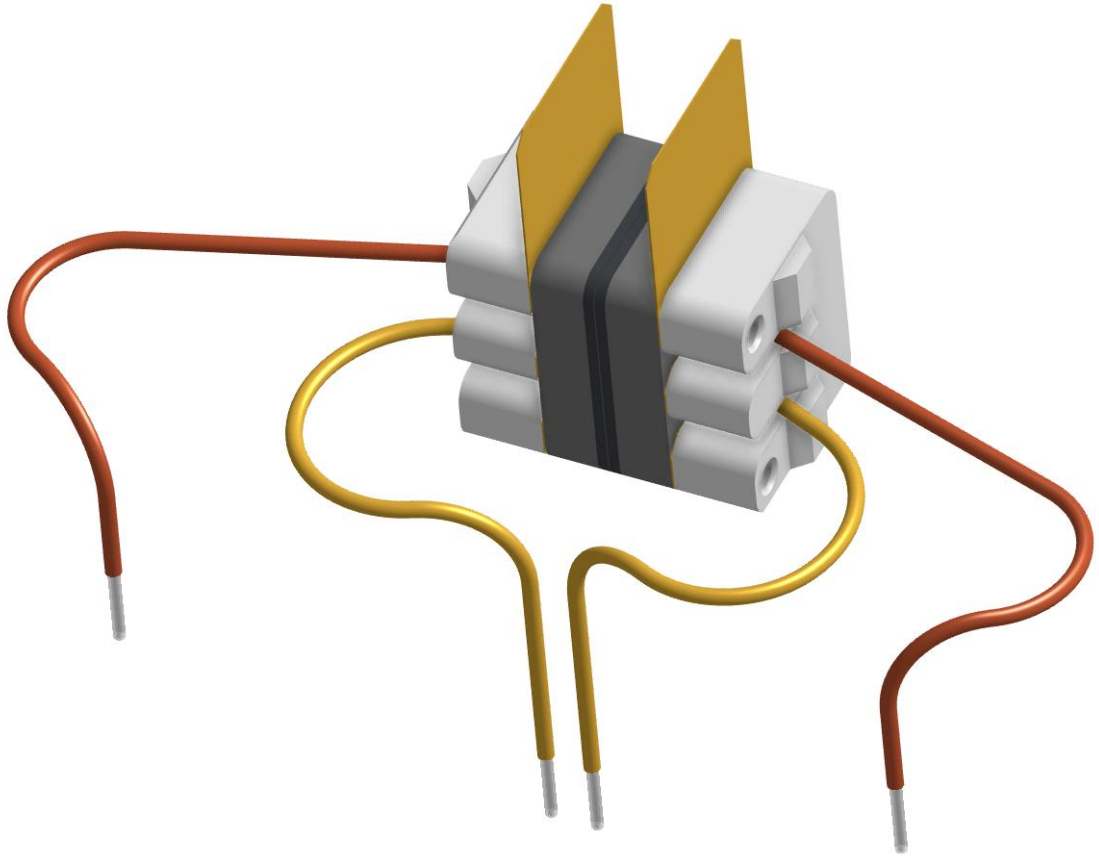


Open Source Design
Flow Battery
Research Collective
https://fbrc.dev/

PNNL Images & design from publication:
https://iopscience.iop.org/article/10.1149/1945-7111/ad9bef

The Redoxino™ Test System: Clamped Cell

- All parts **fabricated by hand** with:
  - **Scissors**
  - **Scalpel**
  - **Dremel press**
  - **Drill bits (1.45mm, 3.1mm)**
  - **Cricut/Brother craft cutter**
  - **3D printer**
  - **Metric nuts / bolts / allen keys**



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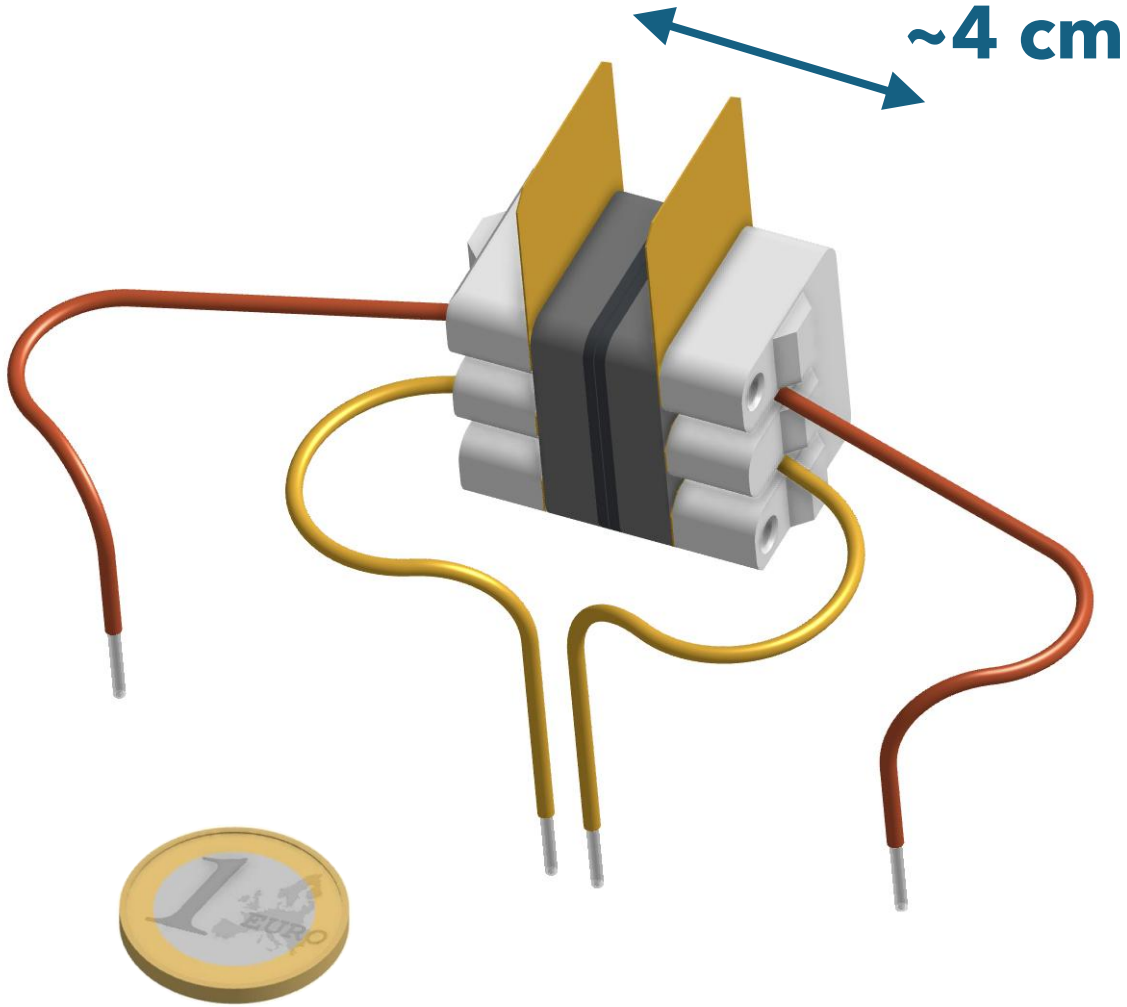
- **Miniaturized** form factor



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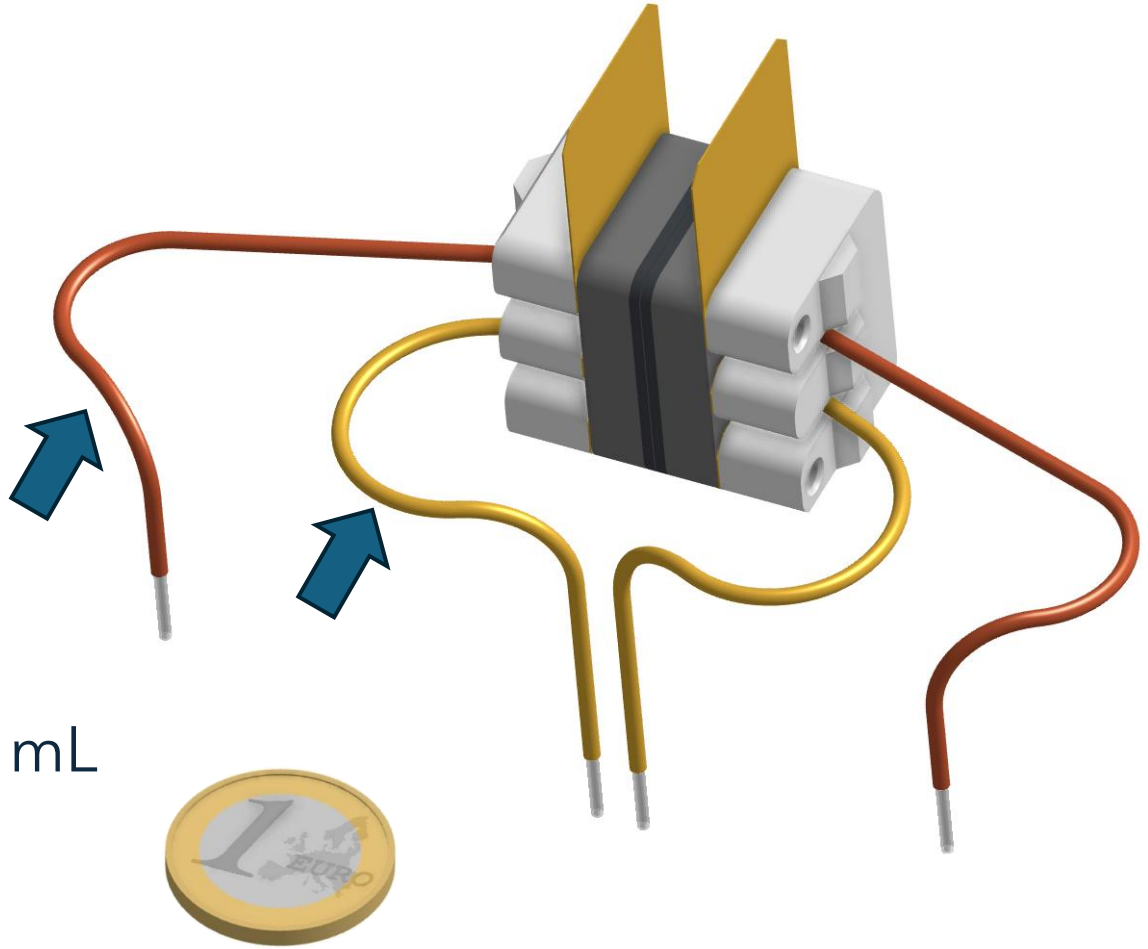
- **Miniaturized** form factor
- **Tiny dead volume** (in tubes) of 0.37 mL



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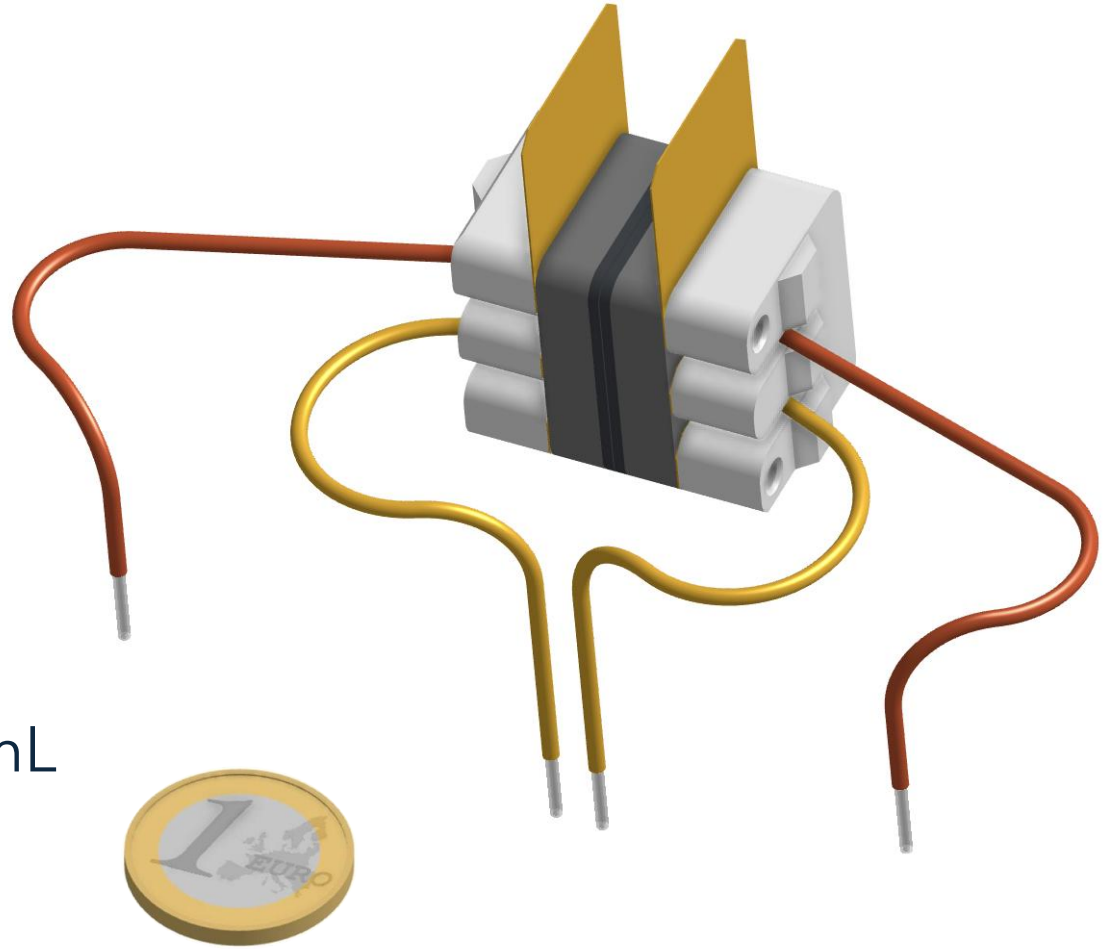
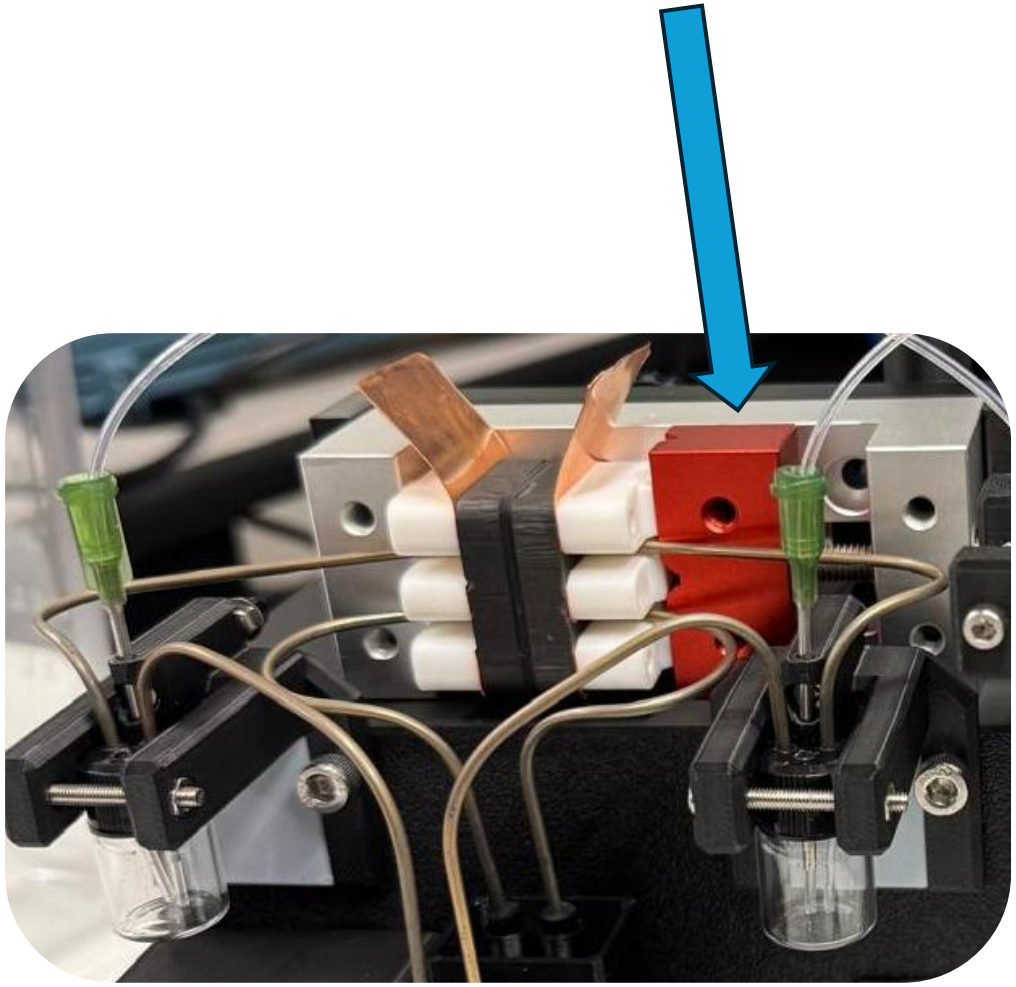
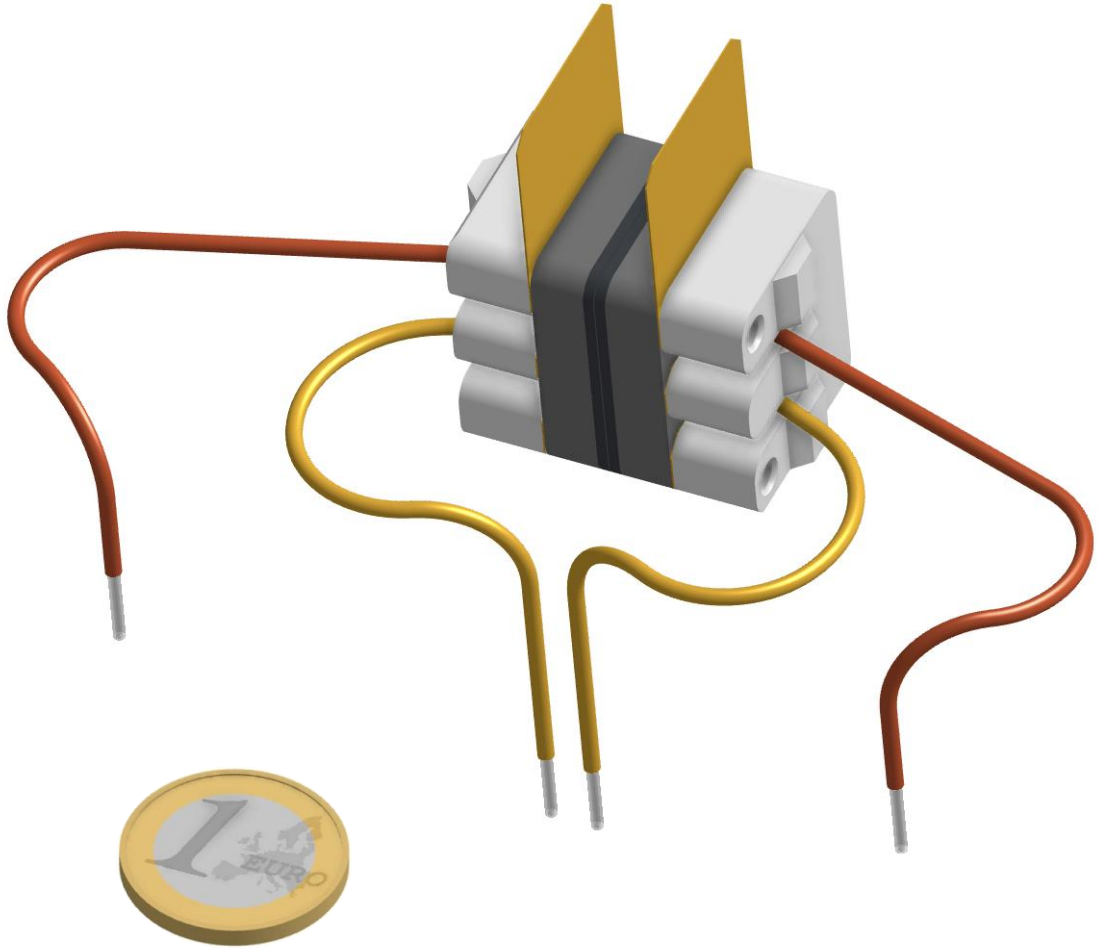
  - **Metric nuts / bolts / allen keys**
- **Miniaturized** form factor
- **Tiny dead volume** (in tubes) of 0.37 mL
- **Easy to modify** designs/parts in CAD



The Redoxino™ Test System: Clamped Cell

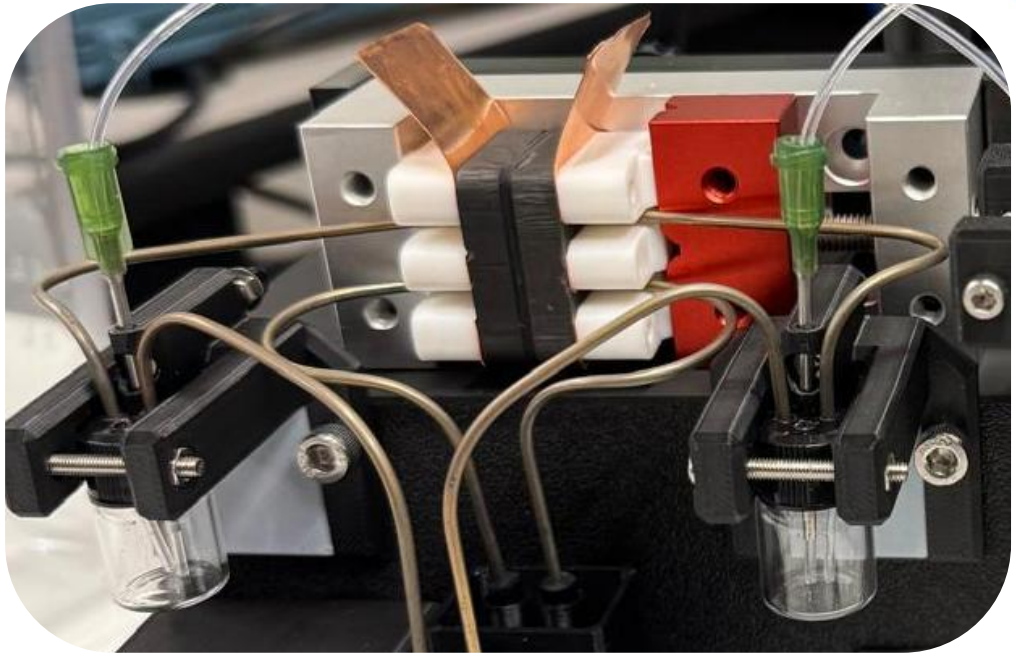
- **No bolts** – single screw clamp

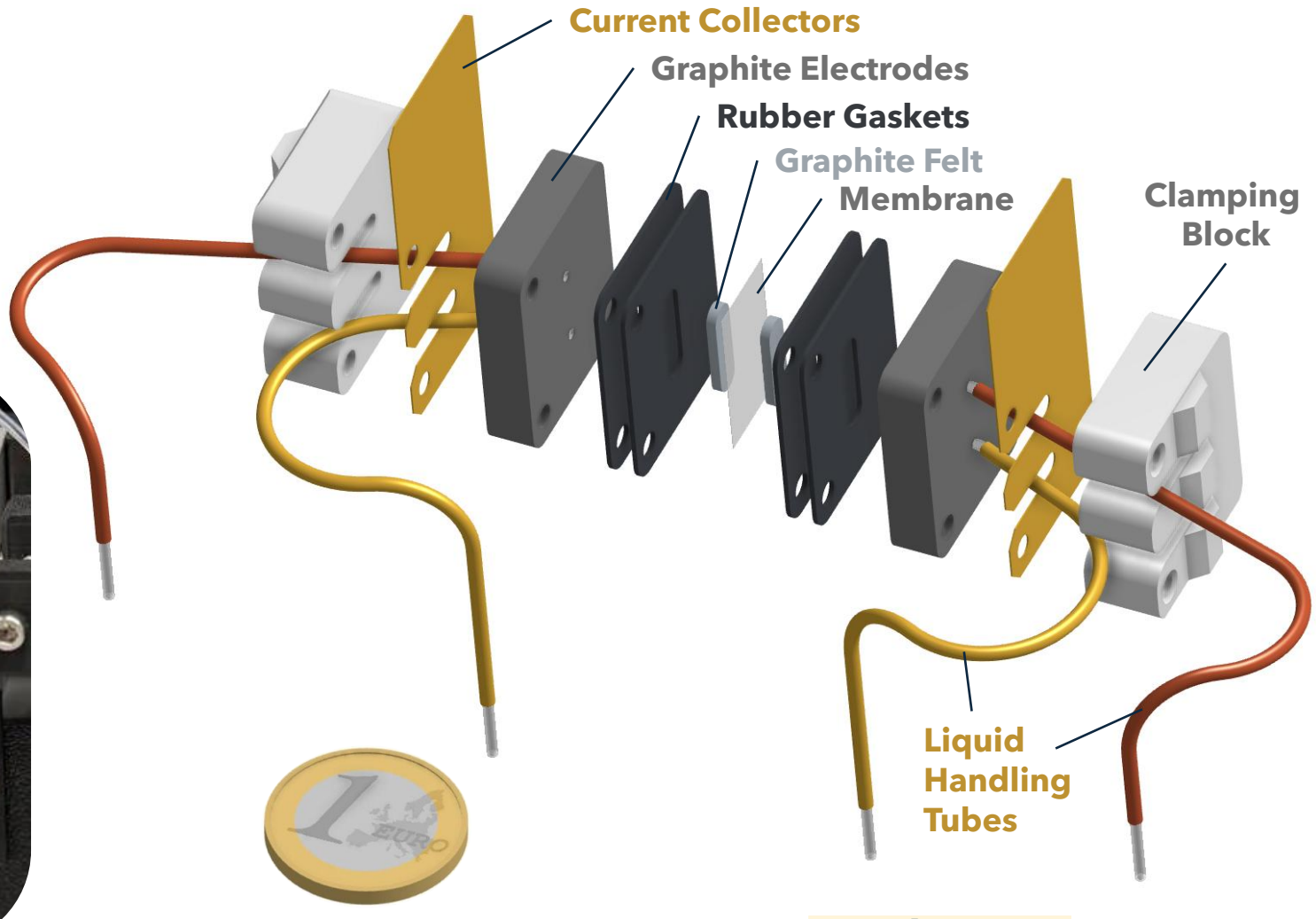




The Redoxino™ Test System: Clamped Cell

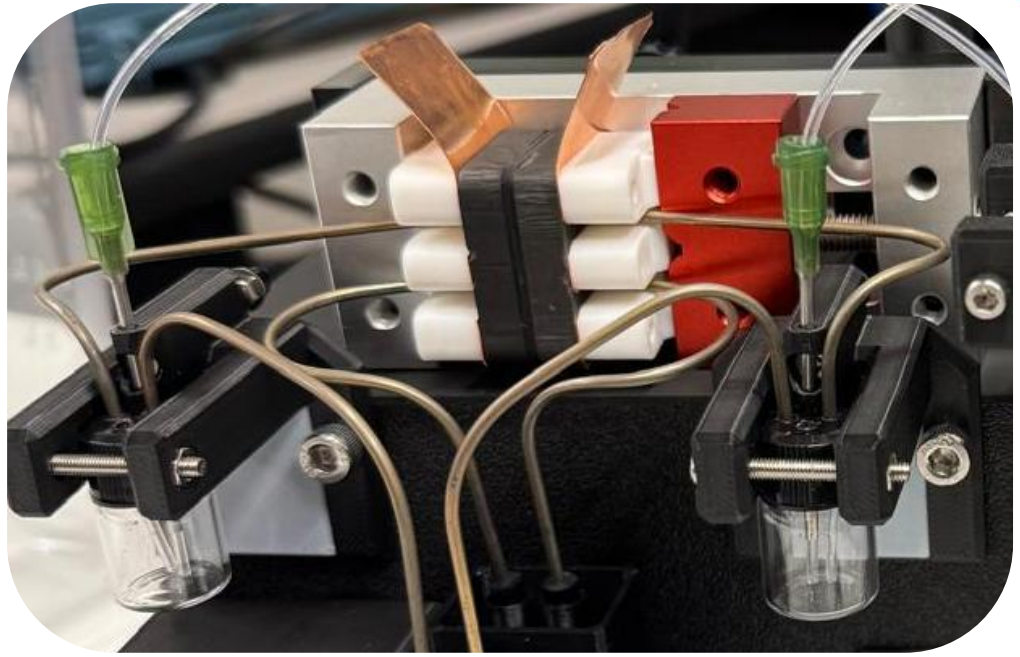
- No bolts – single screw clamp
- **Reduced # of parts** (12+)

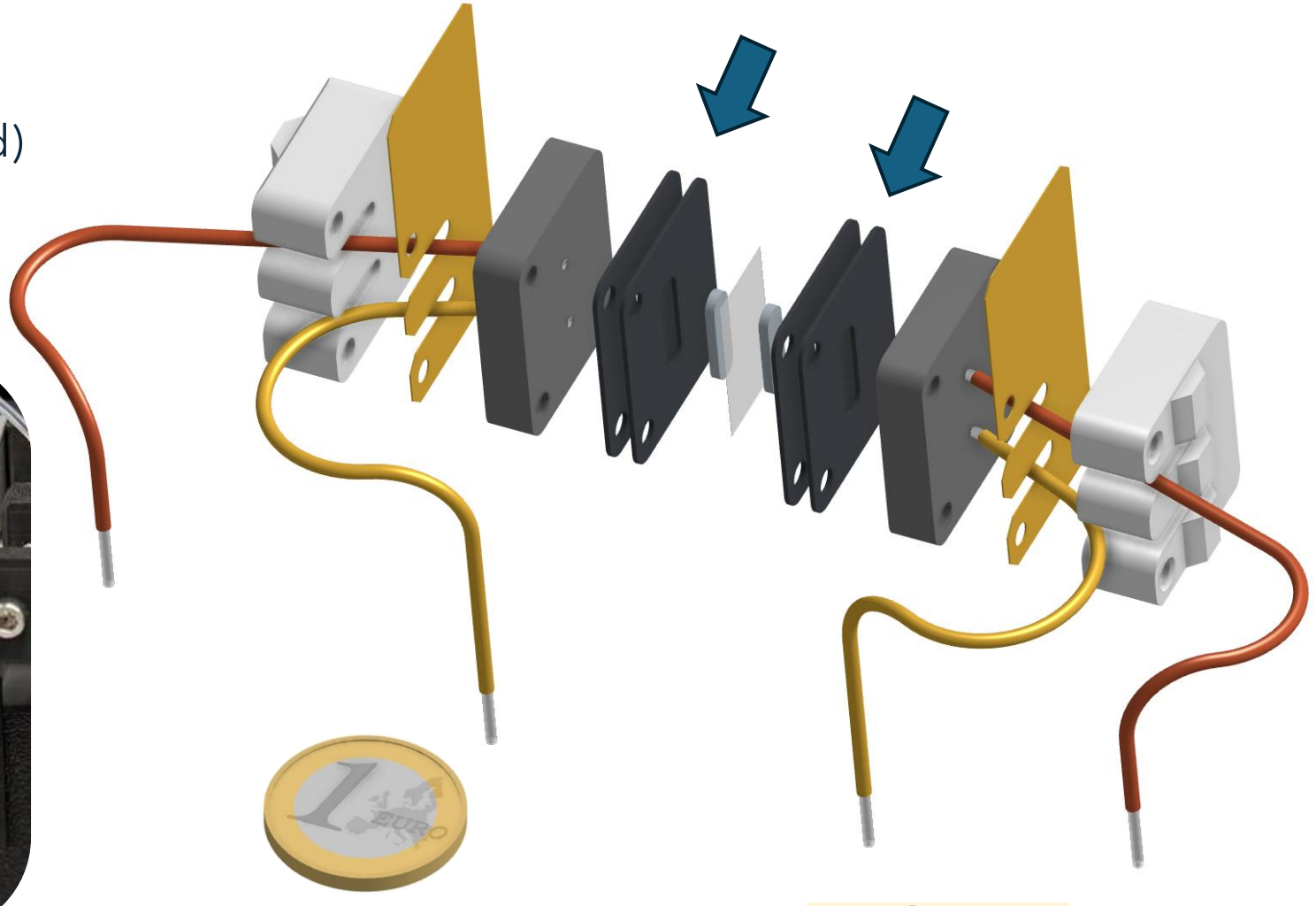




The Redoxino™ Test System: Clamped Cell

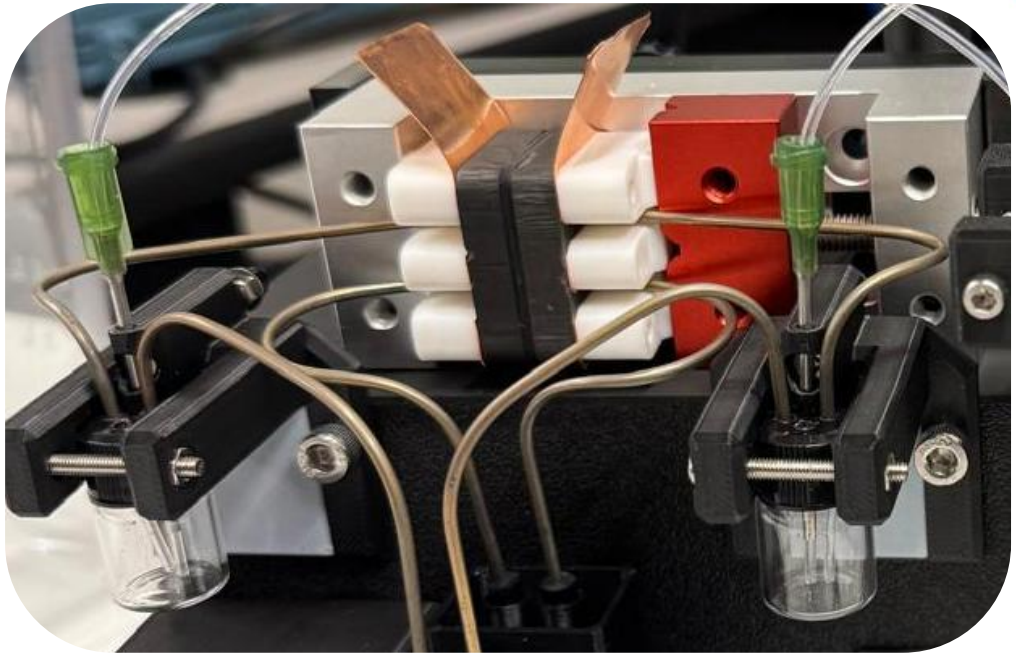
- No bolts – single screw clamp
- Reduced # of parts (12+)
- Flexible **gasket thickness** (also flow field)

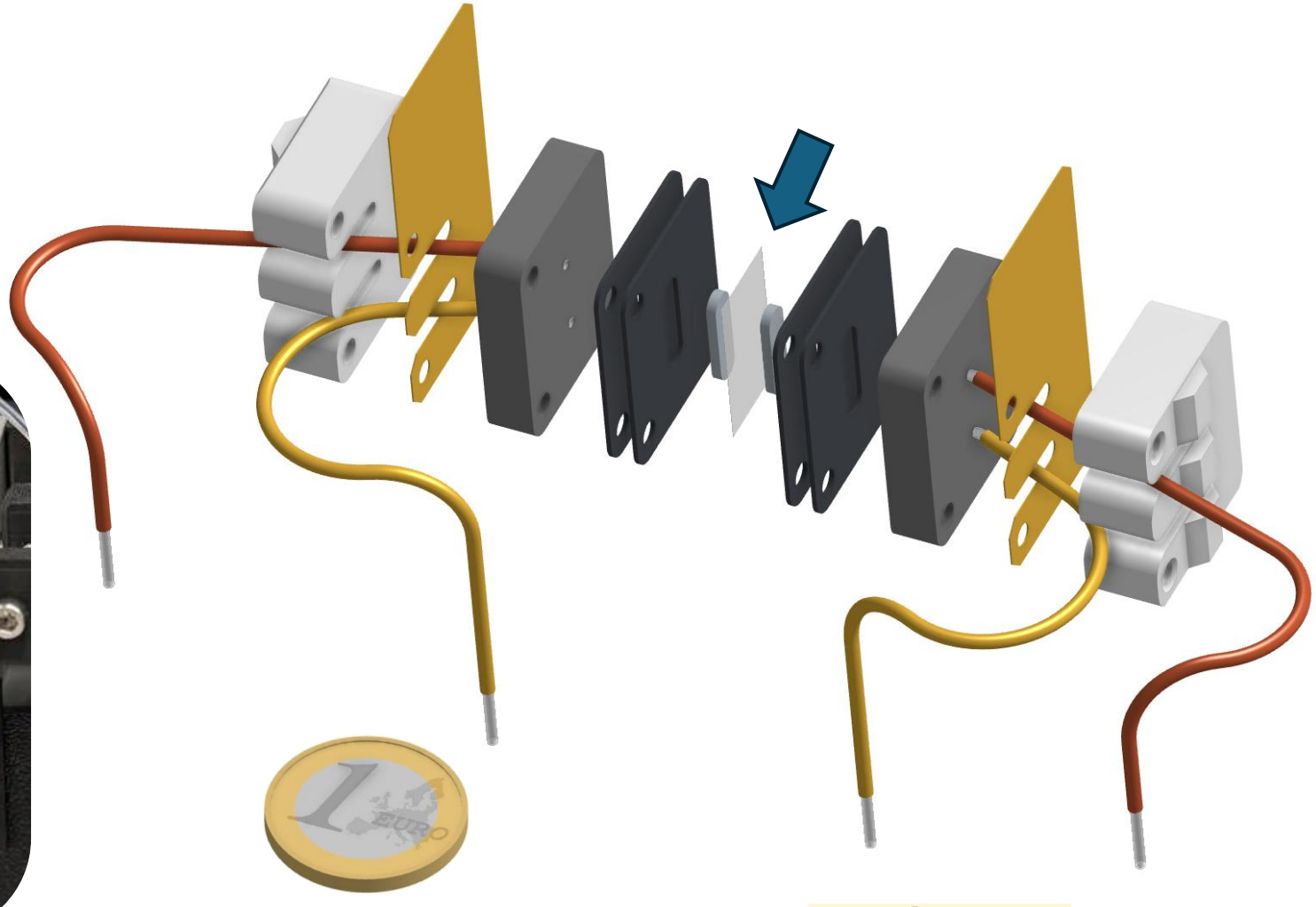




The Redoxino™ Test System: Clamped Cell

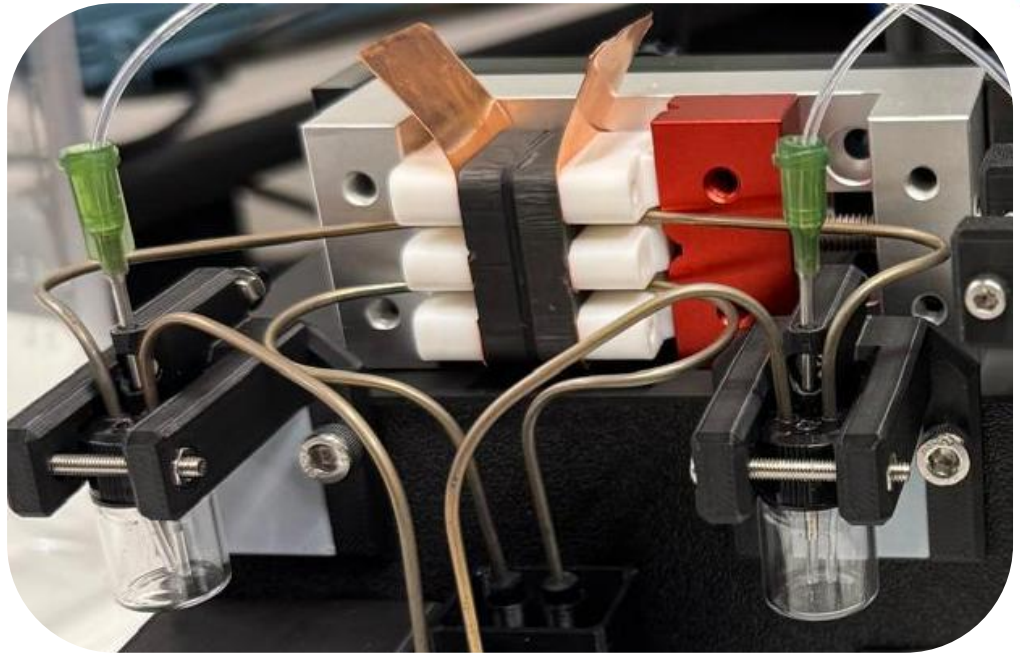
- No bolts – single screw clamp
- Reduced # of parts (12+)
- Flexible gasket thickness (also flow field)
- **Minimal membrane** (>2 cm^2) needed

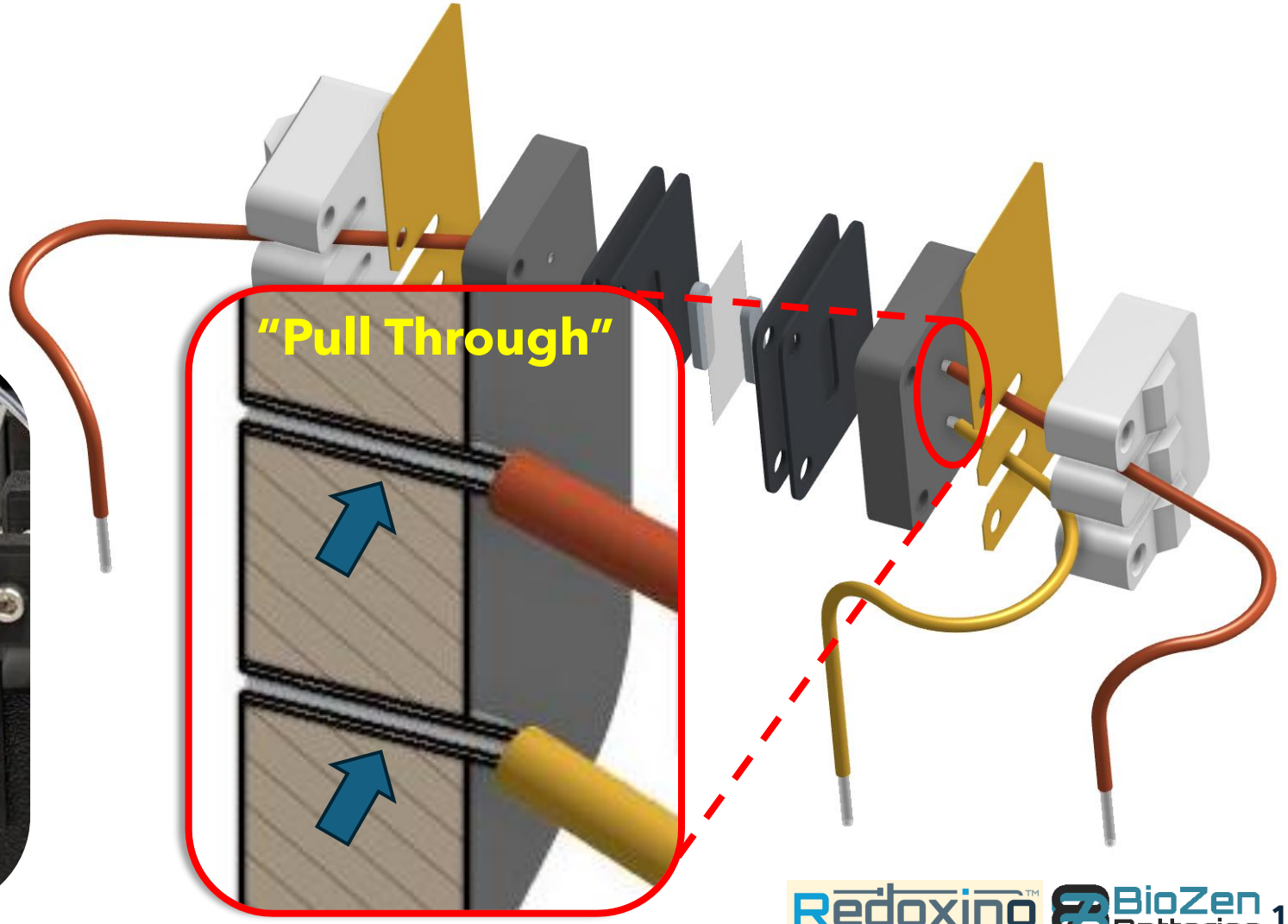




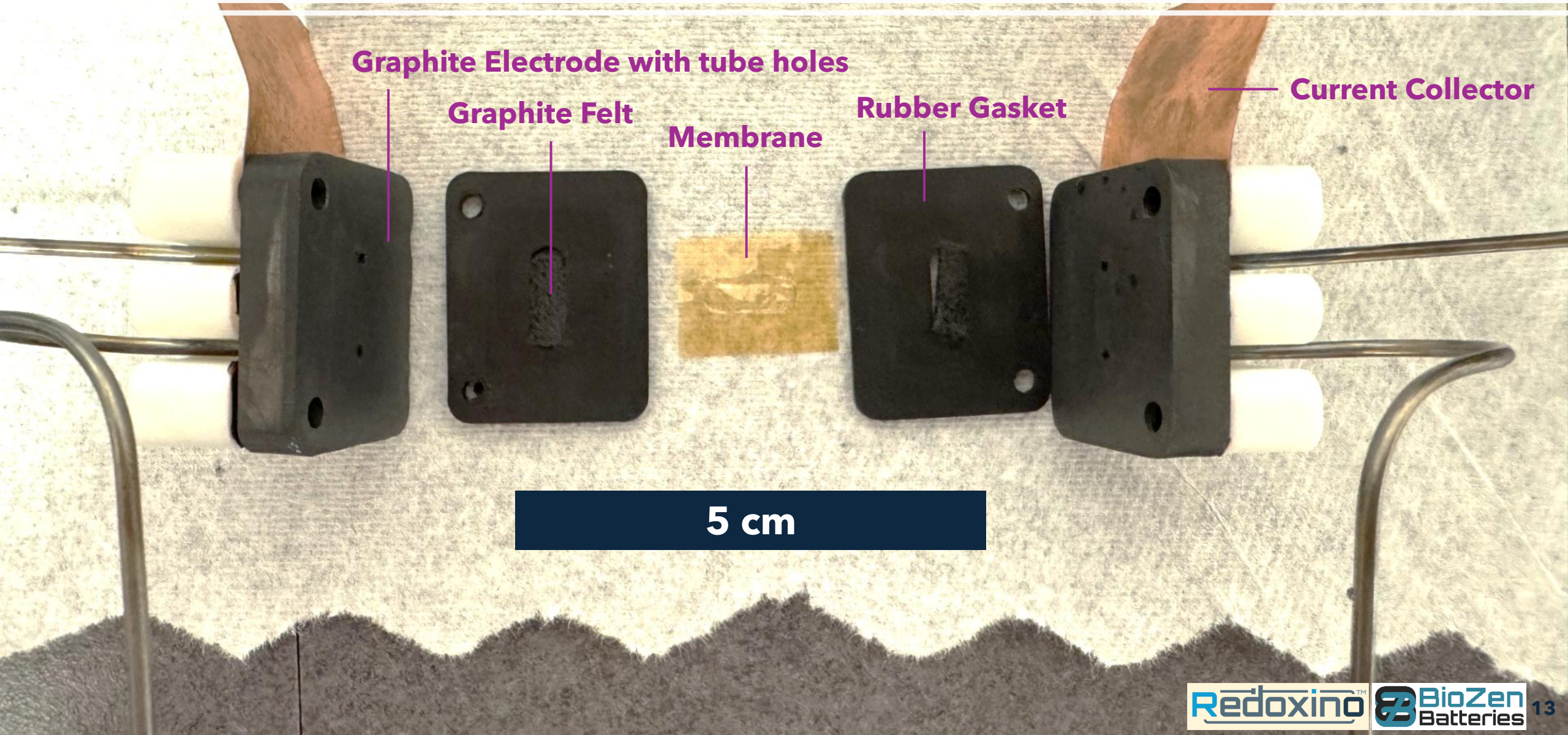
The Redoxino™ Test System: Clamped Cell

- No bolts – single screw clamp
- Reduced # of parts (12+)
- Flexible gasket thickness (also flow field)
- Minimal membrane (>2 cm^2) needed
- **Fittingless "Pull Through"** graphite electrode attachment to tubes



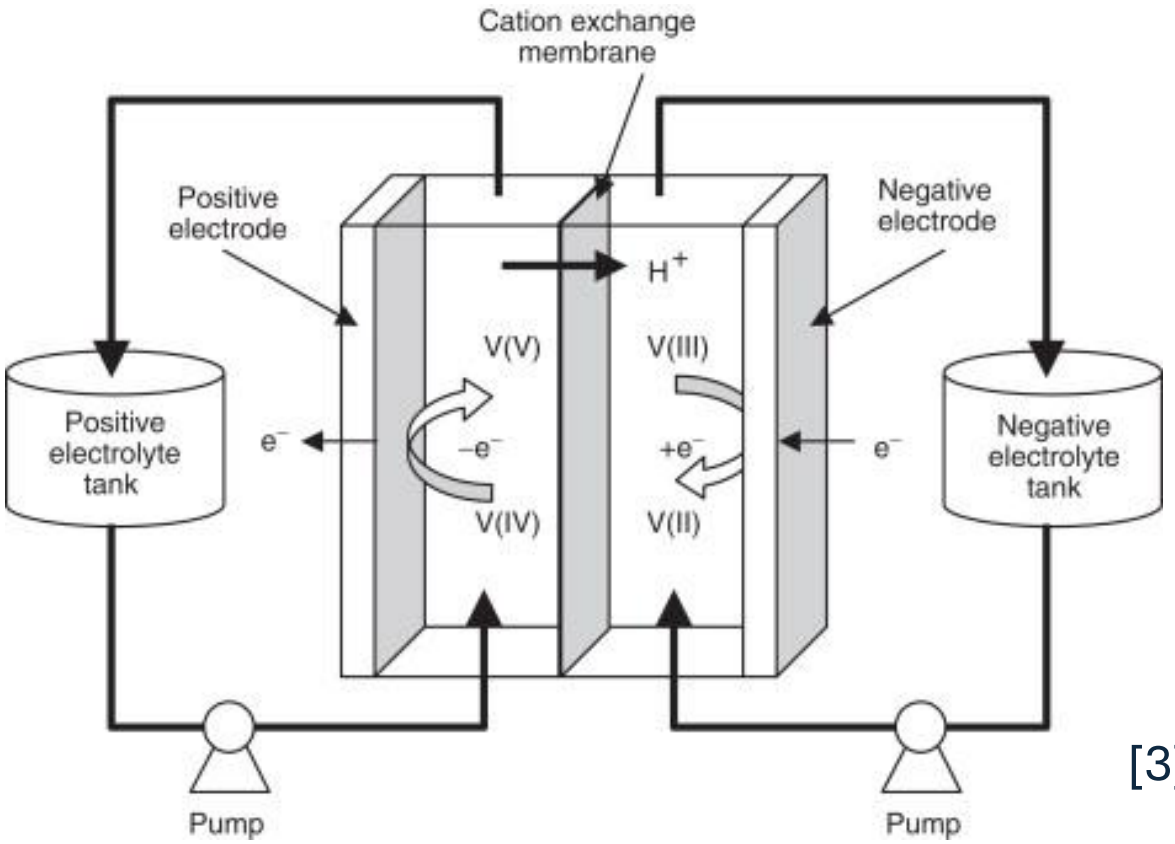


Redoxino™ Test System: Cell Stack Internal View

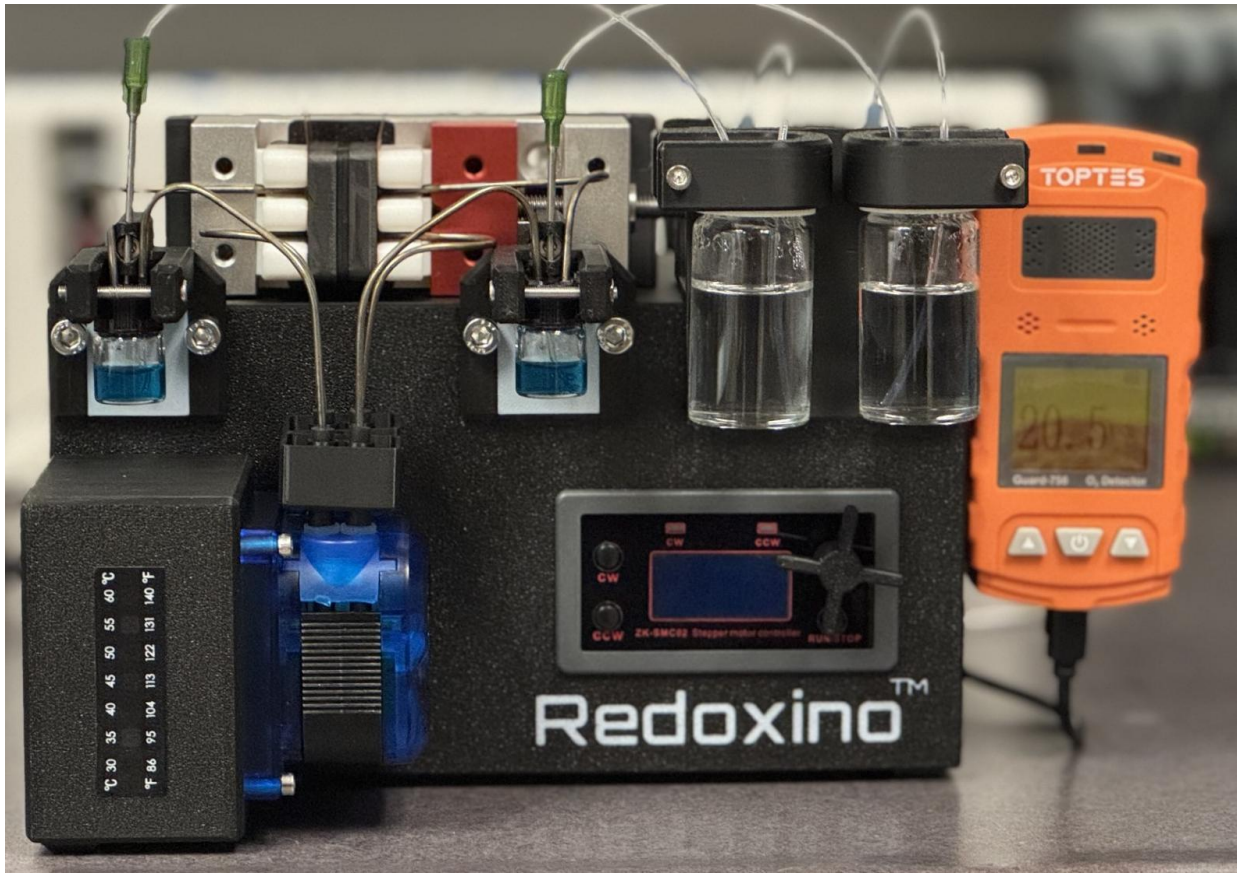


Redoxino™ Test System: a patent-pending fully-integrated miniscale flow battery

- It's patent-pending, but **we're making the design open source**



[3]



Multiplexing: 4 Systems fit easily on 1 bench

- Easy to assemble and begin cycling multiple units in the course of a single day
- **Can this small-volume, fast cycling device produce charge/discharge cycles that reproduce production-scale efficiencies?**

Vanadium Cycling Experiments: Vary Membrane & Electrode

Vanadium

Input Variables

Carbon Felt

- None
- As-received
- Annealed

  ← @ 500C

Membrane

- Nafion™ 212
- Nafion™ 117
- Sandia 20-179
- ENTEK CMJ011

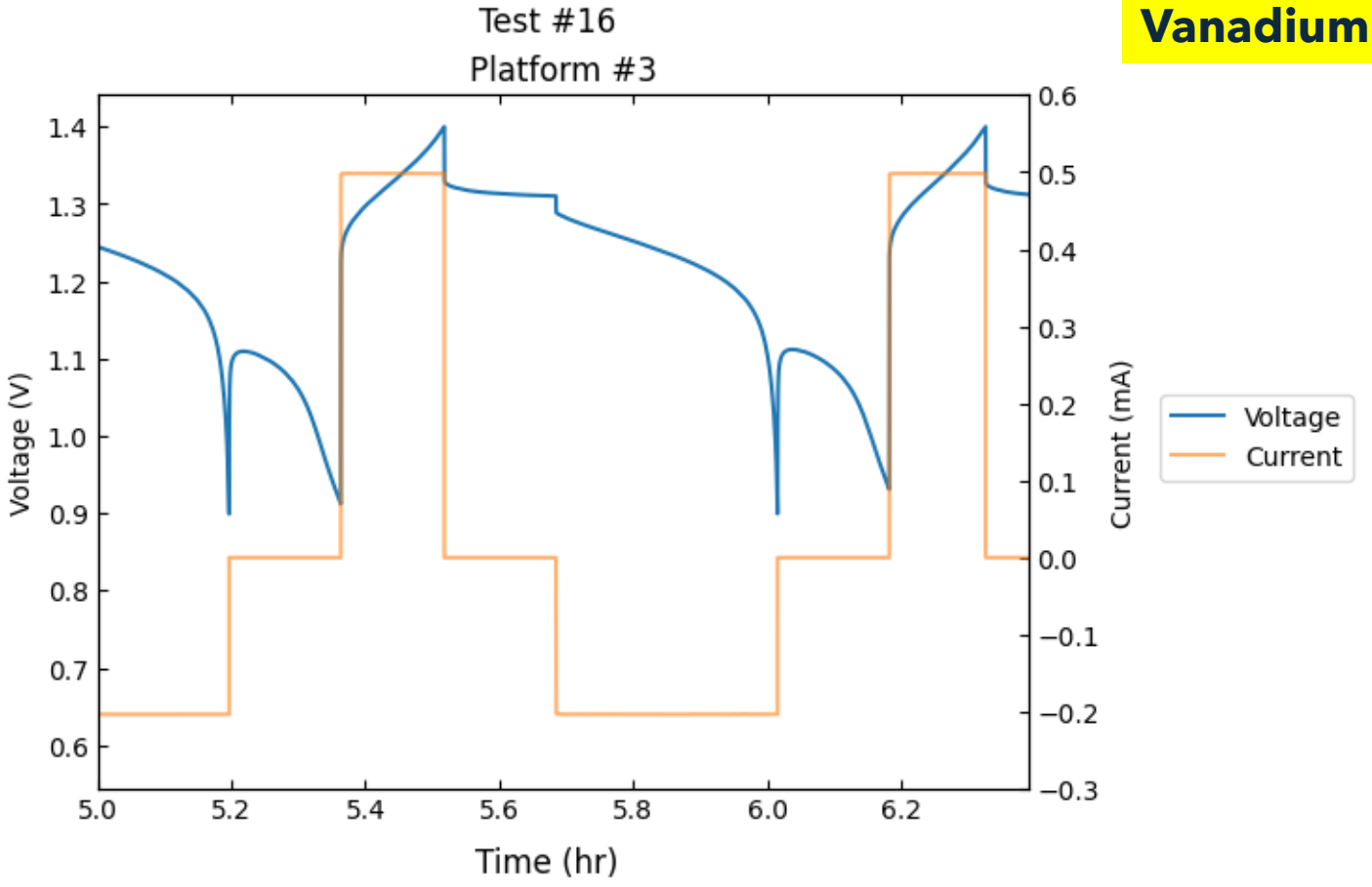
Response Variables

- Charge / discharge features
- Measured round trip efficiencies

Vanadium Electrolyte Shows Characteristic Charge/Discharge Features

Vanadium

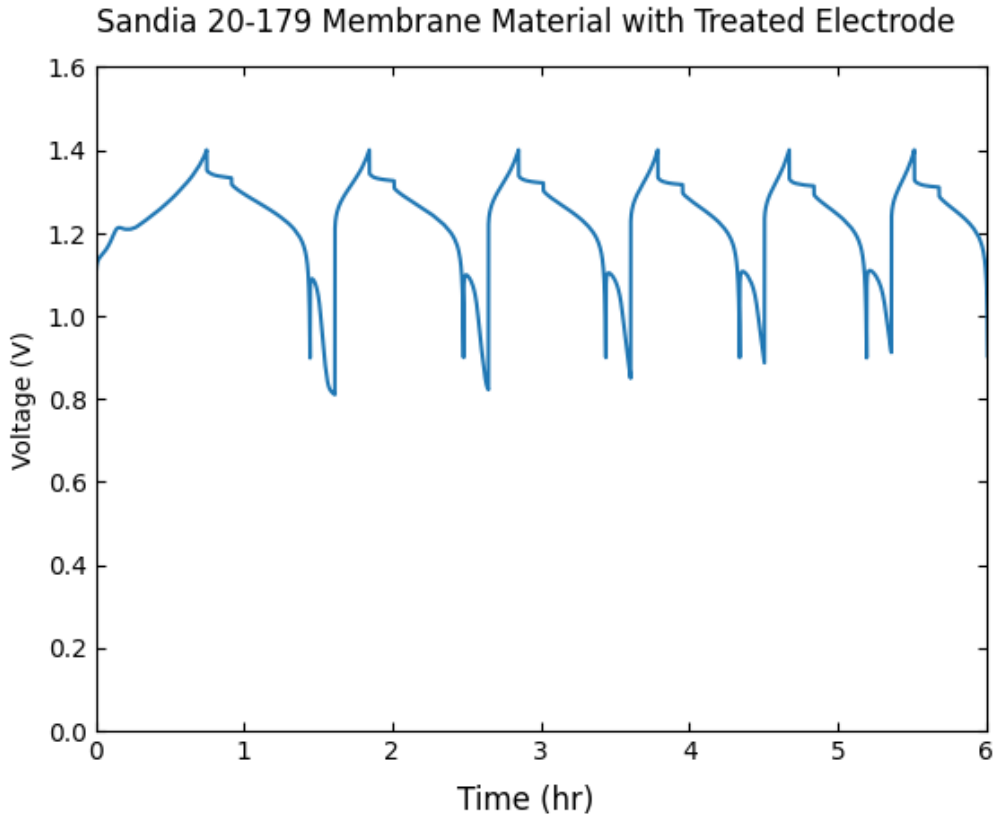
1. Charge at 500 µA to 1.4V
2. Hold at OCV
3. Discharge at -200 µA to 0.9V
4. Hold at OCV
5. Repeat

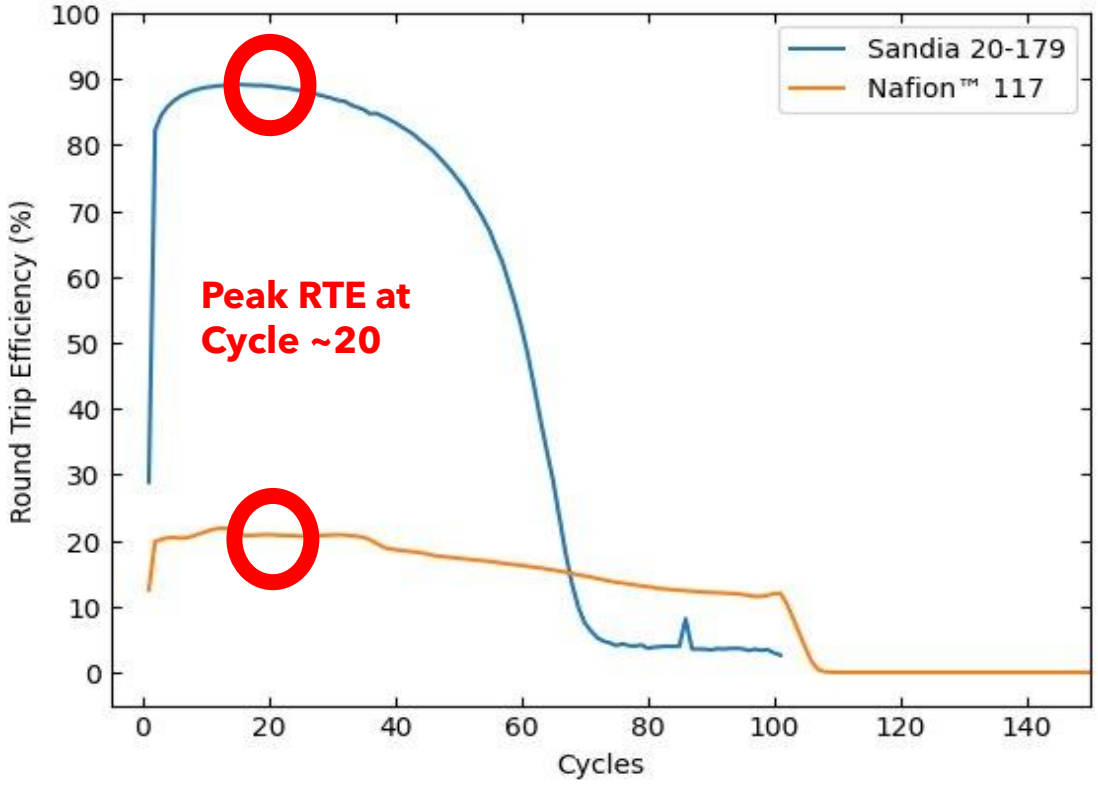


Some interesting / anomalous features suggest device and/or cycling scheme **improvements are possible**

Consistent Battery Performance and Reasonable Efficiency for 10's of cycles

Vanadium

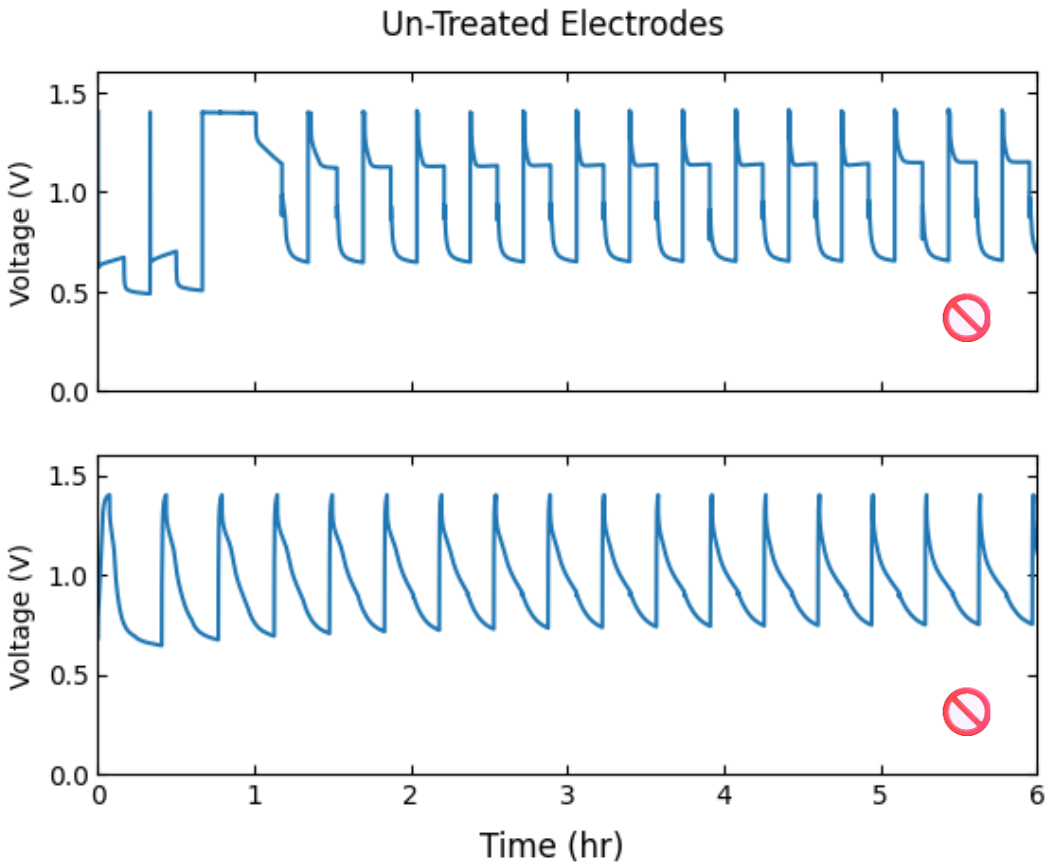


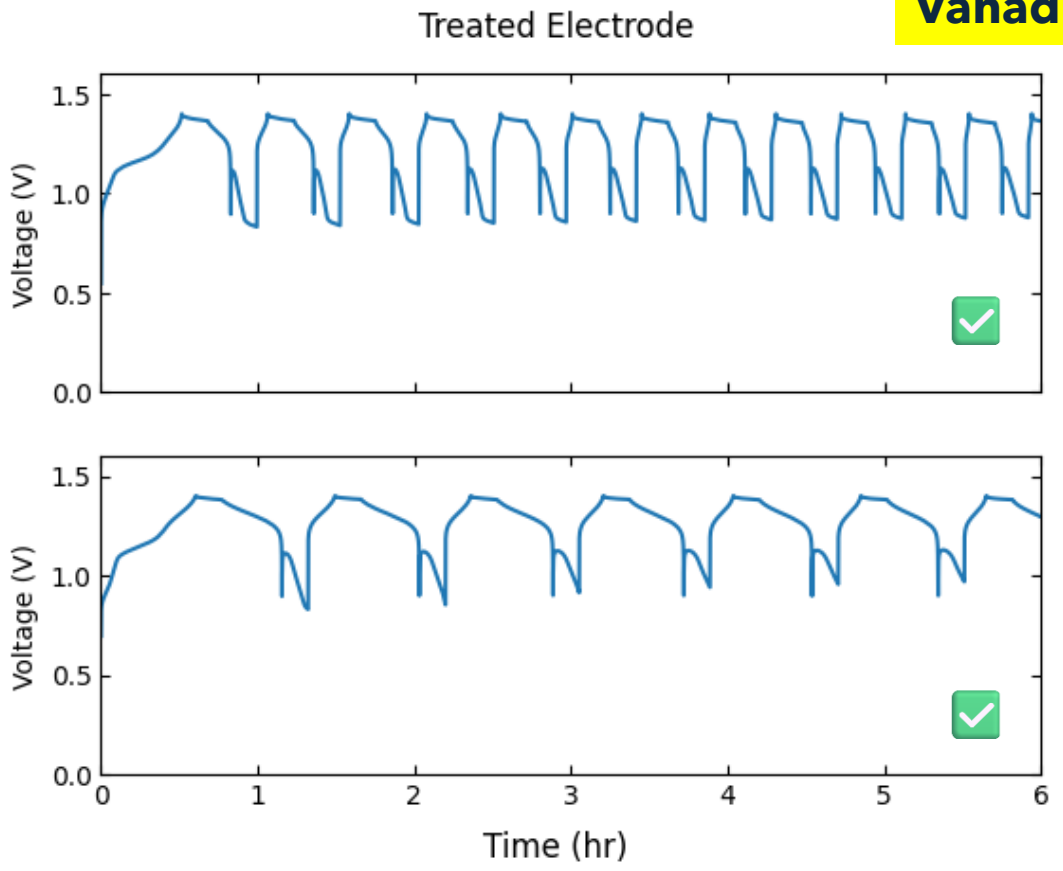


Goal: increasing this performance through device engineering improvements

Electrode Prep Increases Capacity & Consistency

Vanadium



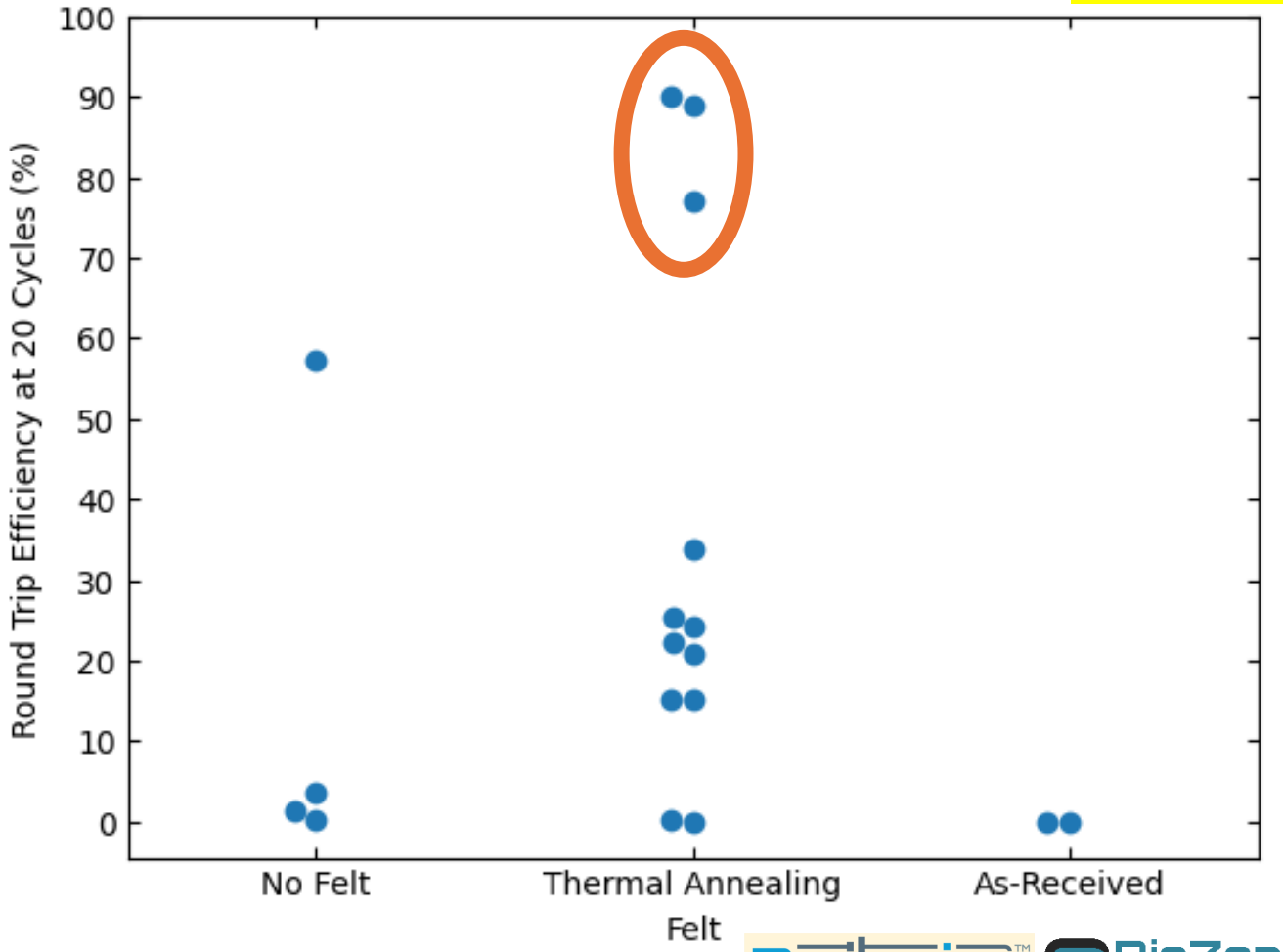


- **Graphite Electrode surfaced with mechanical abrasion**
- **Carbon felt thermally annealed**

Adding Carbon Felt + Thermal Annealing Greatly Improves Performance

Vanadium

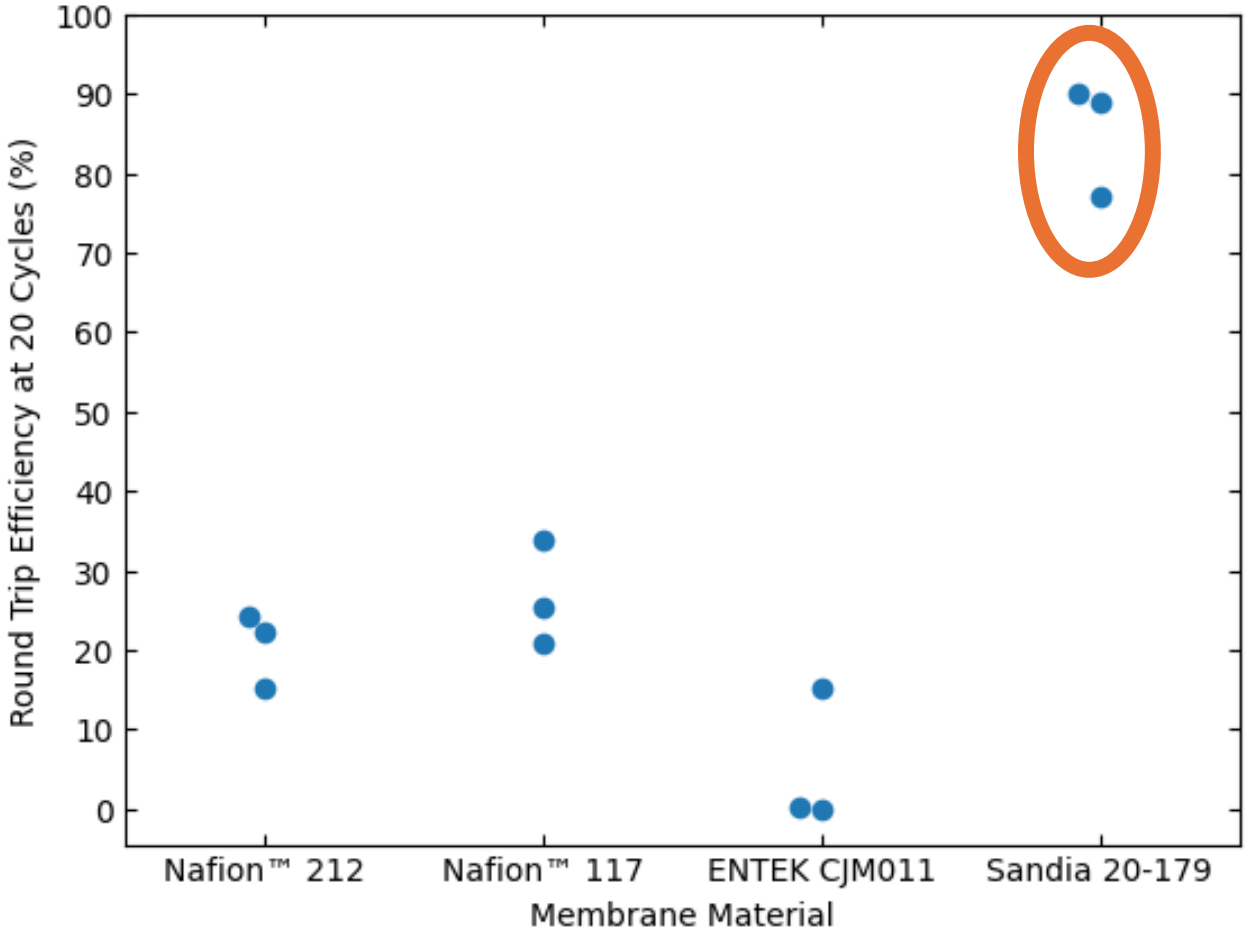
- Adding the carbon felt:
  - Increases electrode surface area for redox reactions
  - Increases the charge transfer efficiency
- Treating the Carbon Felt:
  - As-received felt → extremely poor RTE
  - **Annealed felt → higher RTE results**



Membrane Choice: Big Performance Impact

- Compared membranes with **same electrode treatment**
- Recorded **small data spread** for each material, demonstrating consistency
- **Membrane provided by Sandia National Labs performed best with ~80% RTE**

Vanadium



Aqueous Organic Cycling data: Vary Membrane and Composition (*Currently still running in CA*)

Organic

Input Variables

Electrolyte

- **Separate** P/N
- **Mixed** P/N

0.2 M $(NH_4)_2SO_4$ supporting

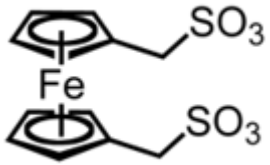
Membrane

- **Nafion™** 212
- **Sandia** 20-179

Response Variables

- Charge / discharge features
- Measured RTEs (*to be calculated*)

P



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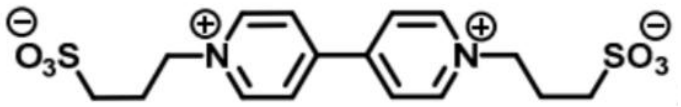
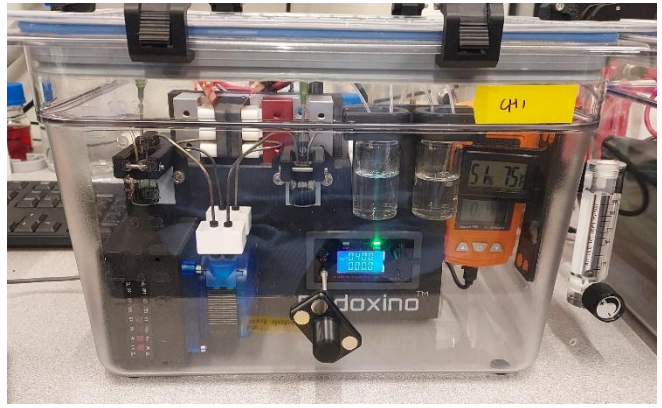


Mixed

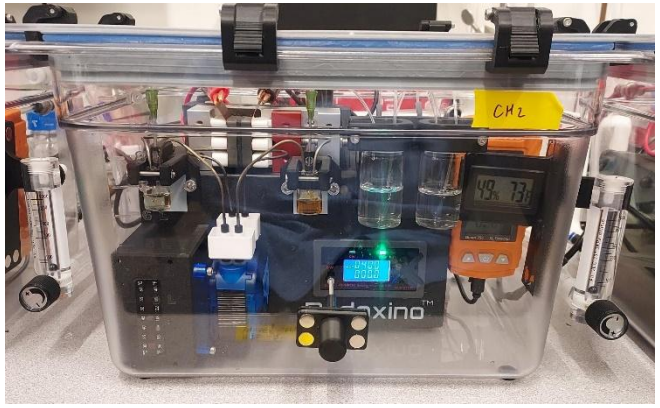
Organic cycling: 4 separate test conditions
No recirculation, tiny 40 uAh capacity

Organic

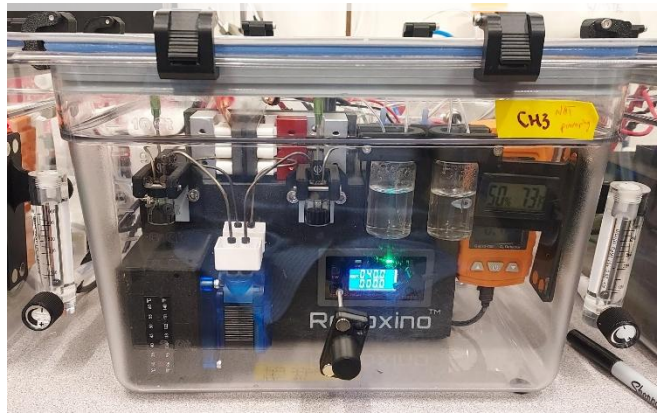
Ch 1 : Sandia Membrane + Mixed P/N



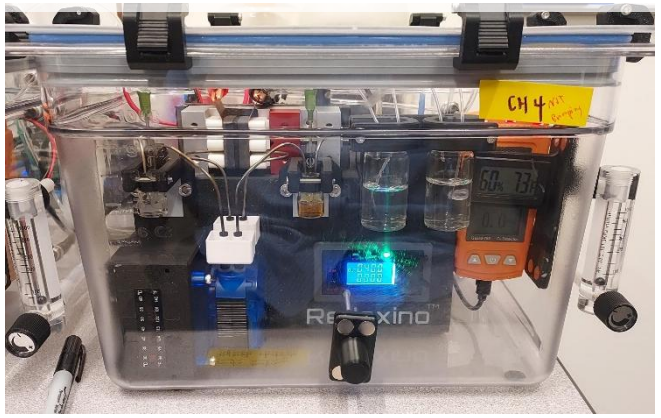
Ch 2: Nafion™ Membrane + Separate P/N



Ch 3: Nafion™ Membrane + Mixed P/N



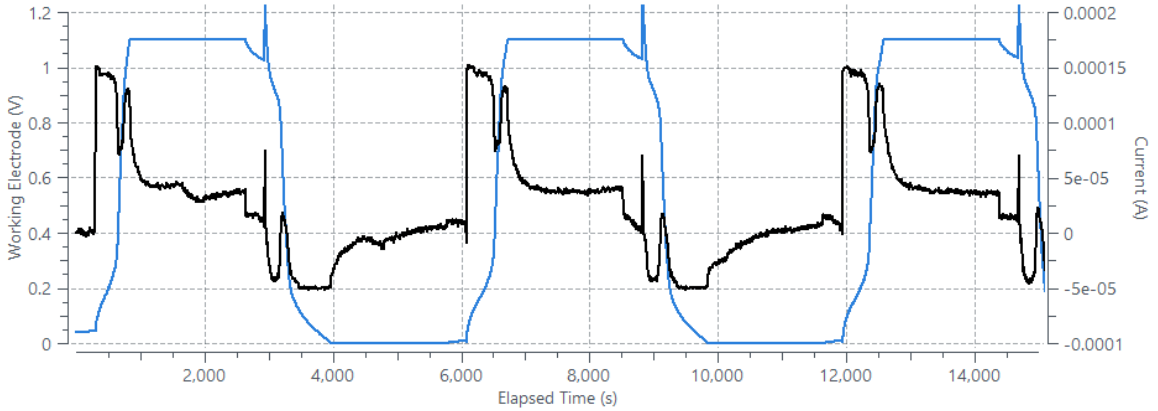
Ch 4: Sandia Membrane + Separate P/N



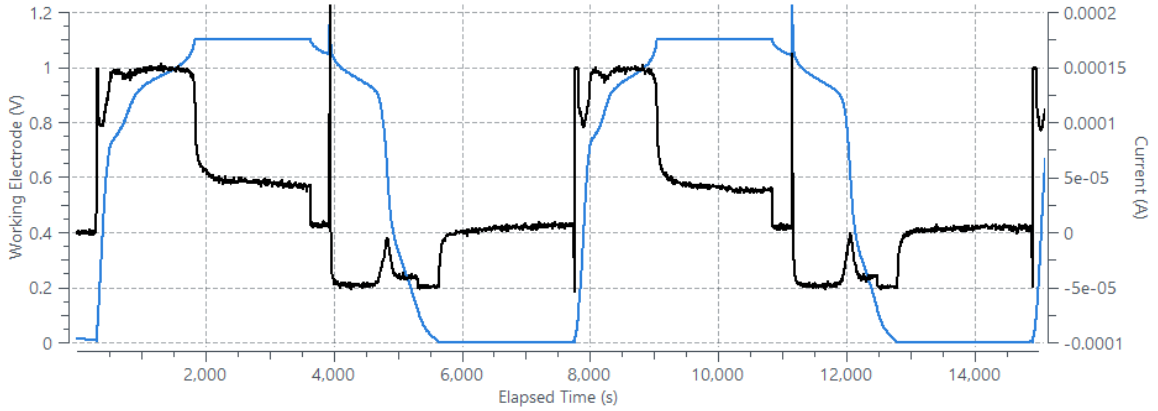
Organic cycling: Cycles are consistent for each experimental condition & separate P/N is better

Organic

Ch 1 : Sandia Membrane + Mixed P/N



Ch 2: Nafion™ Membrane + Separate P/N



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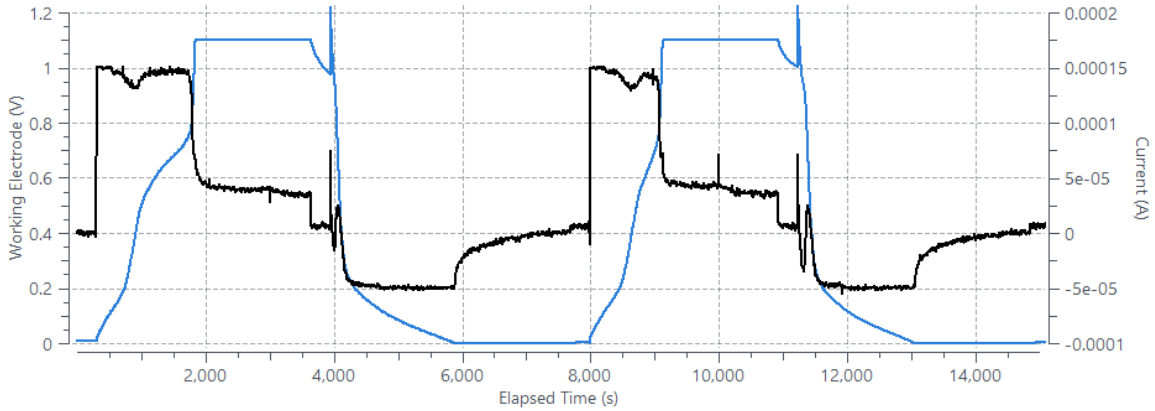
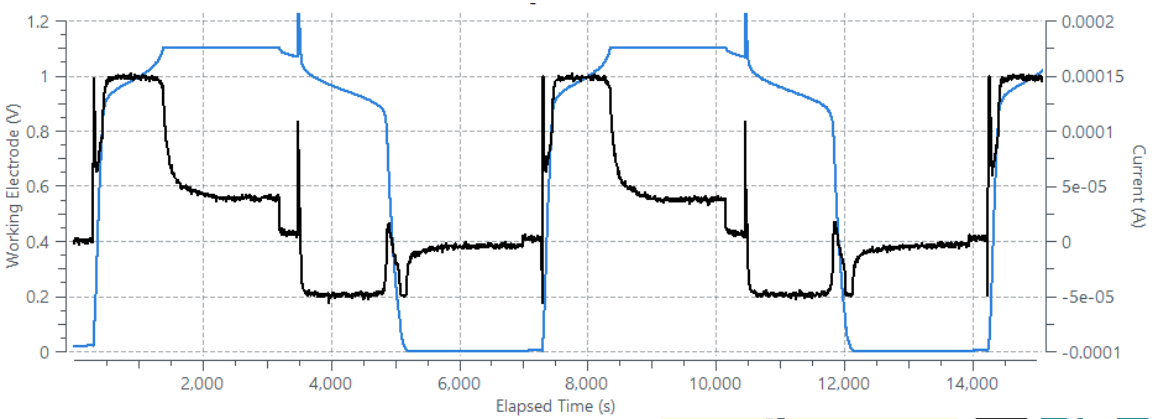


Ch 4: Sandia Membrane + Separate P/N

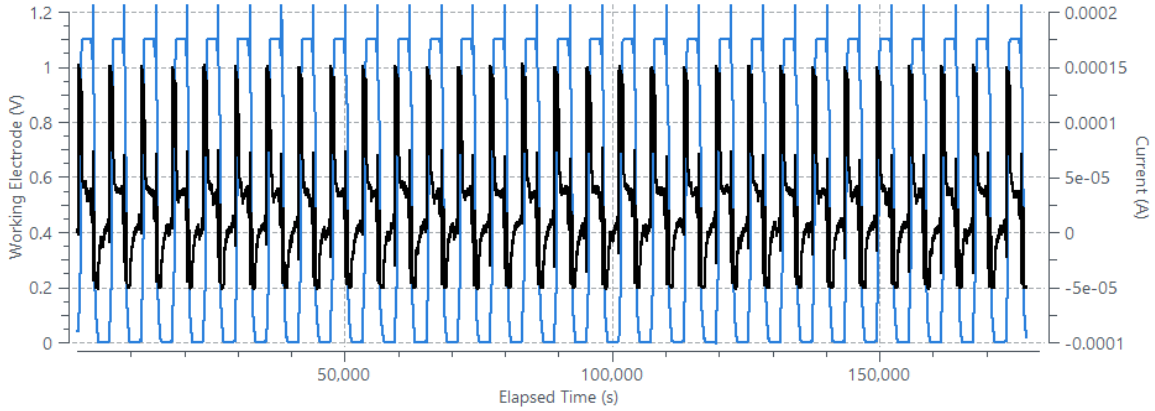


Voltage — Current

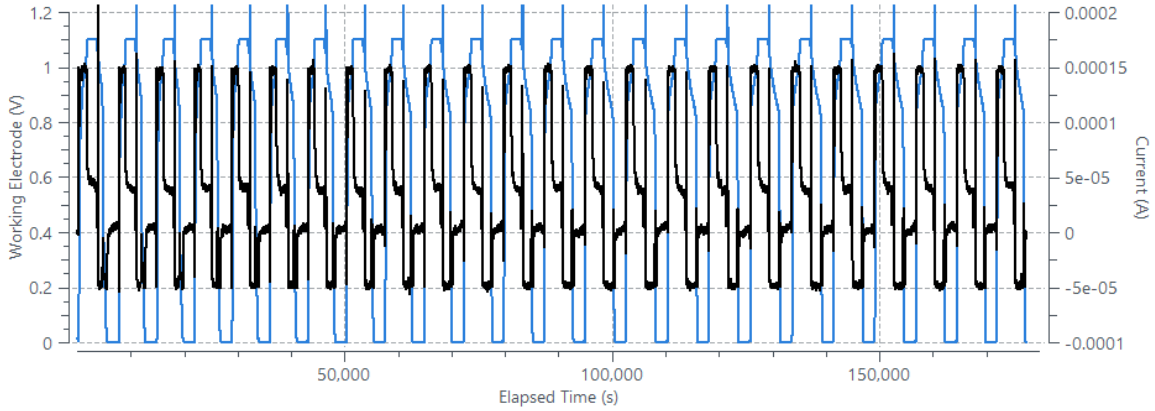
Organic cycling: RTE does not seem great (yet) but cycles are consistent over many days

Organic

Ch 1 : Sandia Membrane + Mixed P/N



Ch 2: Nafion™ Membrane + Separate P/N



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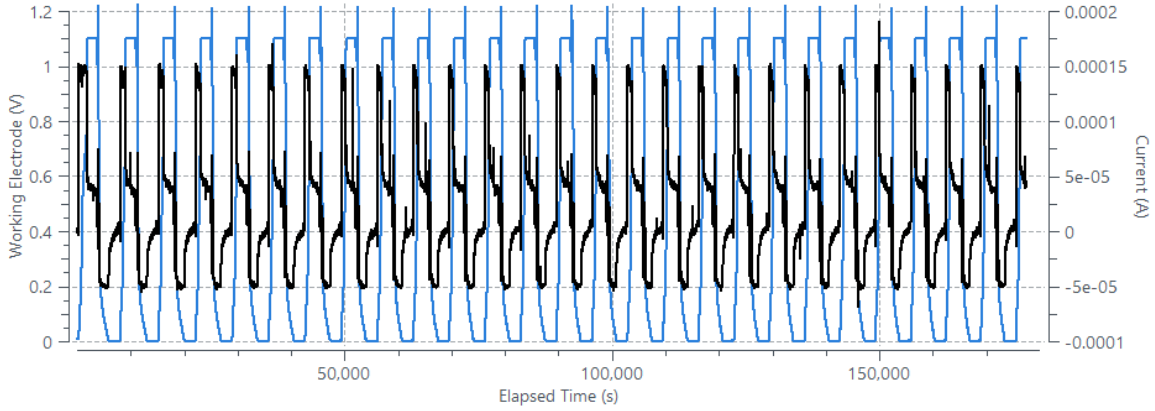

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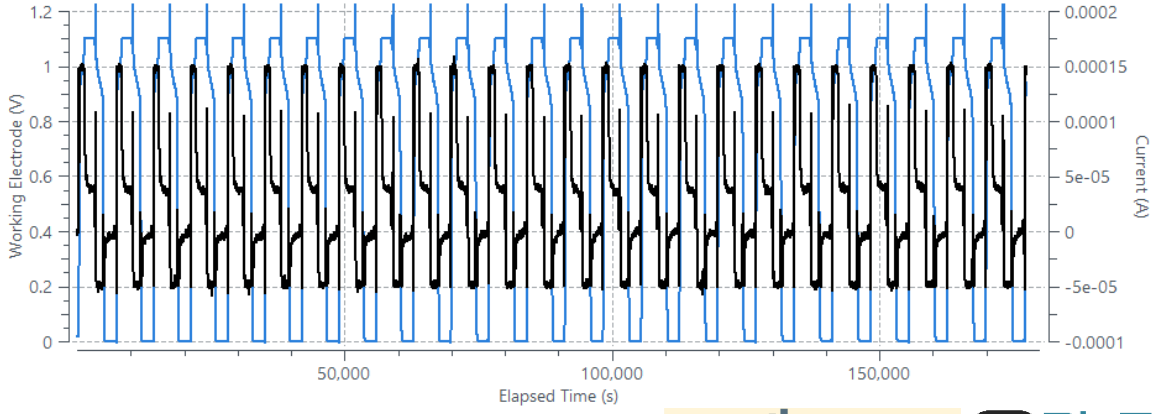
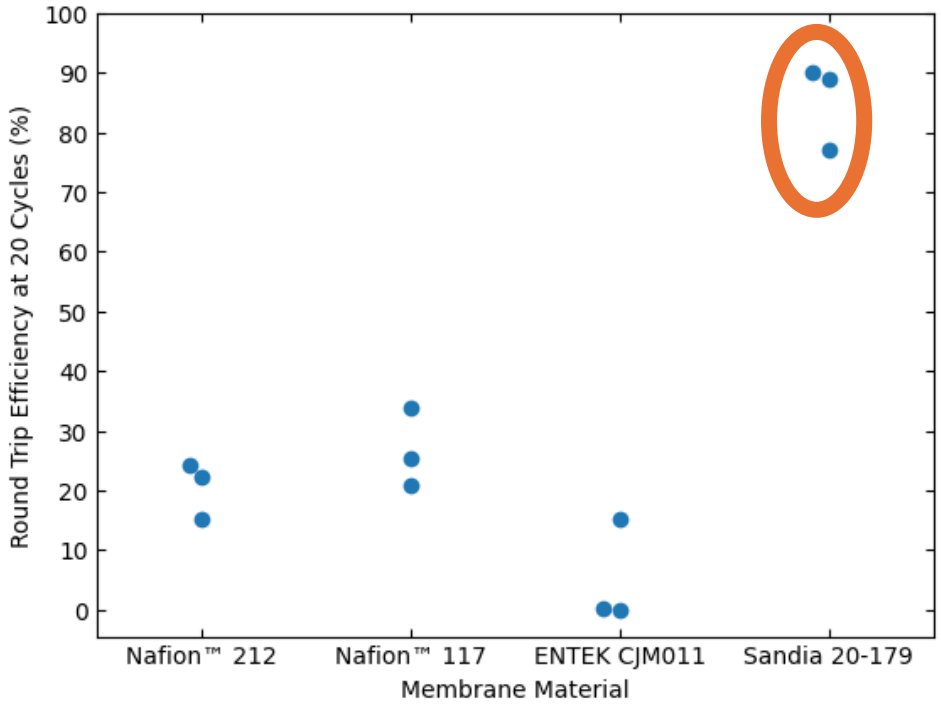


Voltage Current

Conclusions

- Cycling **consistent** between devices
- Achieved limited cycles of ~80% RTE with vanadium, consistent with literature [4]
- **Thermally annealed carbon felt** is best
- **Sandia membrane best** for vanadium
- **Electrode Surface Preparation**: cleaning the surfaces after each test is most effective
- **Separate P/N organic composition** is best, no obvious difference b/t Nafion/Sandia
- Still **optimizing parameters and collecting data for organic devices** with BioZen's proprietary ***Redoxolyte Electrolytes***



Future Works

1. Continued data collection to improve statistical power
2. Test using an industry standard **vanadium electrolyte**
3. Use Redoxino™ Test Systems to further explore novel **aqueous organic chemistries**
4. Investigate current collector contact resistance and performance optimization
5. Make fully open-source available at **redoxino.com**

References

[1] B. P. and N. Popovich, “Giant batteries are transforming the way the U.S. uses electricity,” The New York Times, https://www.nytimes.com/interactive/2024/05/07/climate/battery-electricity-solar-california-texas.html (accessed May 4, 2025).

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