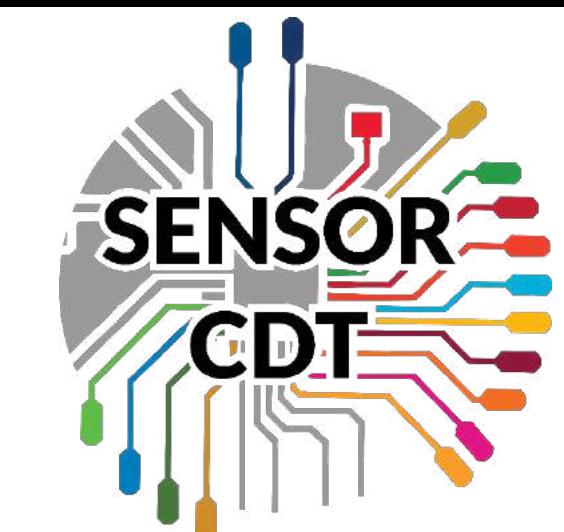
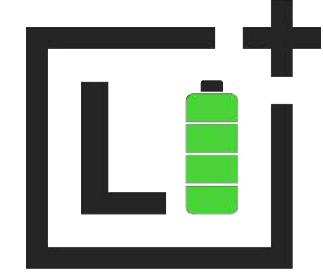




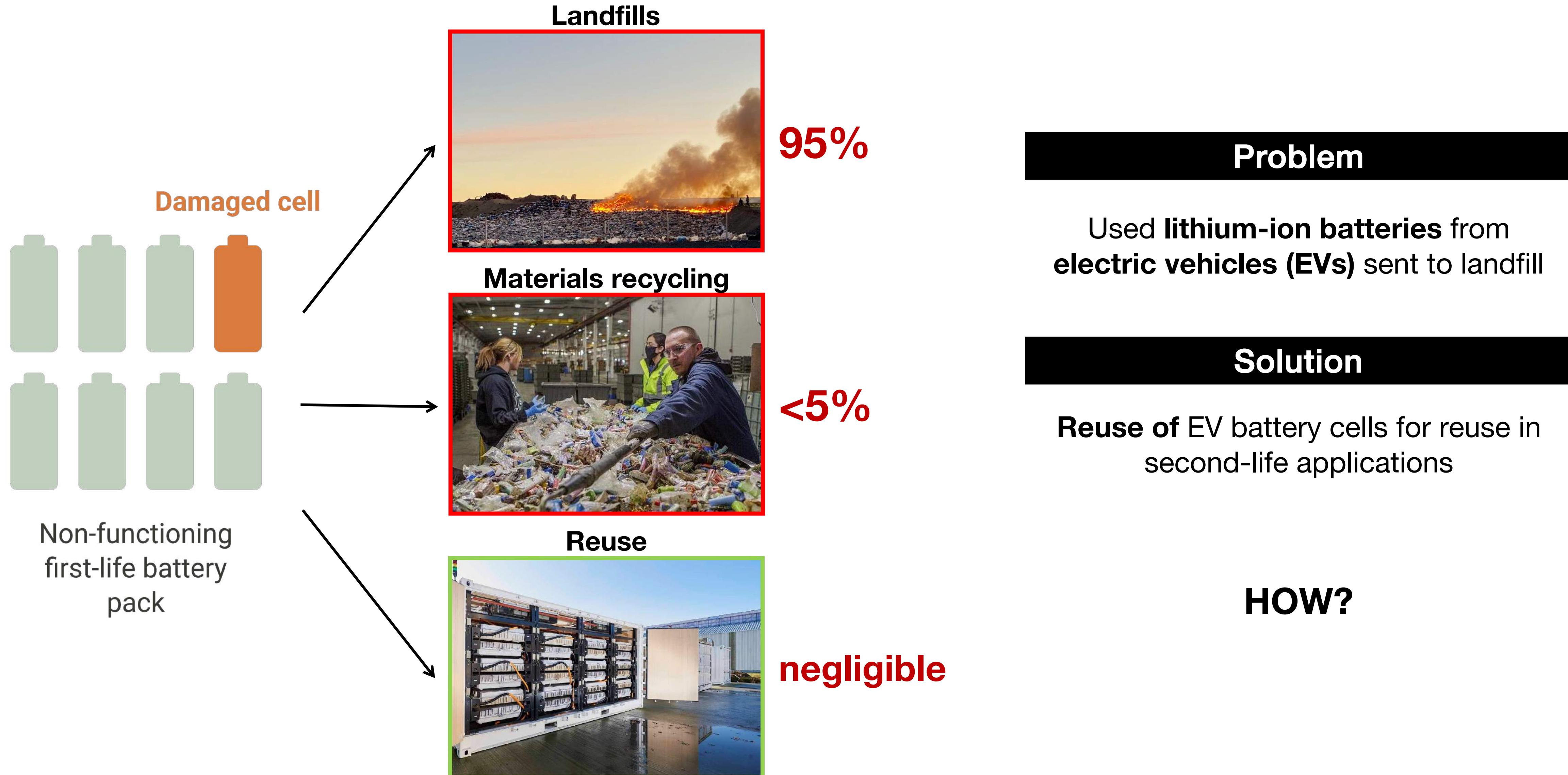
Low-cost, open-source lithium-ion cell health assessment

Enabling second-life battery production

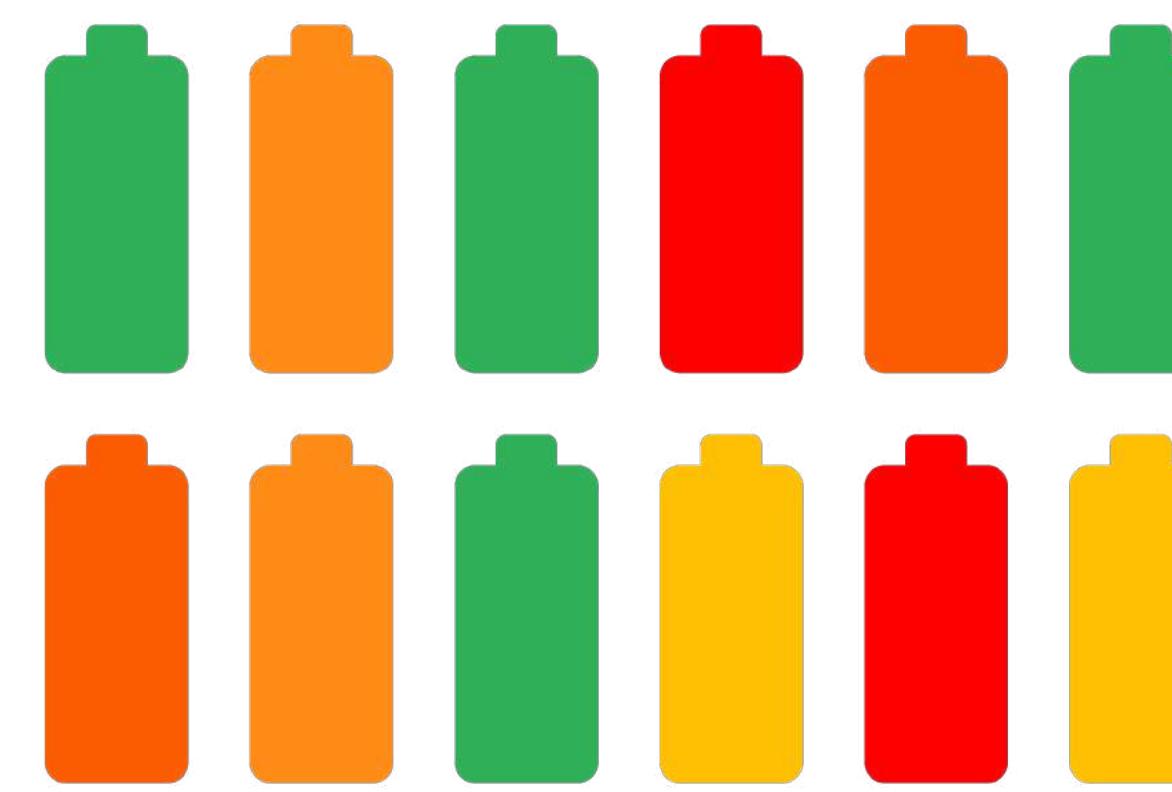
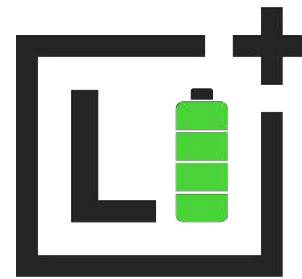




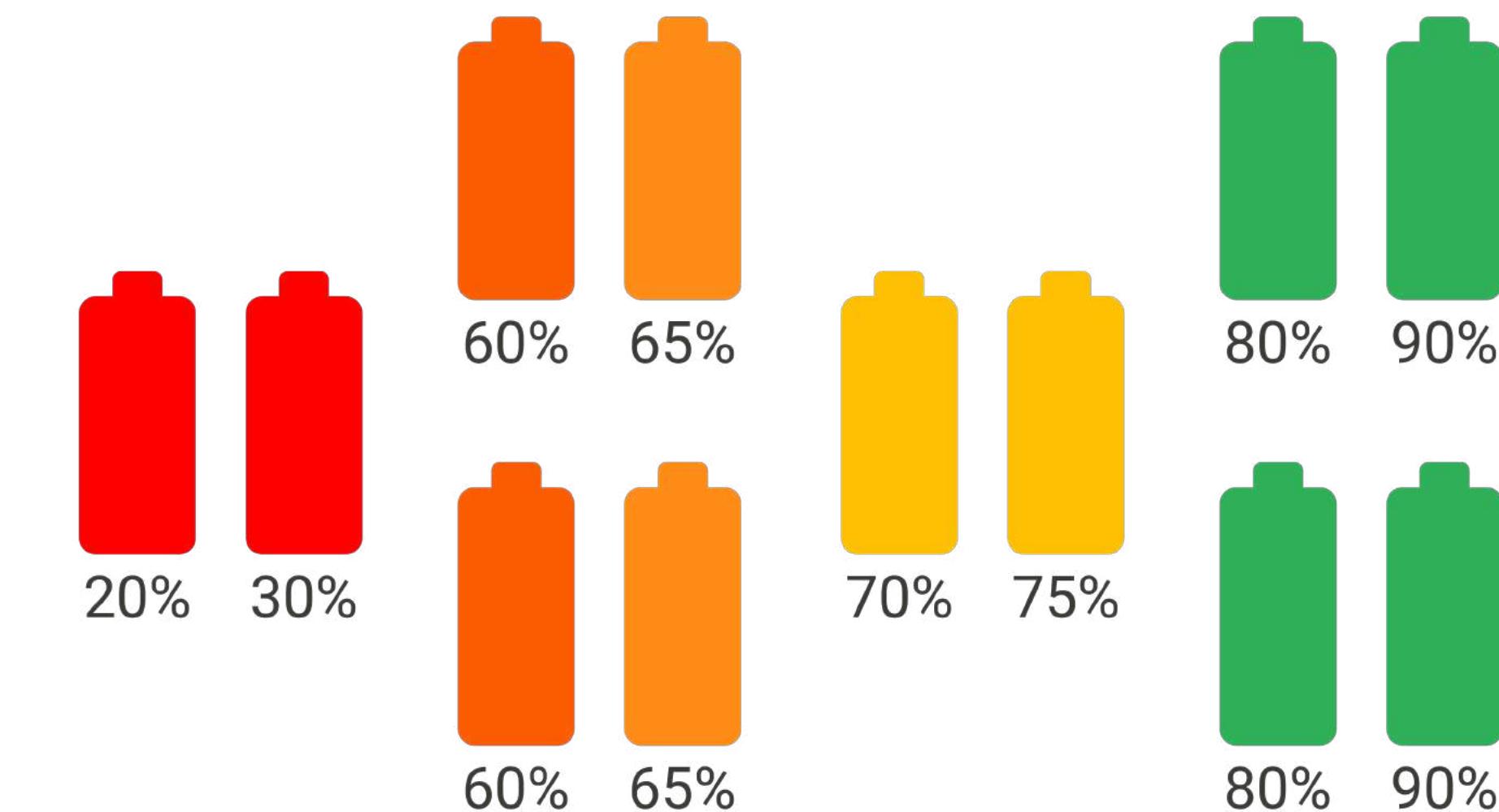
End-of-life Electric Vehicle Batteries



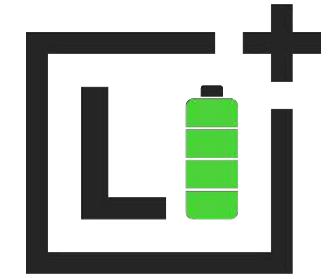
Cell health assessment enables reuse



determine cell health



Circular Economy of EV batteries



In markets with a **demand for less power-heavy applications**, battery **reuse** can provide the most **value**, compared to traditional recycling and disposal

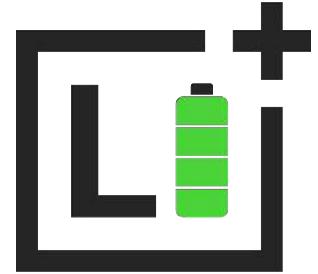


*Image credit Joy Nyangweso, WEEE Centre,
Nairobi, Kenya*

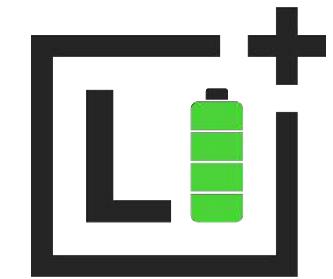


*Image credit Joy Nyangweso, WEEE Centre,
Nairobi, Kenya*

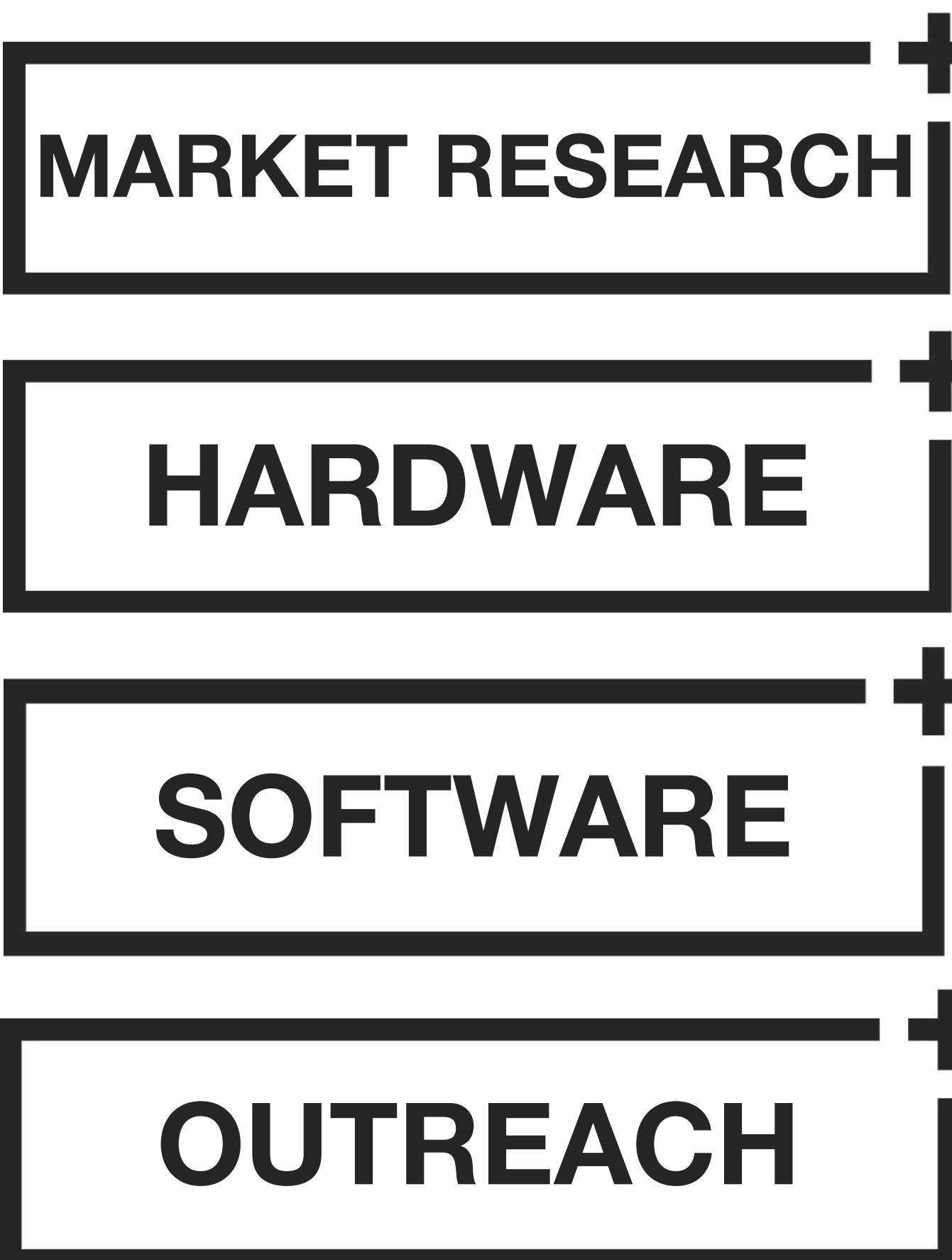
Aim: Testing equipment for cell health assessment in Low- and Middle-Income Countries



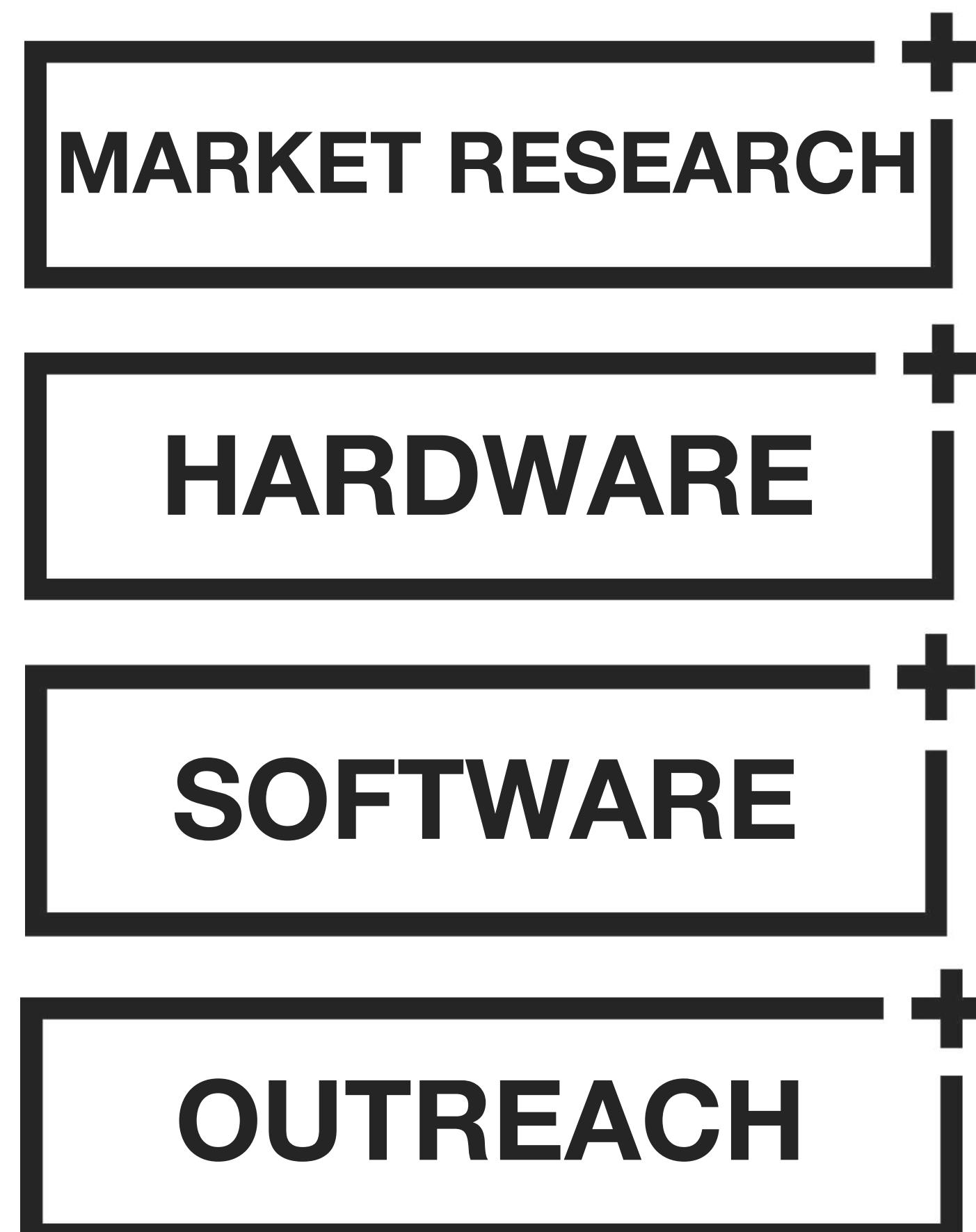
Challenges	Requirements
Component availability	✓ Cost-effective and accessible materials
Diversity of battery types	✓ Open-source
Battery safety	✓ Safe
Government guidelines	✓ User-friendly
Time efficiency	✓ Portable
Accuracy	



Our approach



- **Industry needs**
- **End-users**
- **Impact**
- **Capacity measurements**
- **Charge and discharge**
- **Cell cycling toolkit**
- **Data-driven modelling approach**
- **Incremental Capacity Analysis**
- **Dataset, software package & app**
- **Education campaign**
- **Open-source community**
- **Co-creation workshops**



Eleni Papafilippou



Robert Petrie



Tomas Paulik



Melissa Watt



Jieni Wang



Aparna Kaaraal Mohan



Nicolas Spiesshofer



Jasper Ward-Berry

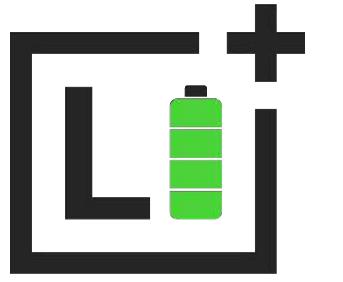


Alec Sargood

Software

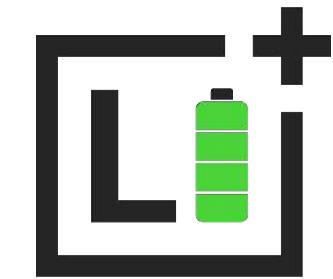
Outreach

Modelling

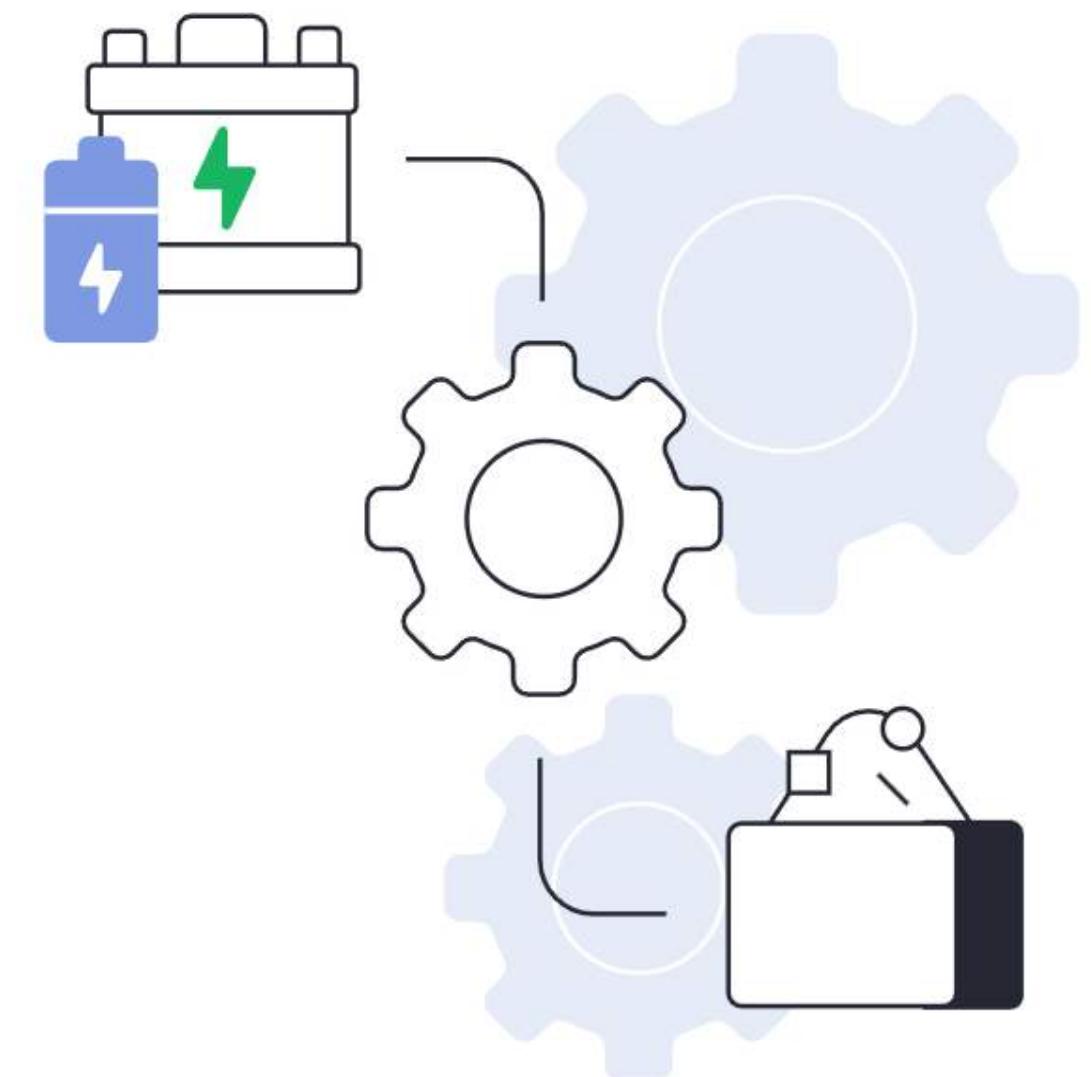


MARKET RESEARCH

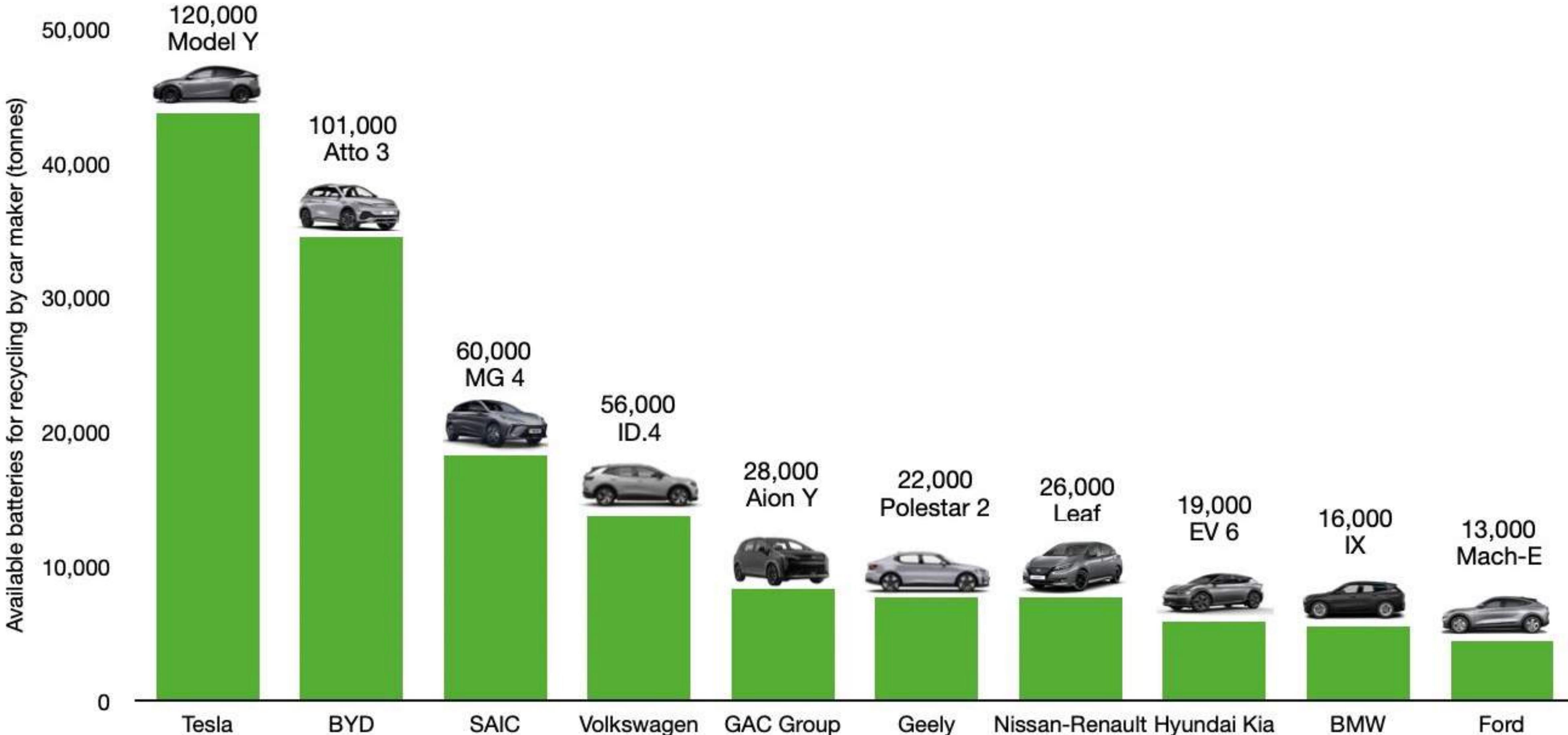
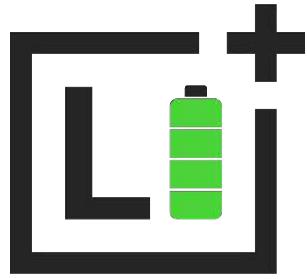
The most common process that used batteries are subjected to is recycling.

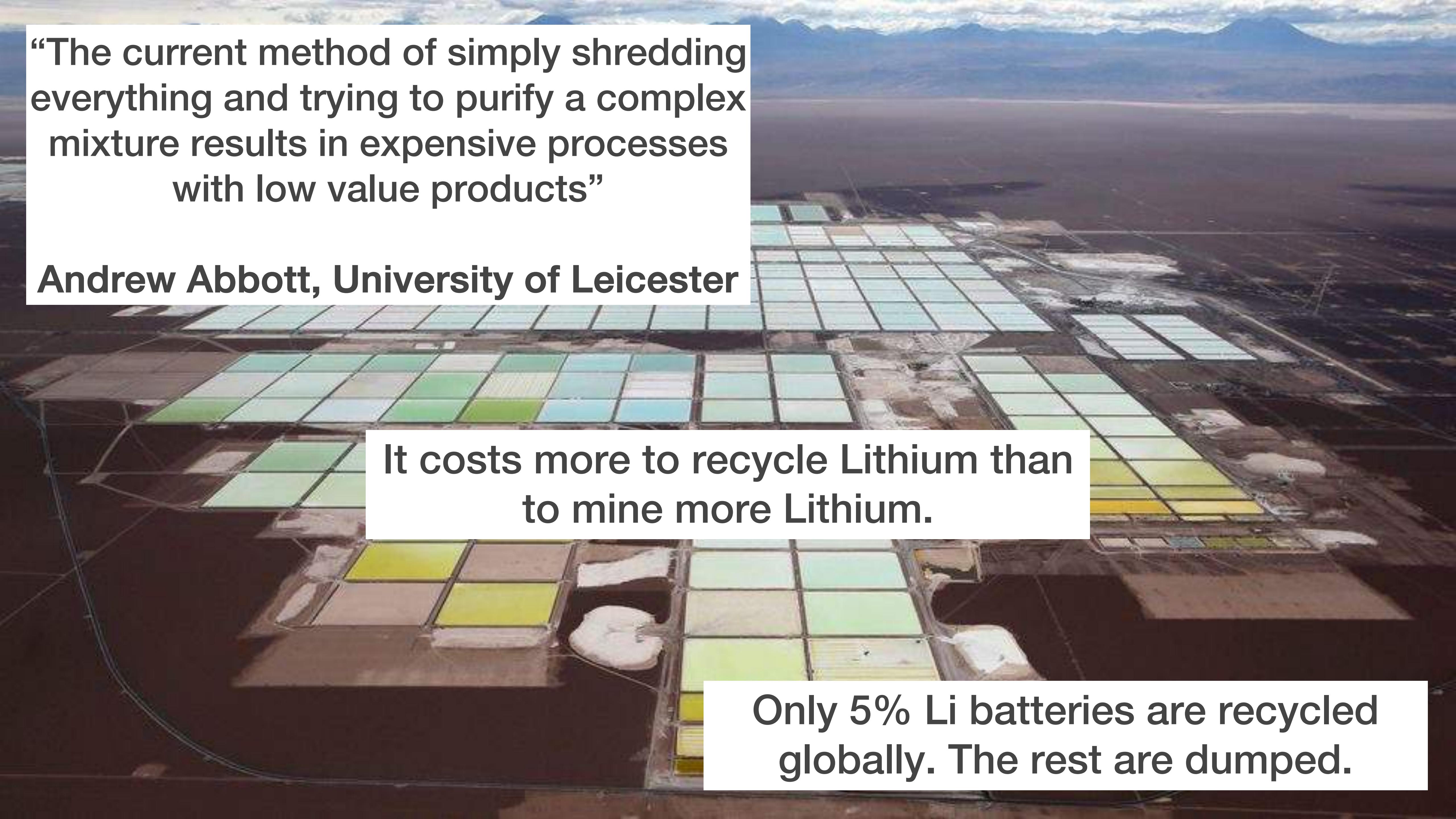


R&D to recover metals from mining and smelting wastes



How many EVs can be powered with recycled battery materials alone, by 2030?





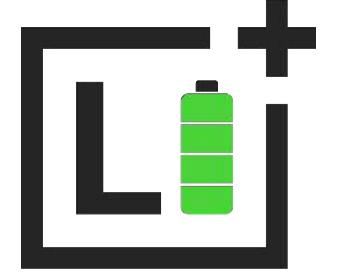
“The current method of simply shredding everything and trying to purify a complex mixture results in expensive processes with low value products”

Andrew Abbott, University of Leicester

It costs more to recycle Lithium than to mine more Lithium.

Only 5% Li batteries are recycled globally. The rest are dumped.

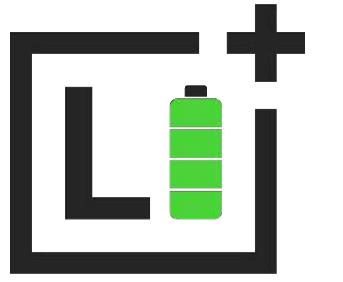
The star solution – Reuse



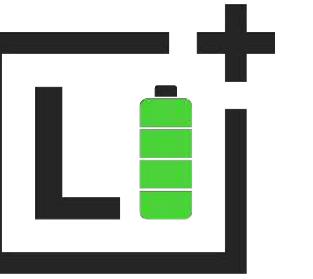
cling

The word 'cling' is written in a large, lowercase, sans-serif font. The letter 'i' has a small orange plus sign (+) positioned below its vertical stem.

CIRCULAR LITHIUM-ION BATTERIES

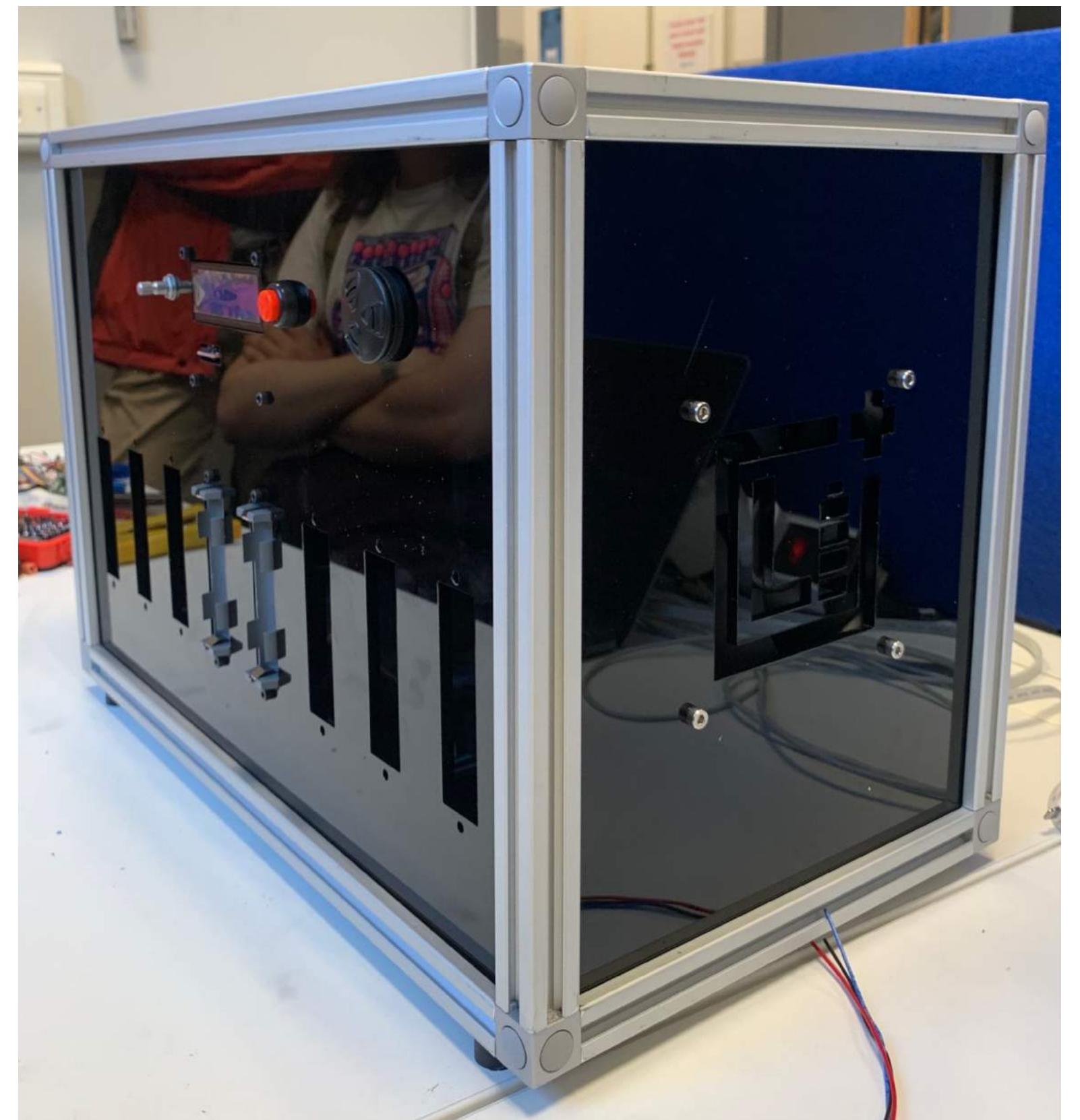


HARDWARE

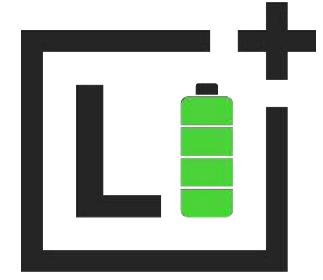


Specification

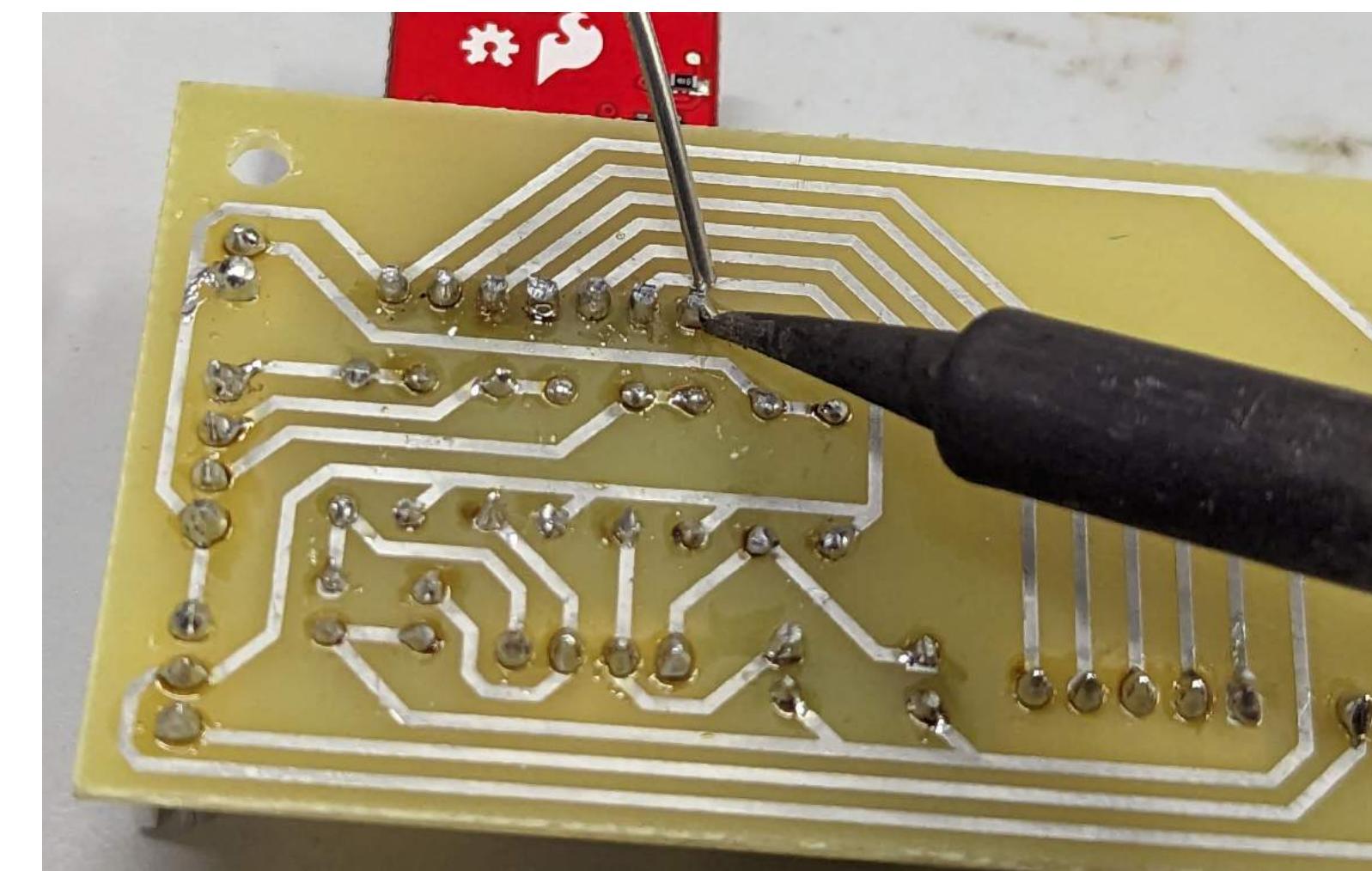
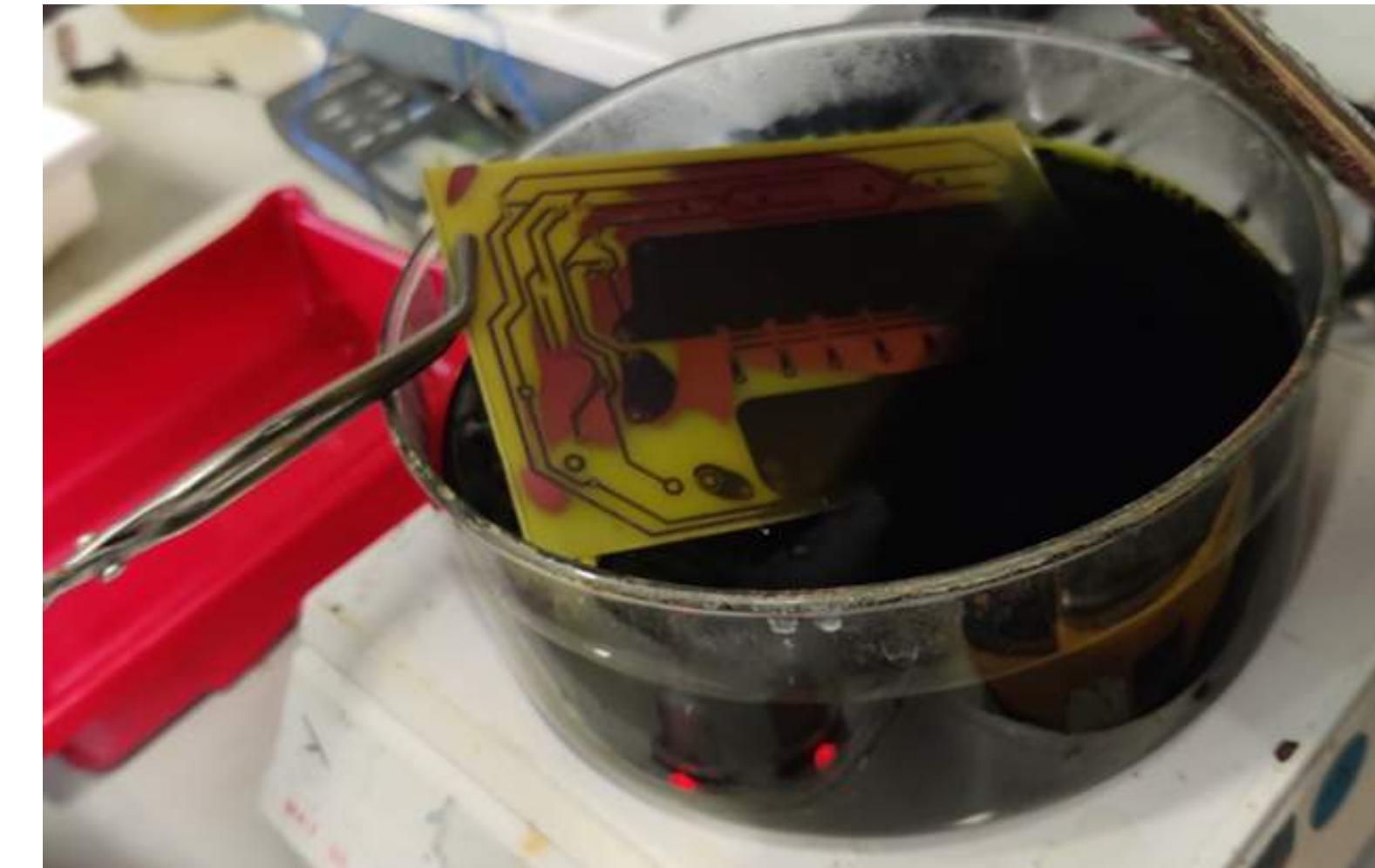
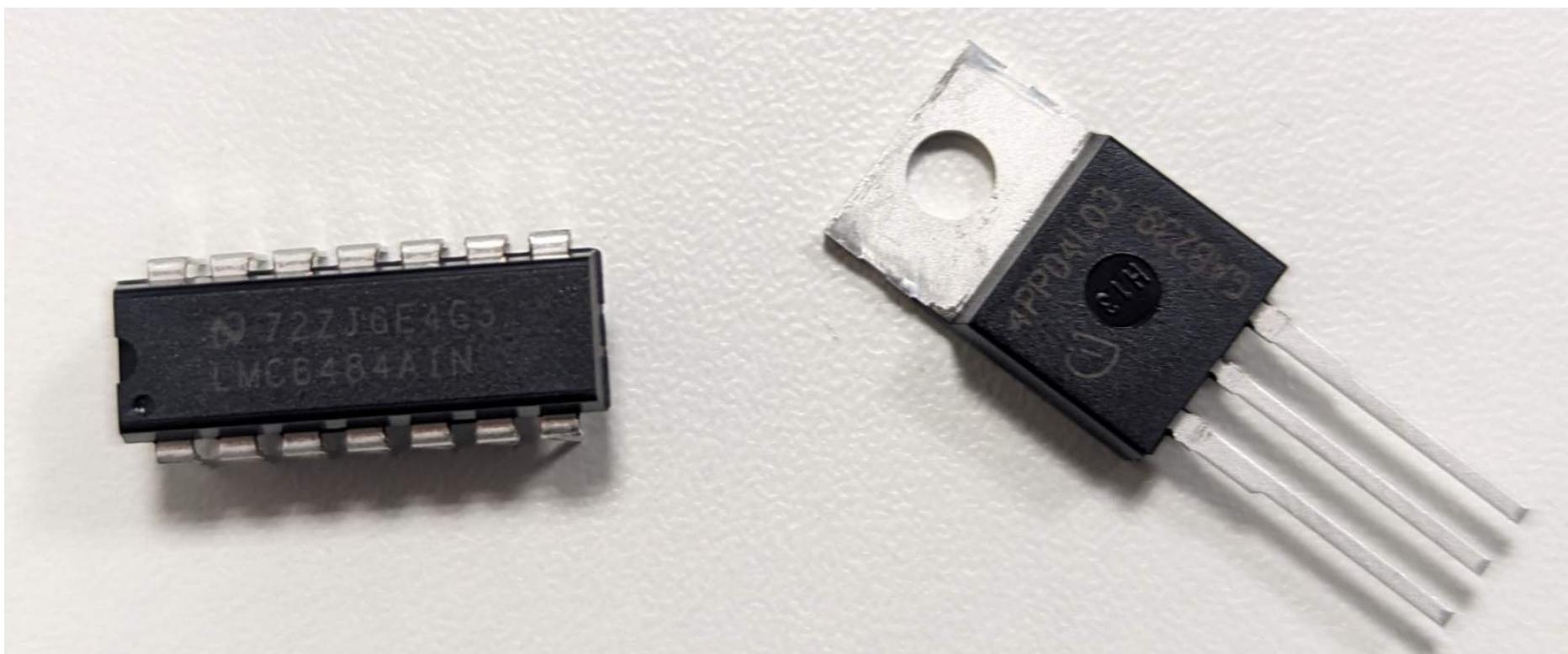
- Pico W microcontroller – on board Bluetooth
- Up to 8 channels (dis)charge with programmable current
- Current and voltage measurement on all cells.
- User interface with physical controls and LCD screen.
- Power supply has capacity for all channels at maximum charge current

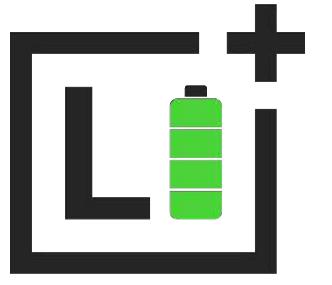


Part & Process Selection

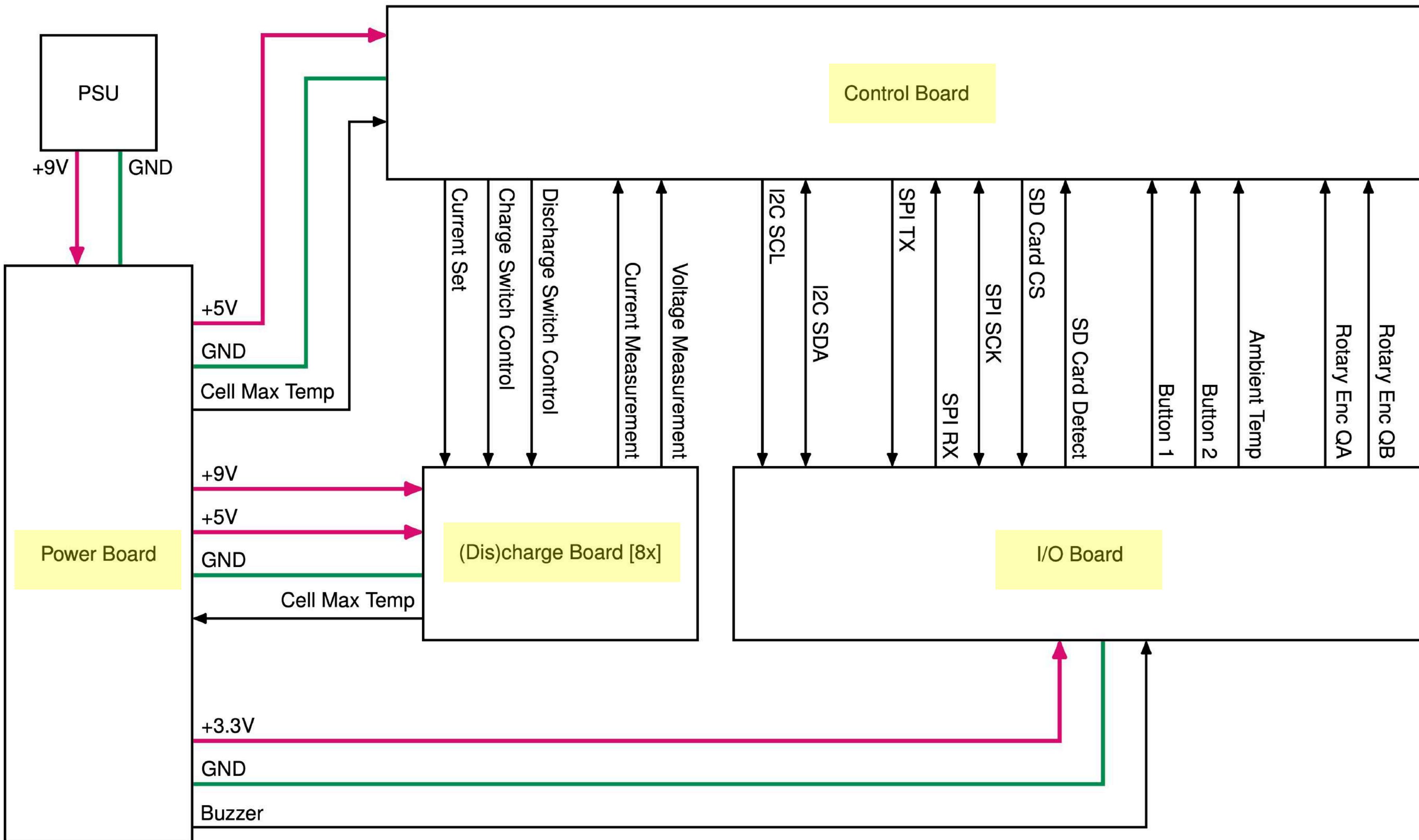


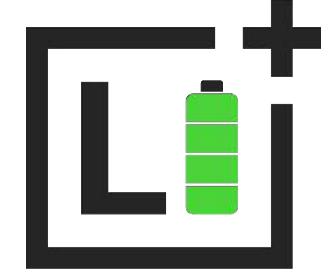
- Parts should be like-for-like interchangeable.
- Through hole rather than surface mount.
- Single sided PCBs, more complicated to route but easier to fabricate.
- Relatively large PCB traces increase tolerance when fabricating.



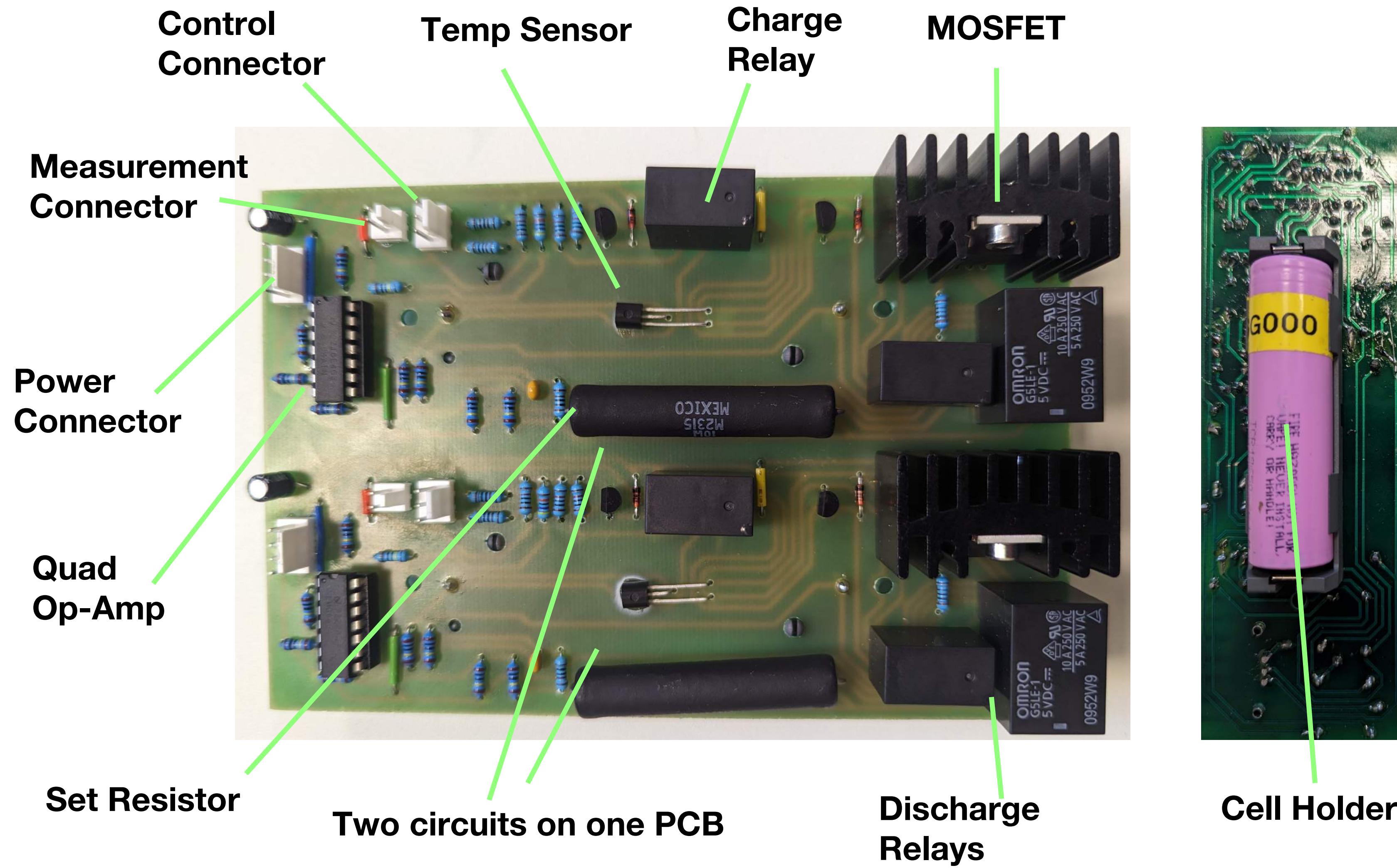


Electronics Overview

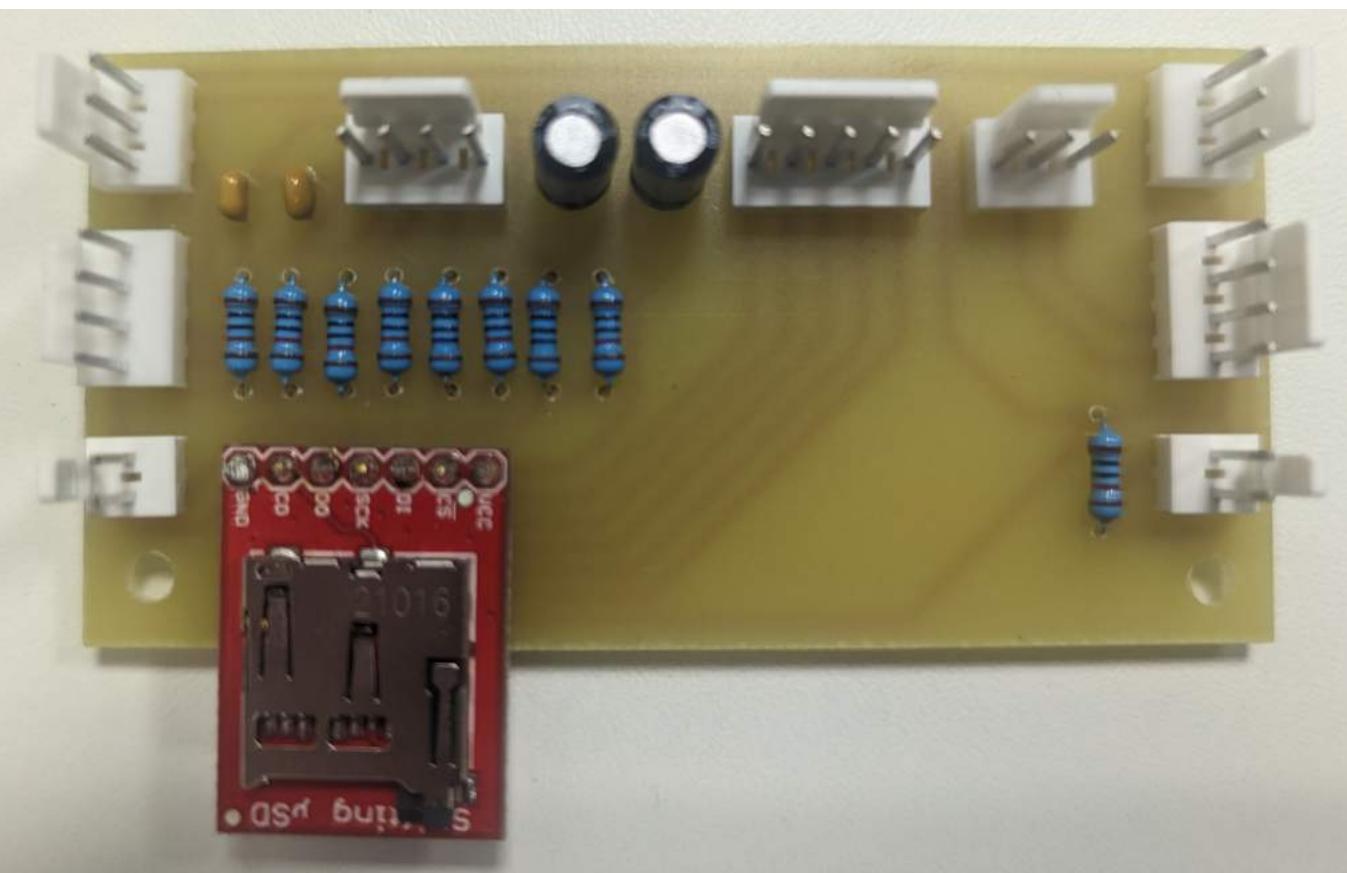




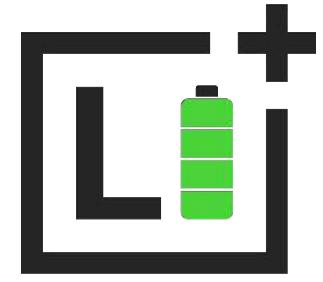
(Dis)charge boards



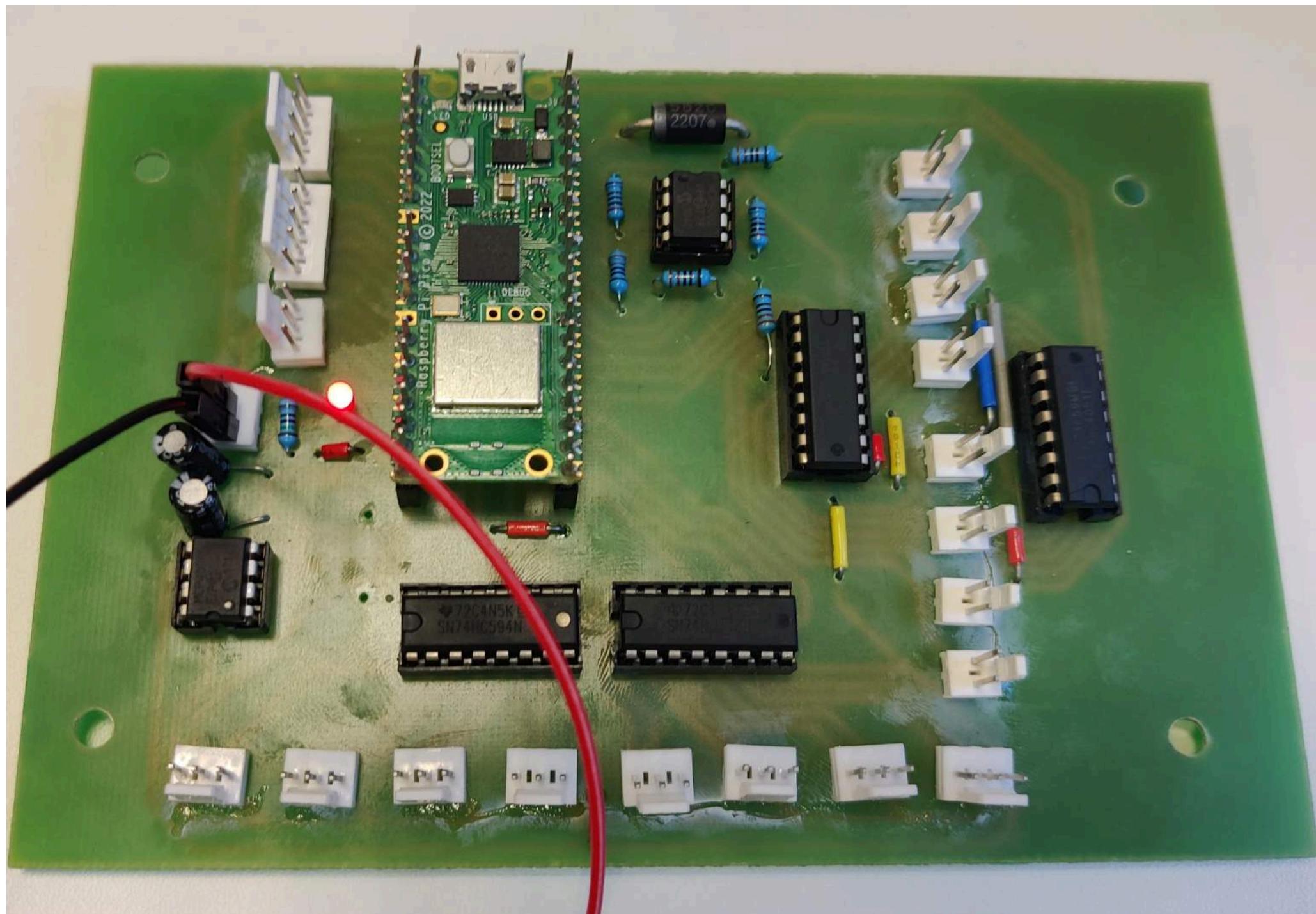
IO board

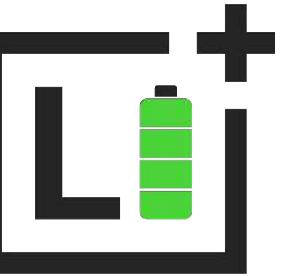


Power distribution



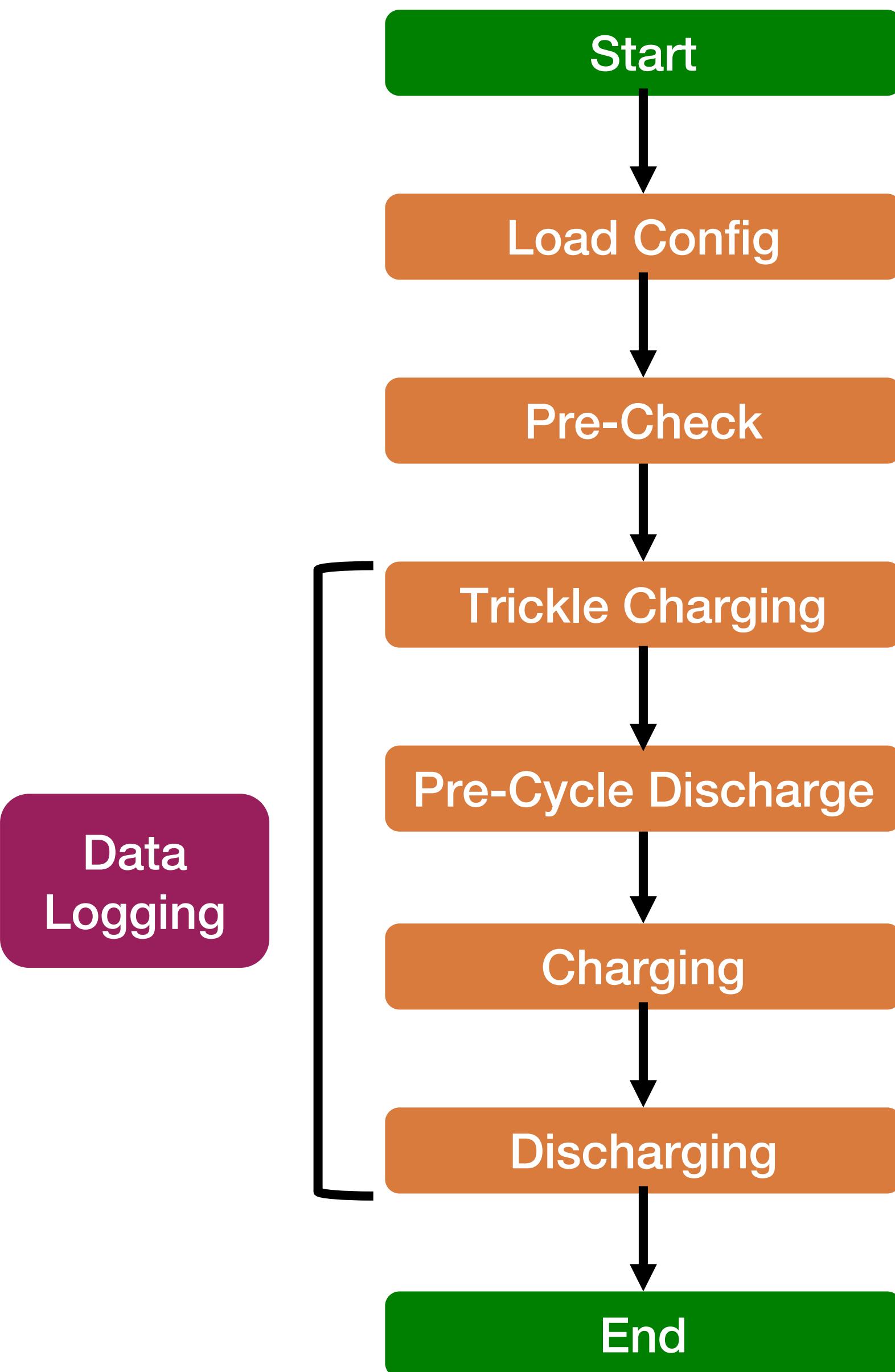
Control board

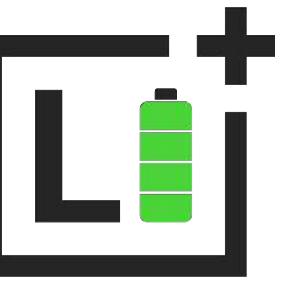




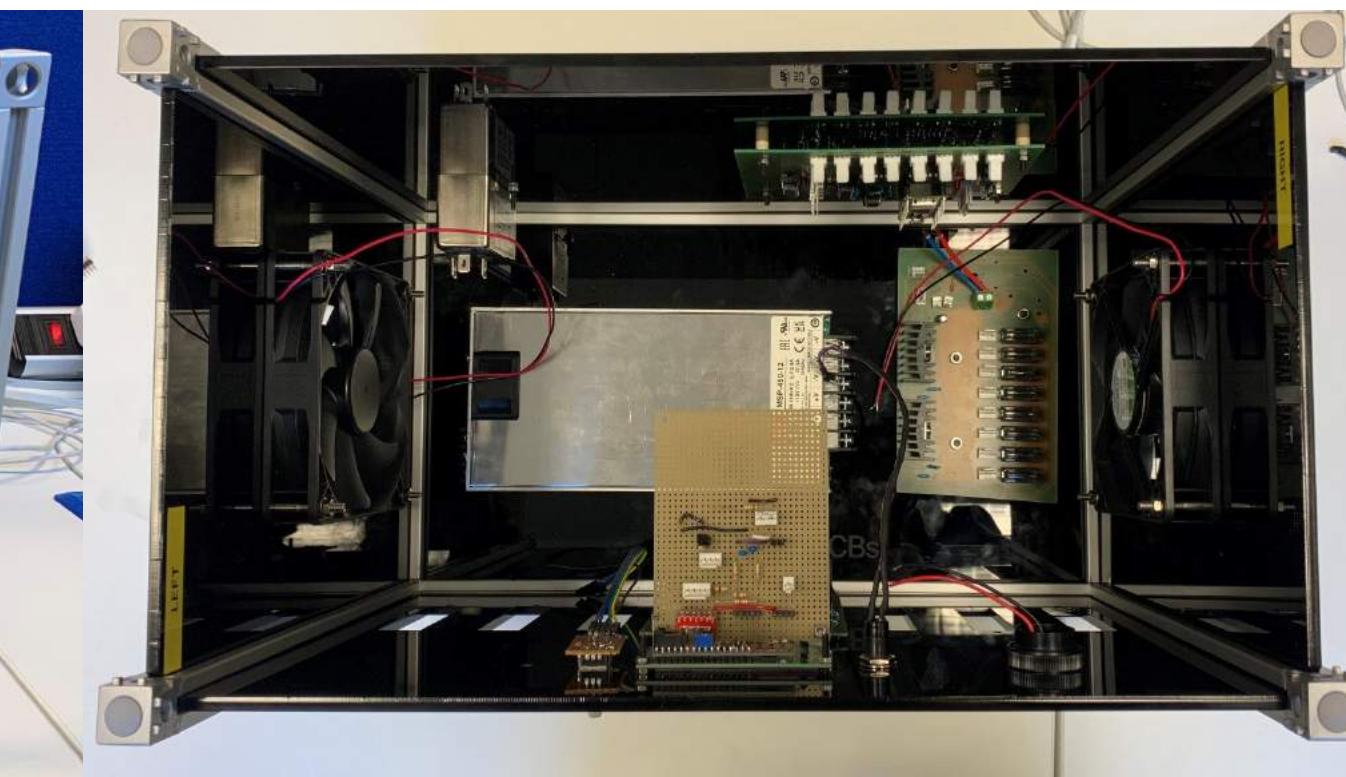
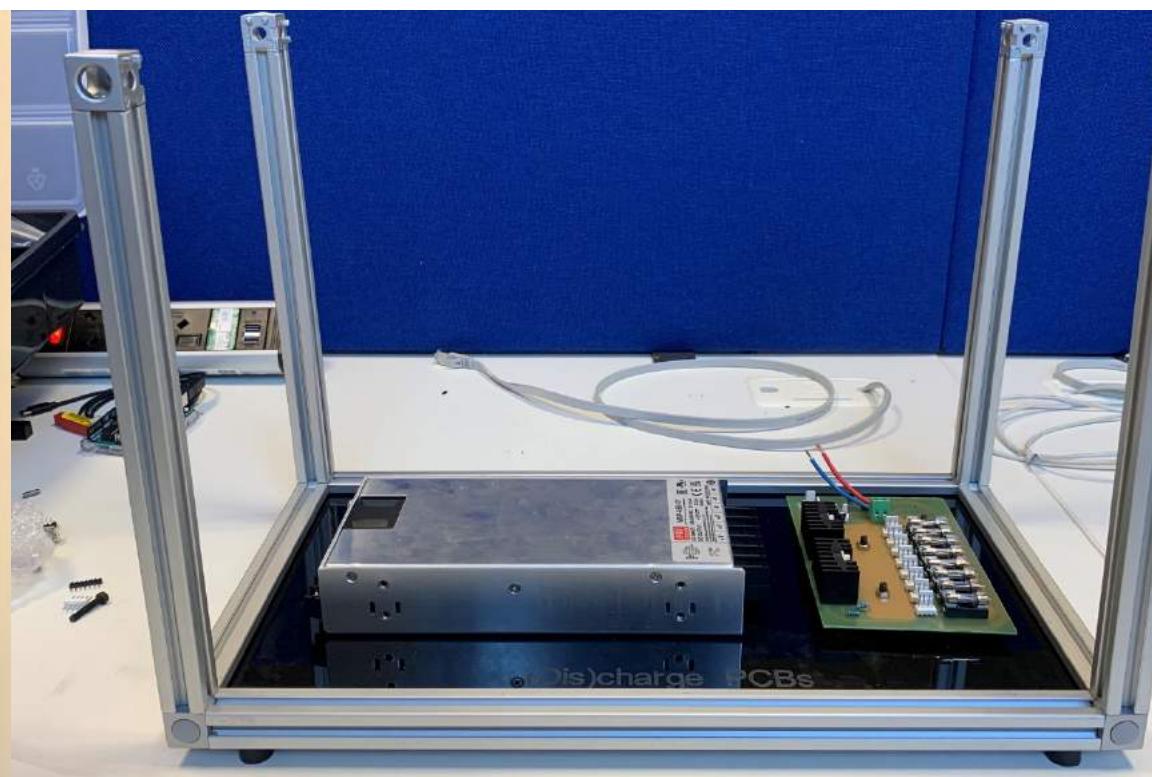
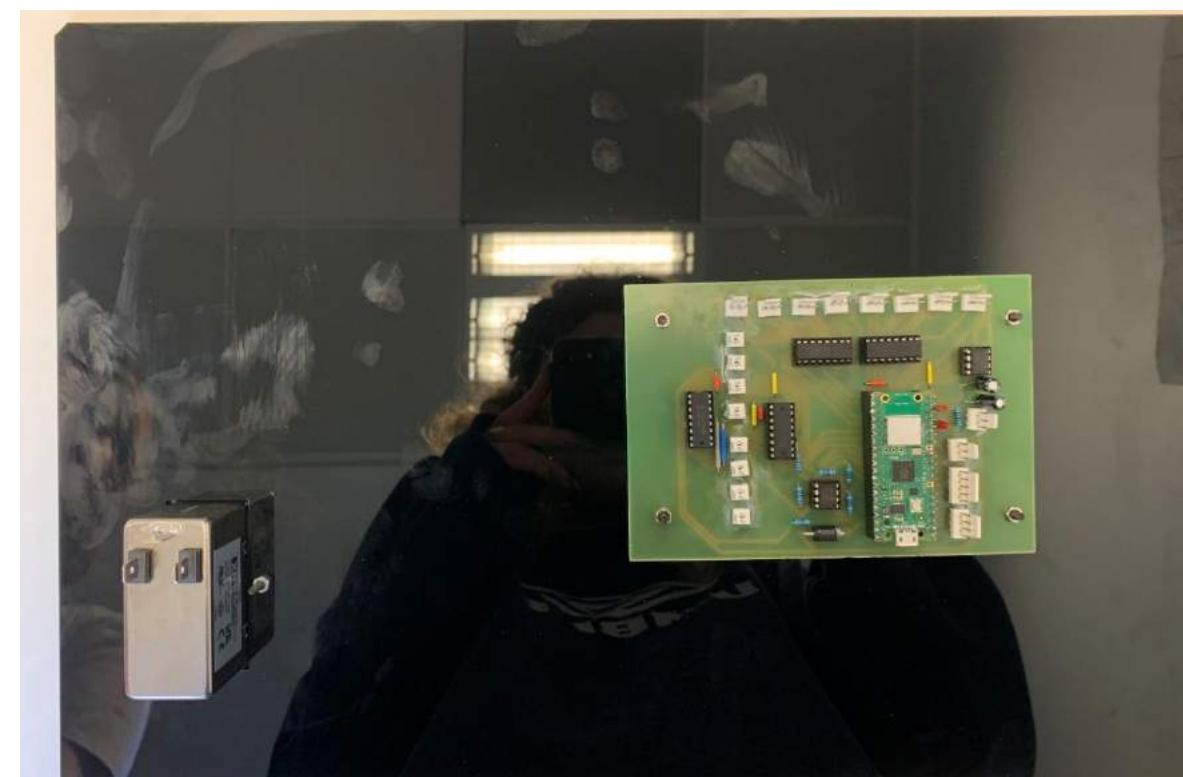
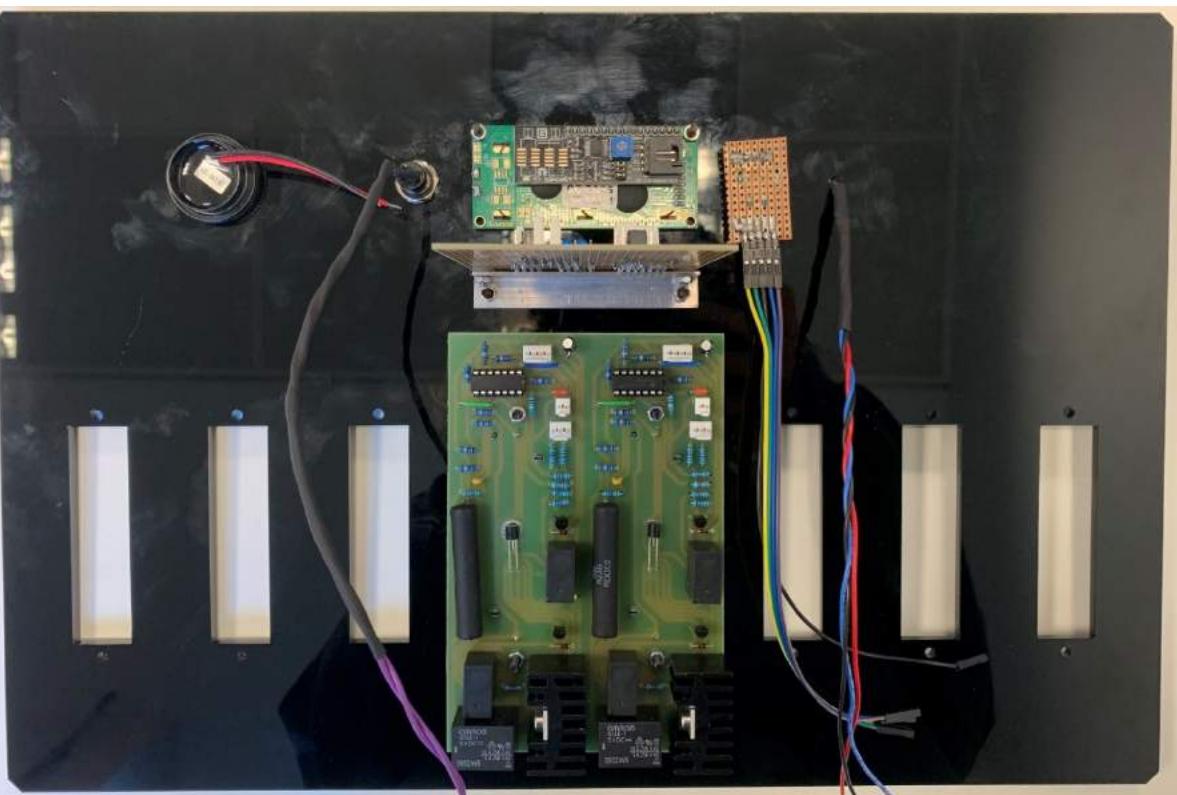
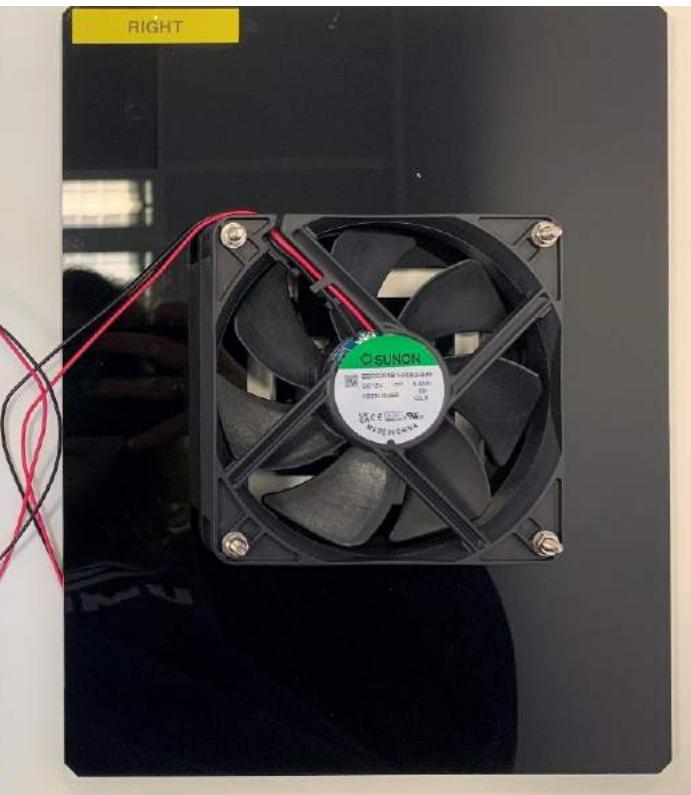
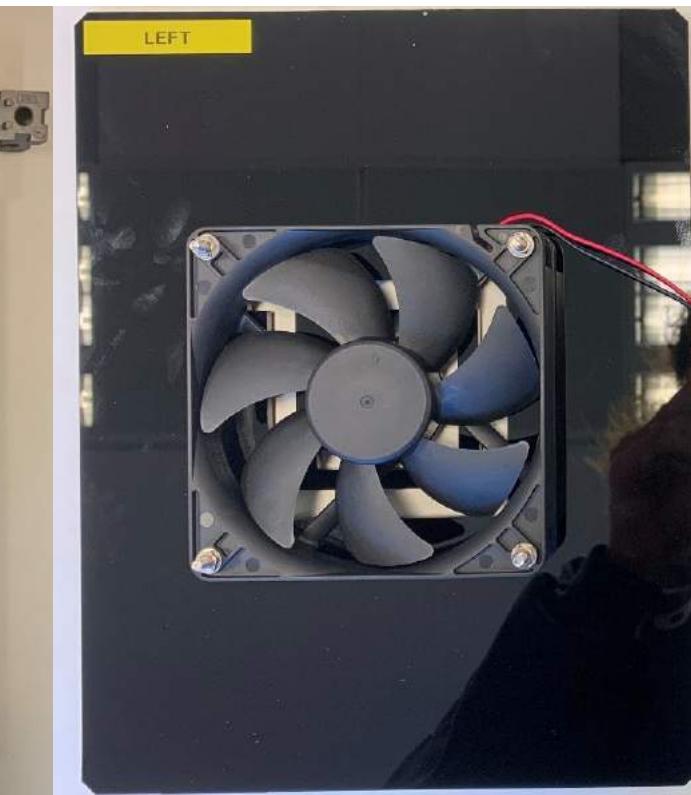
Firmware

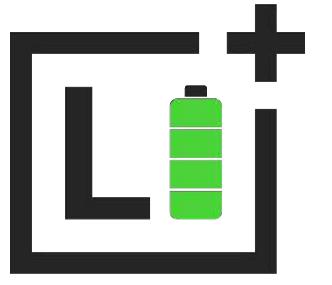
- Structured as a state machine
- Ensures robust, safe, logical operation
- Key parameters set by config file (no coding required)



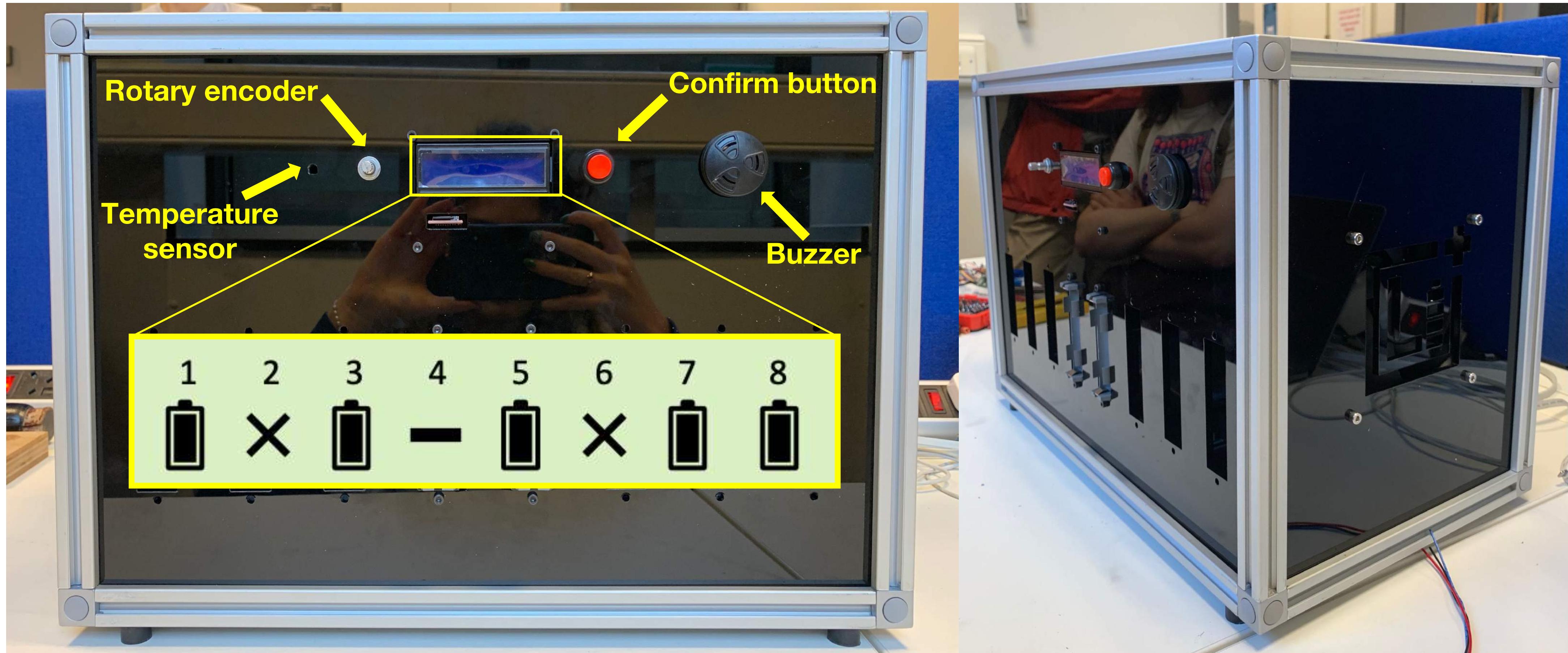


Assembly



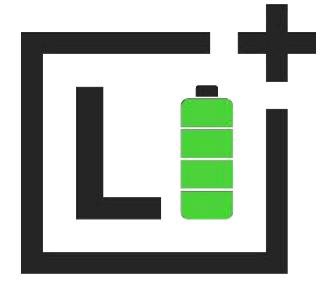


Assembled prototype

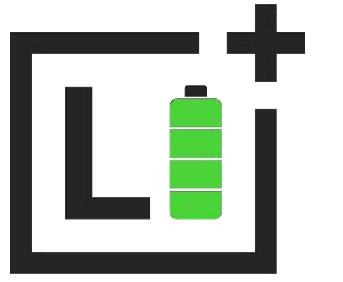


*Perspex can be very reflective ☺

Single-cell prototype

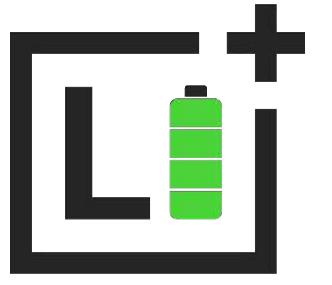


....

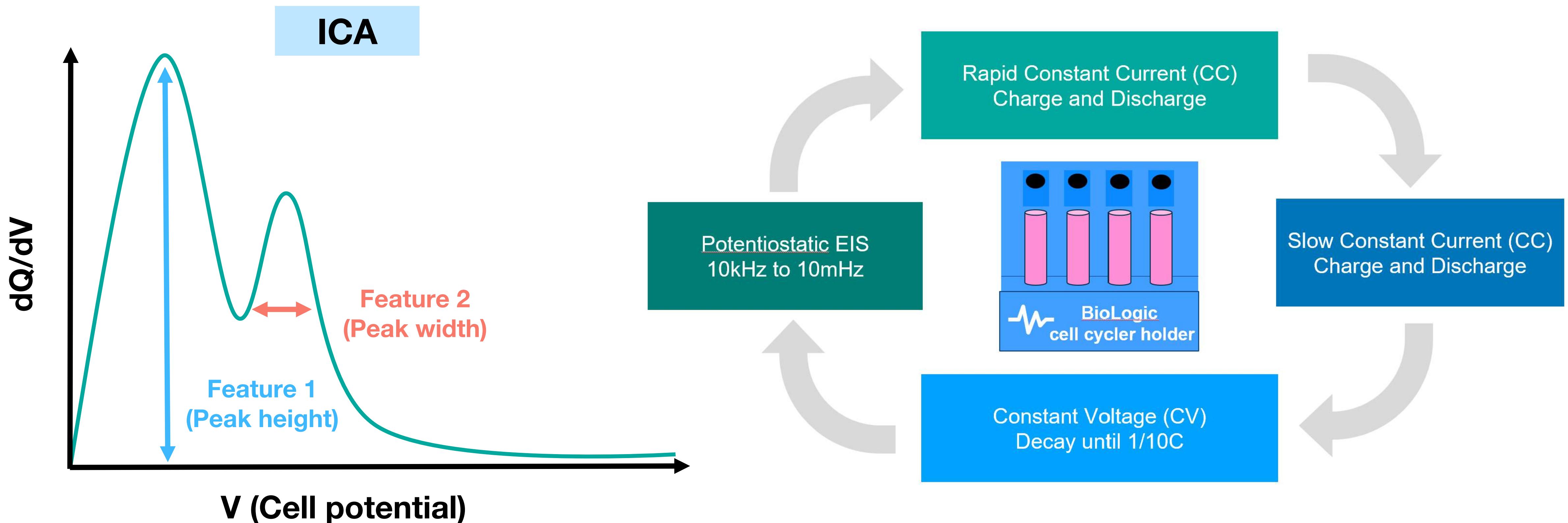


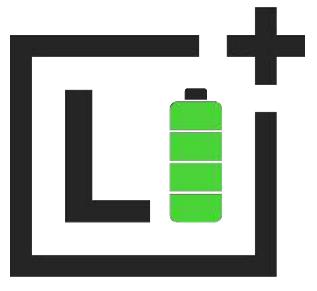
SOFTWARE



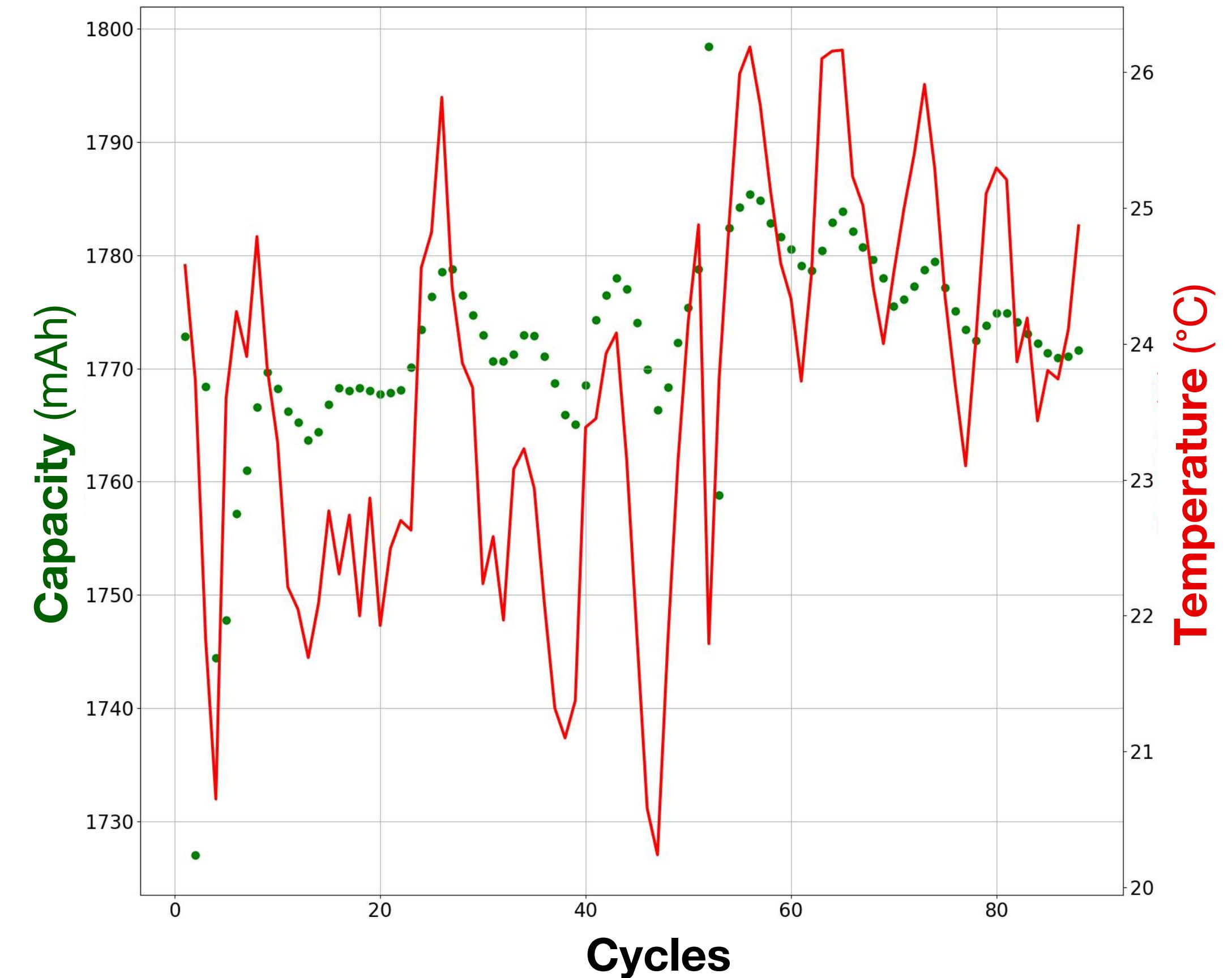
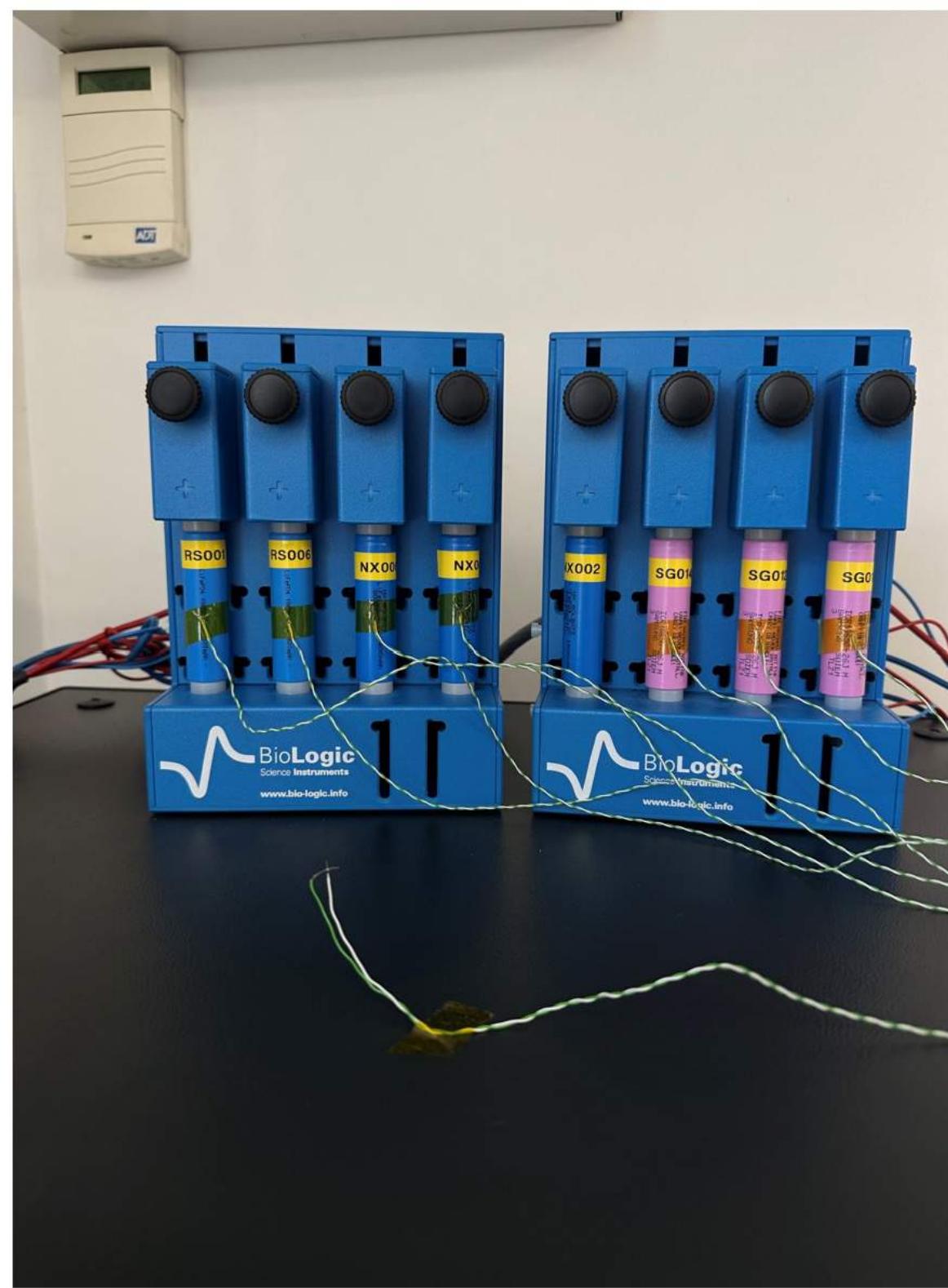


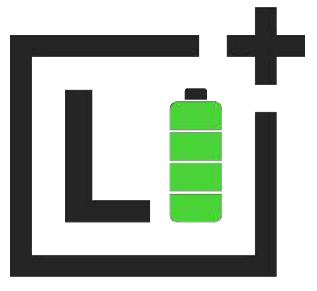
Battery cycling





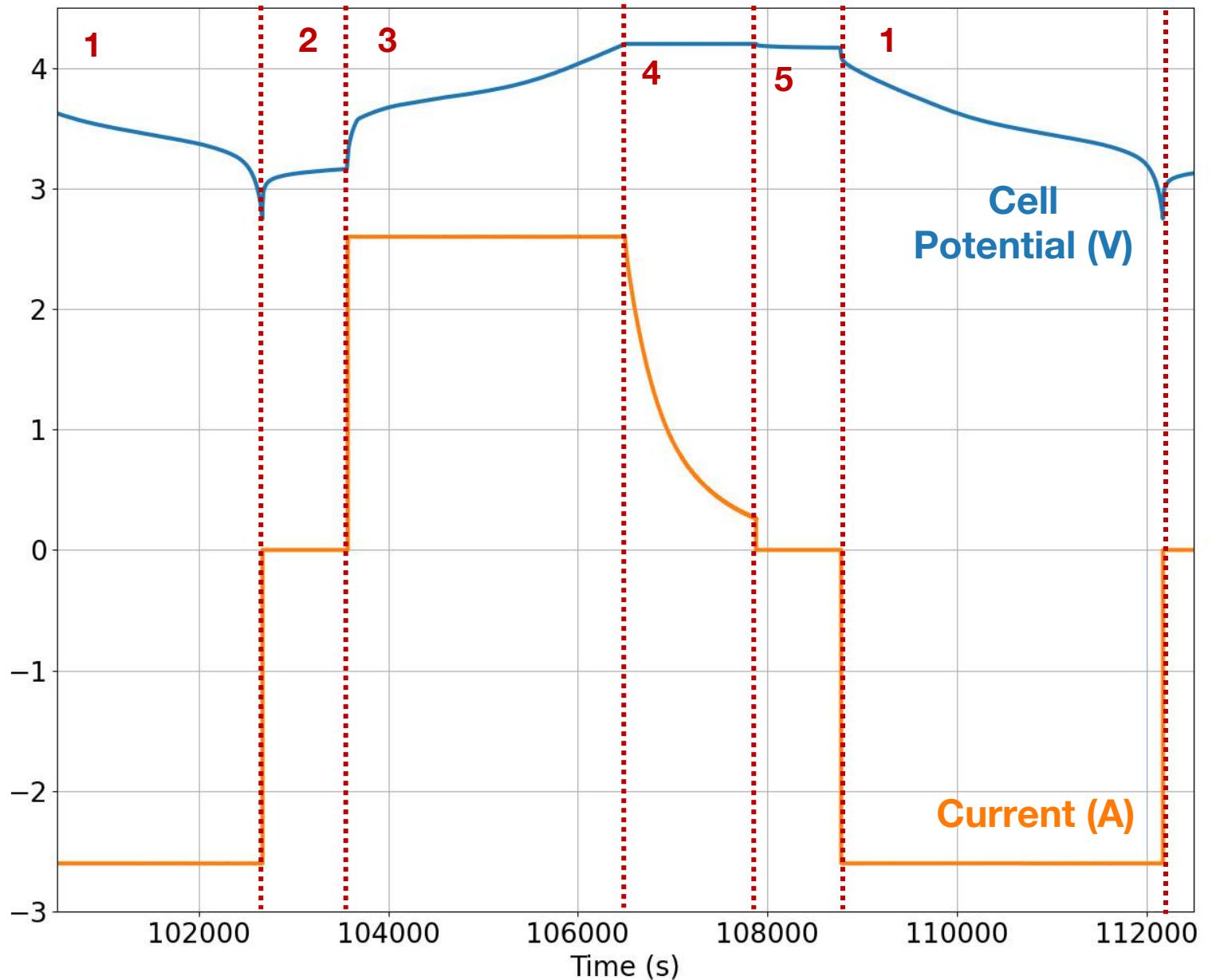
Battery cycling



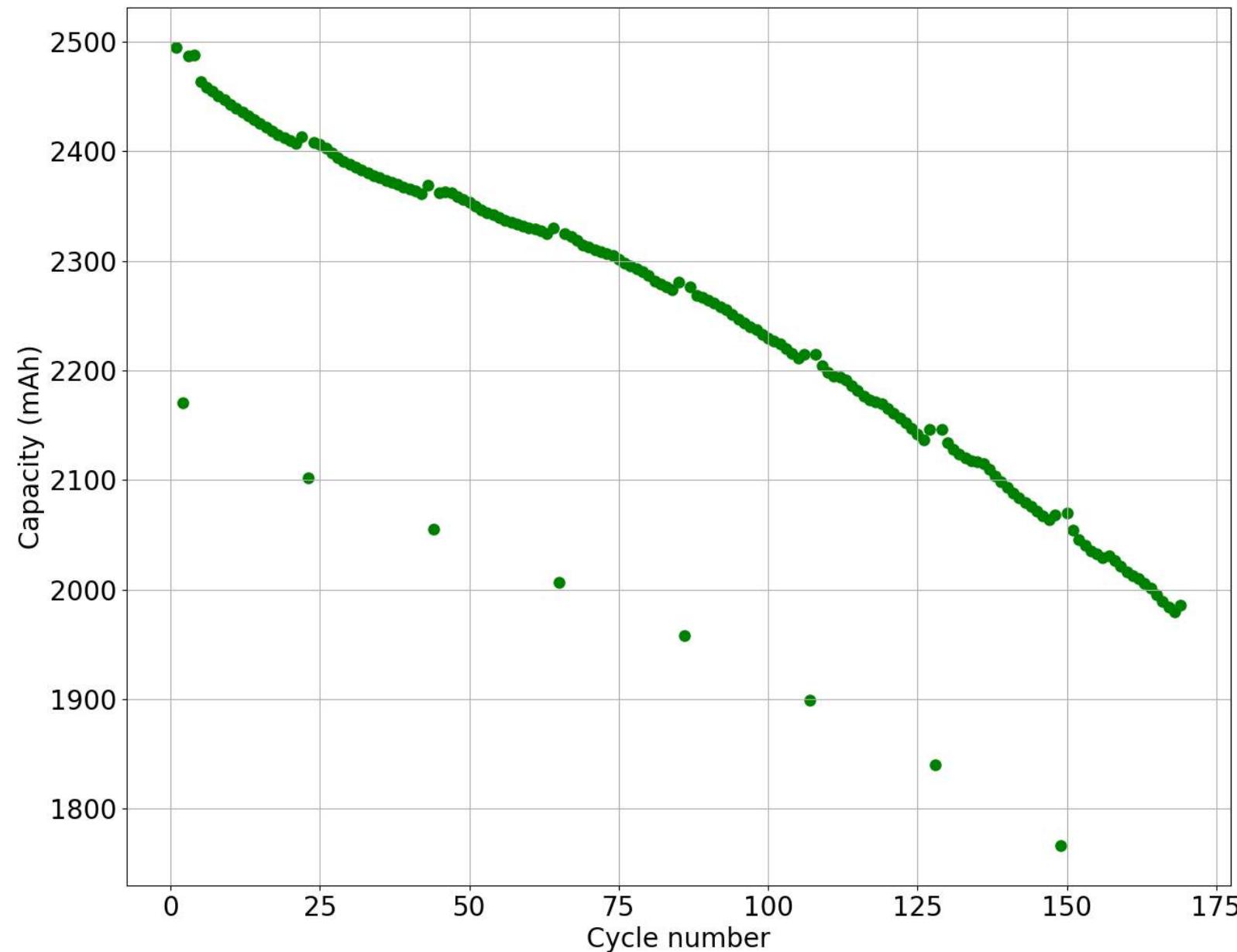


Battery cycling

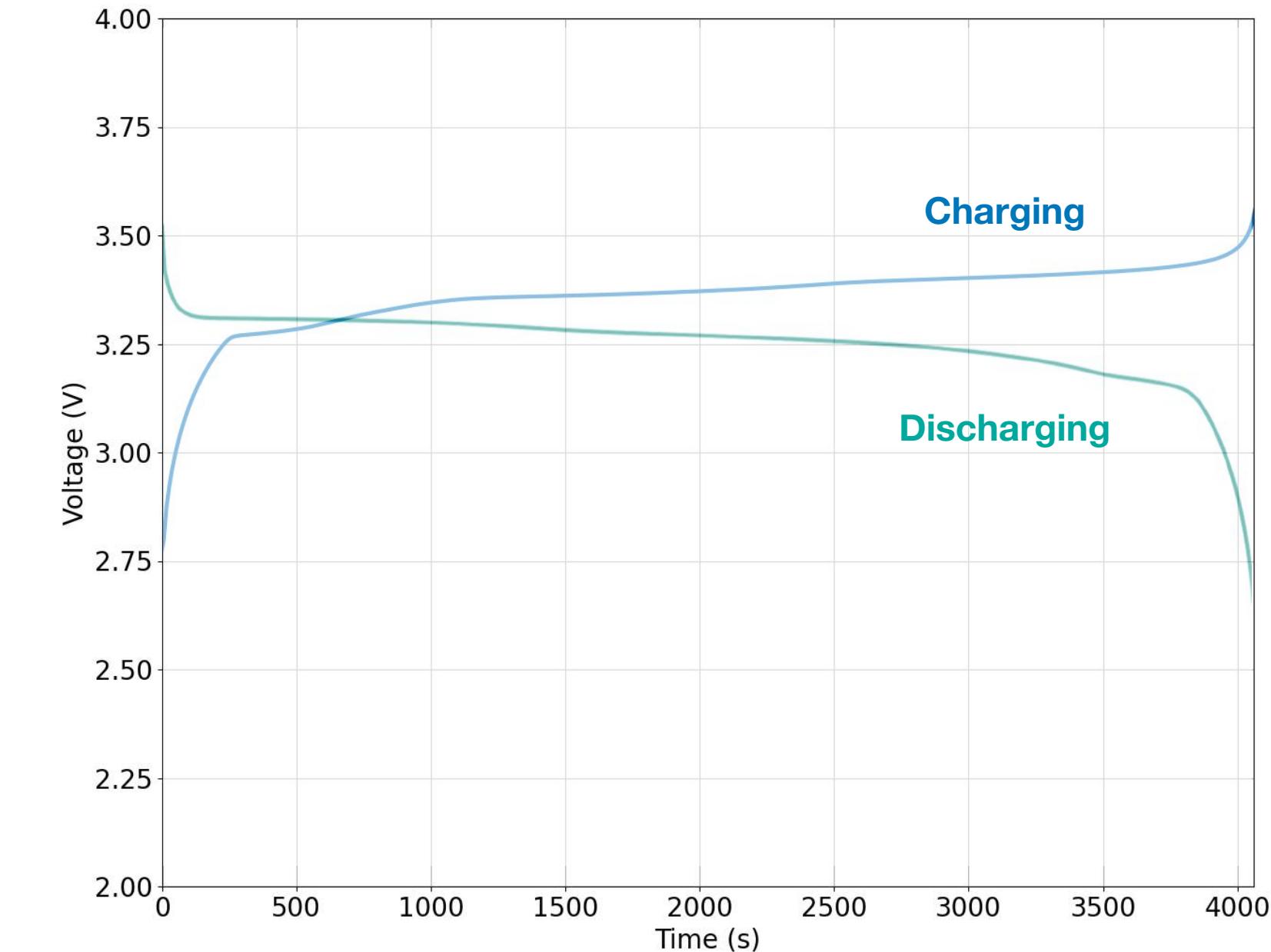
Full Cycle

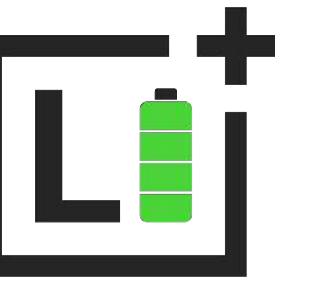


Capacity



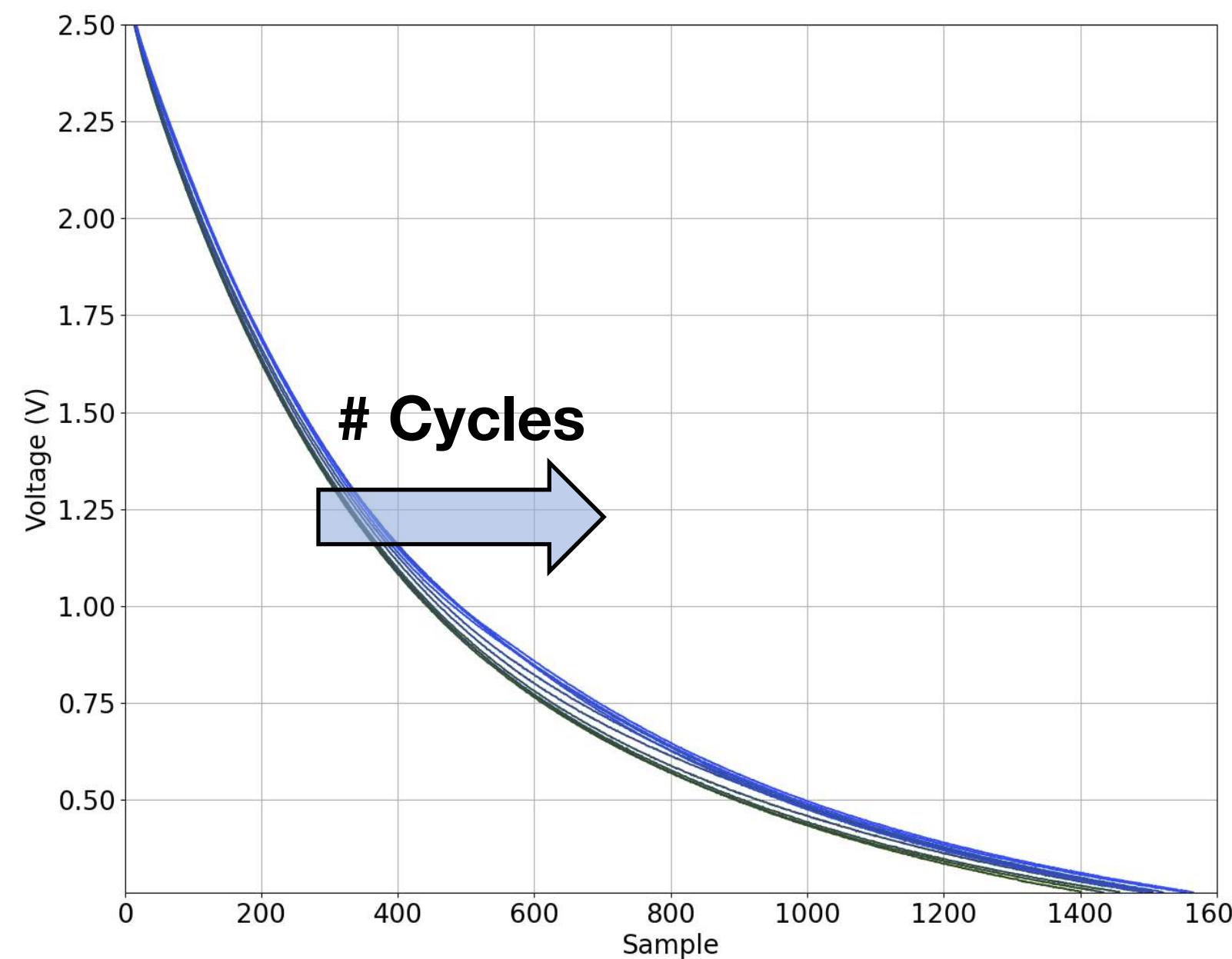
Charge-Discharge



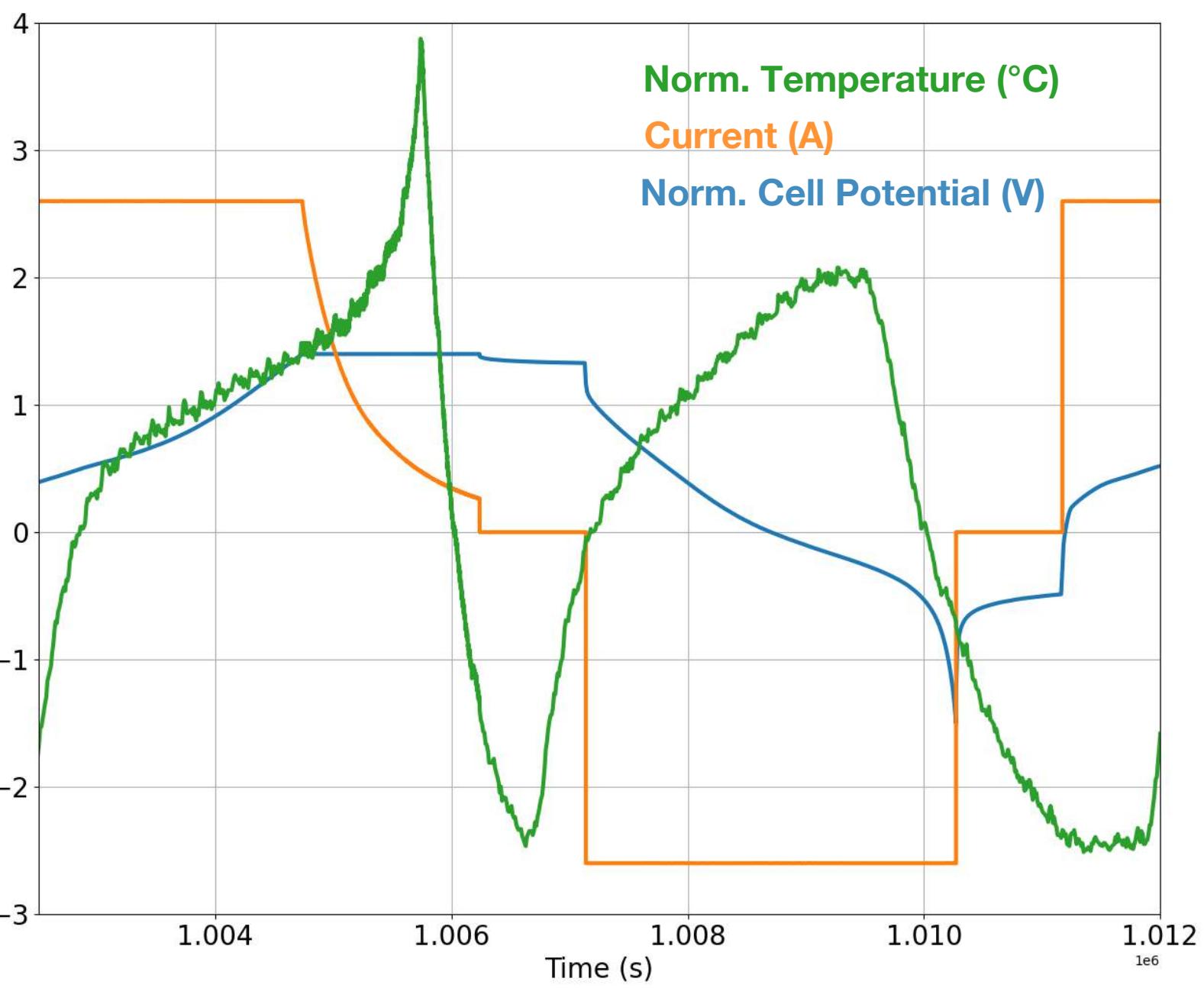


Battery cycling

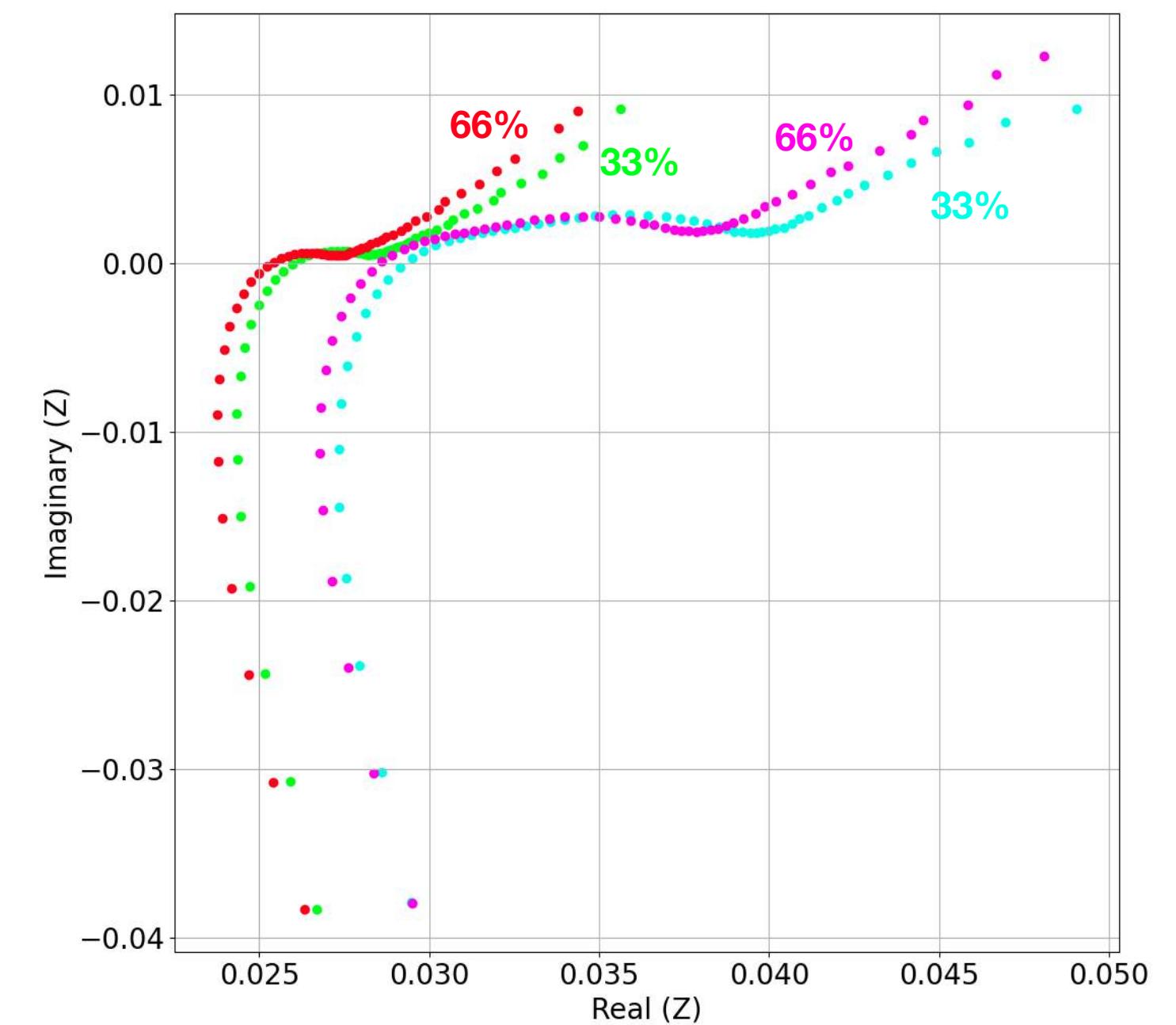
Constant Voltage



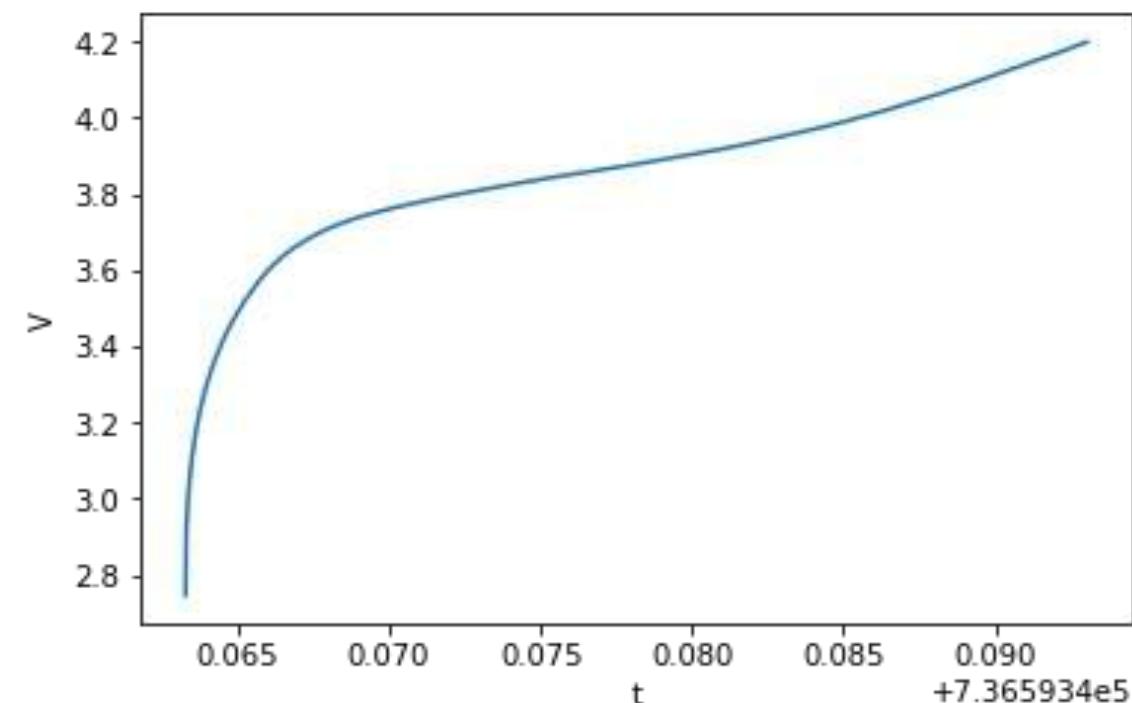
Temperature



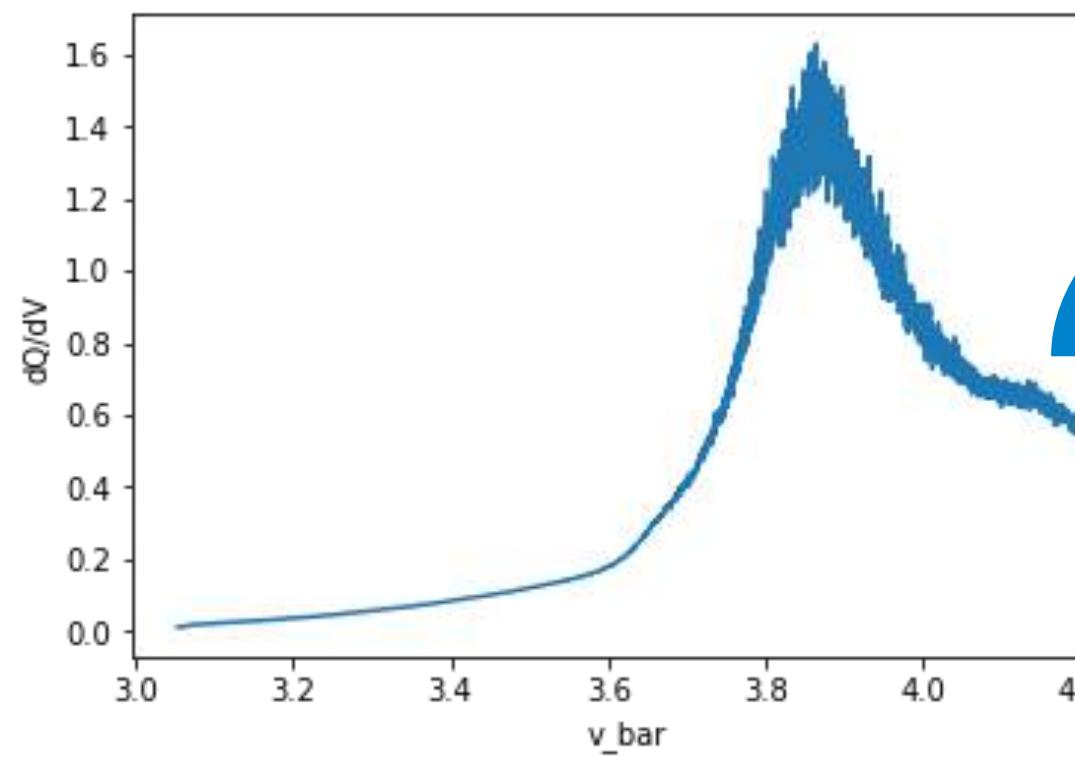
Potentiostatic EIS



Feature Selection

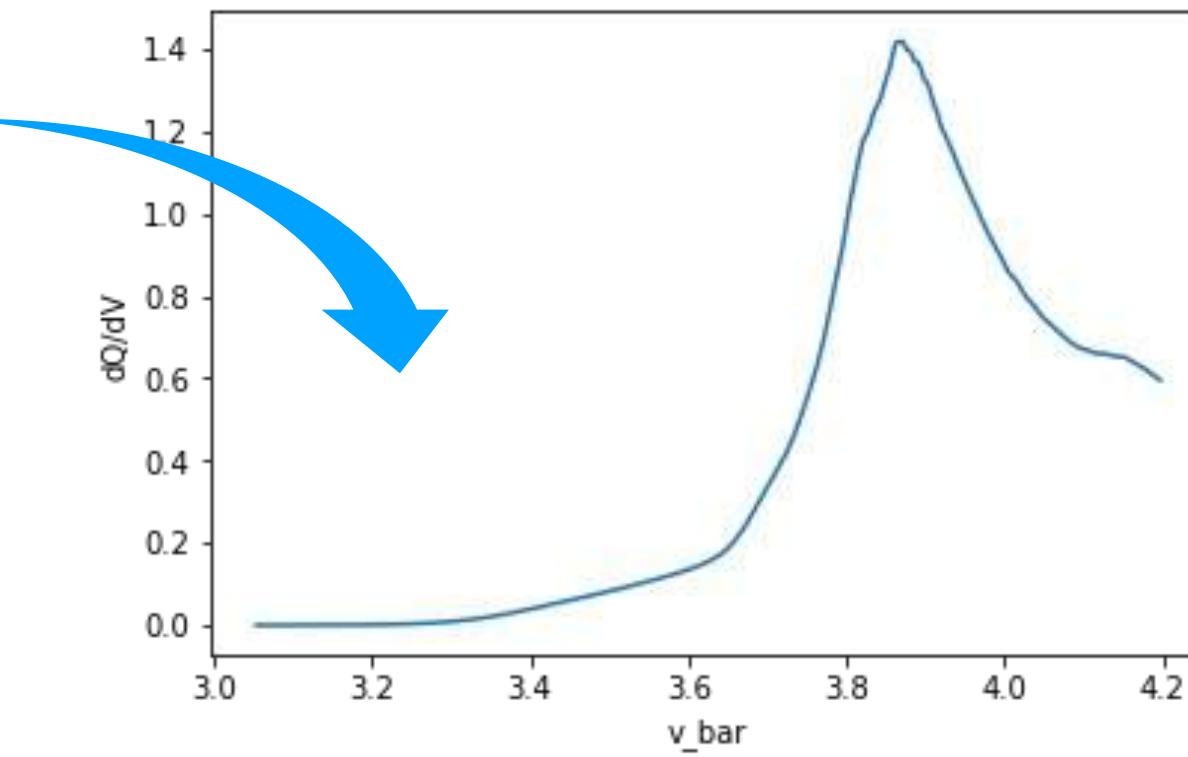


- Charging cycle



- 1st order derivative approx.

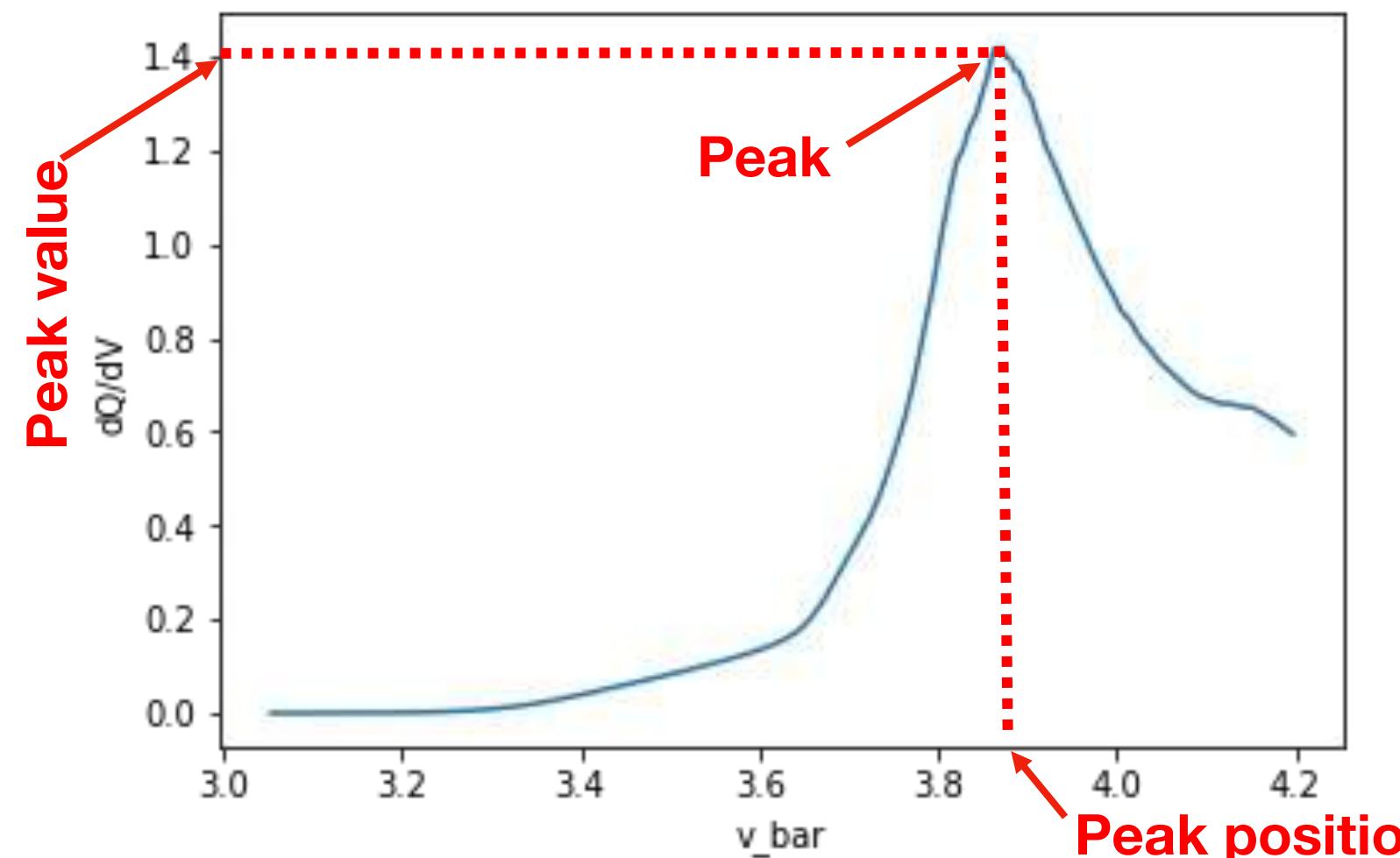
$$\left. \frac{\partial Q}{\partial V} \right|_{t_i} \approx \frac{Q_i - Q_{i-N}}{V_i - V_{i-N}}$$



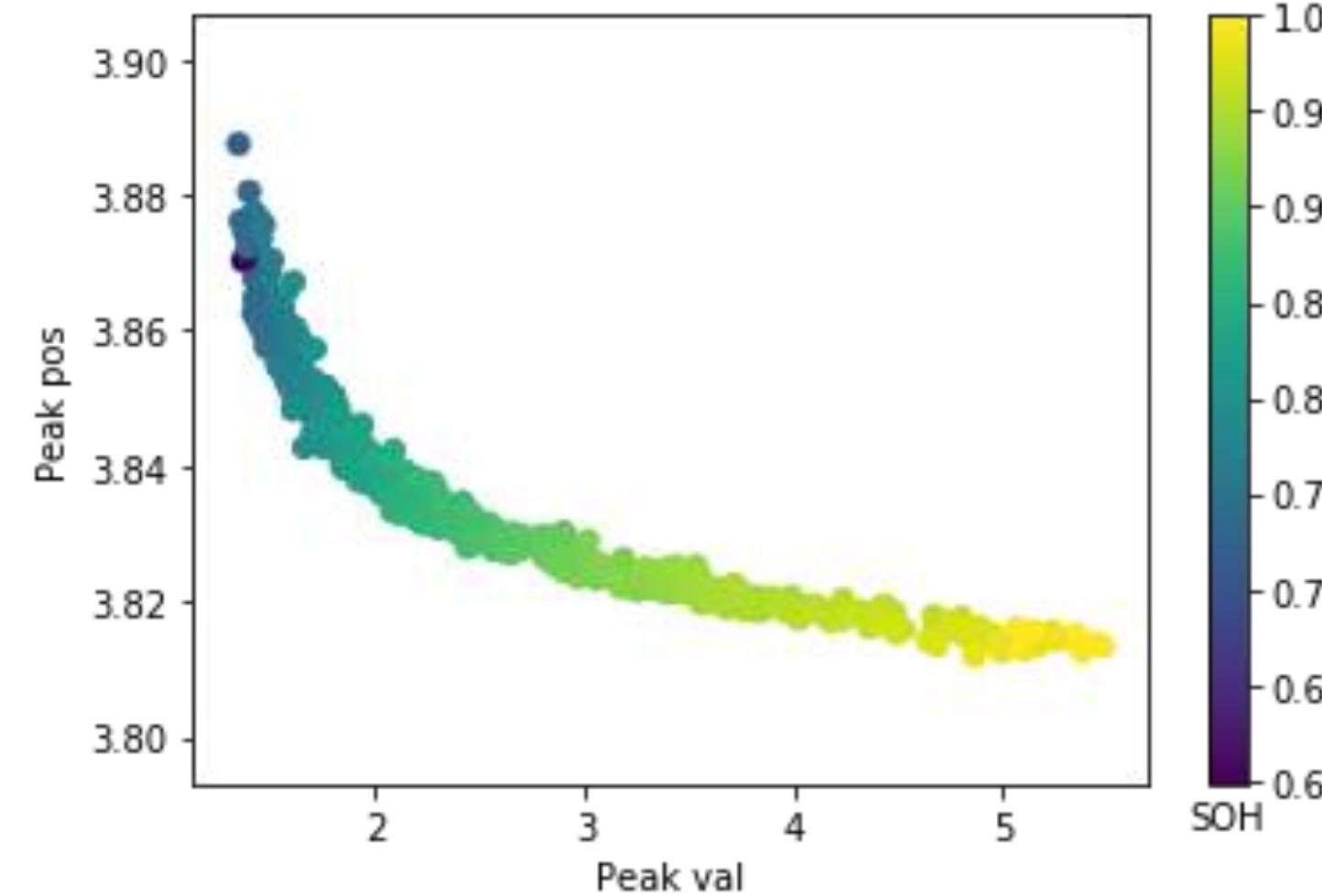
- 1D Gaussian filter

$$g_{\sigma}(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

Chosen features

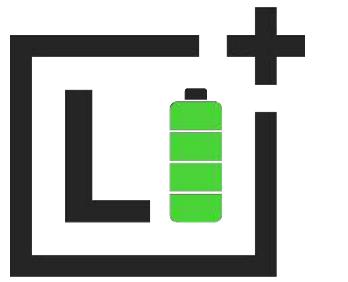


Oxford Dataset Features



In Literature?

- Gaussian Process Models
- Kalman Filters
- SVM
- Deep Learning



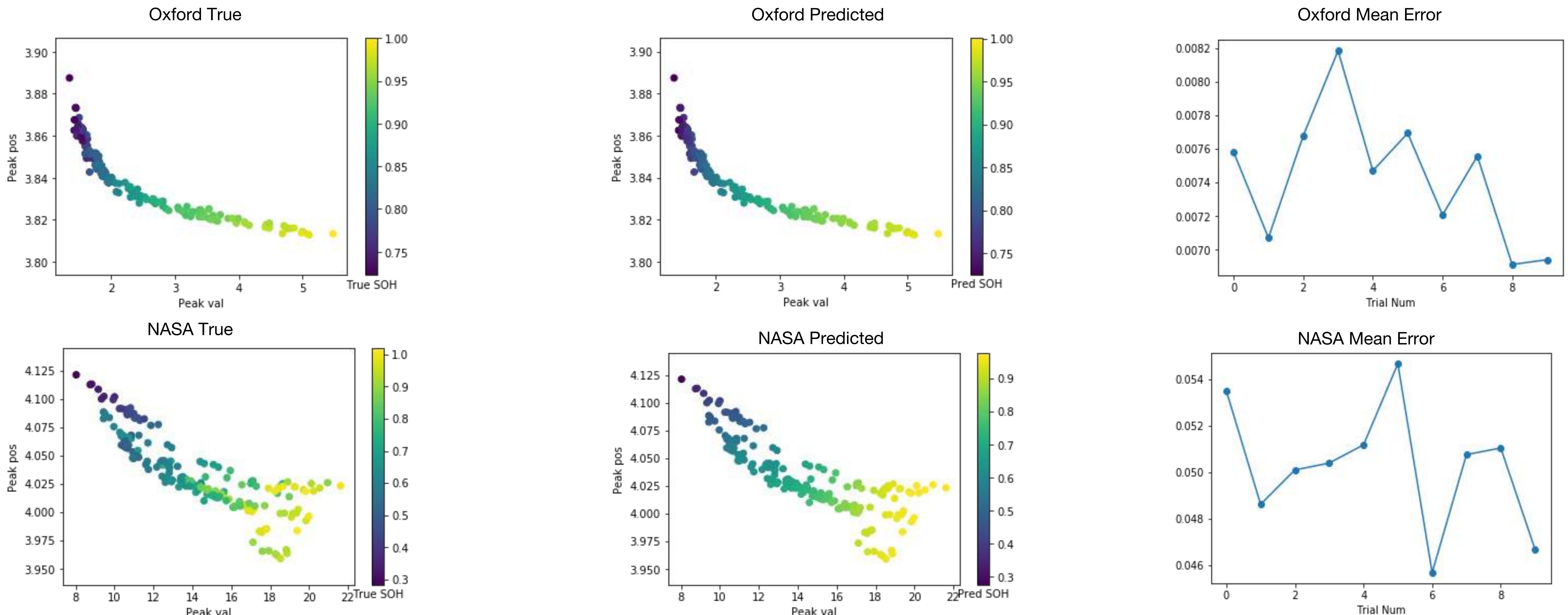
Model Validation

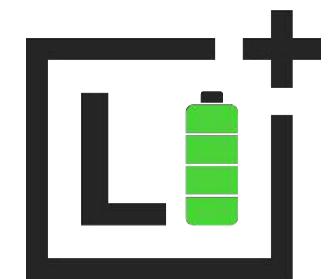
- Gaussian Process model

$$x \sim \mathcal{N}(\mu, \Sigma); \quad p(x|\mu, \Sigma) = (2\pi)^{-\frac{D}{2}} |\Sigma|^{-\frac{1}{2}} \exp\left(-\frac{1}{2}(x - \mu)^T \Sigma^{-1} (x - \mu)\right)$$

- SE Covariance function - smoothness

$$k(x, x') = \nu^2 \exp\left(-\frac{(x - x')^2}{2l^2}\right)$$



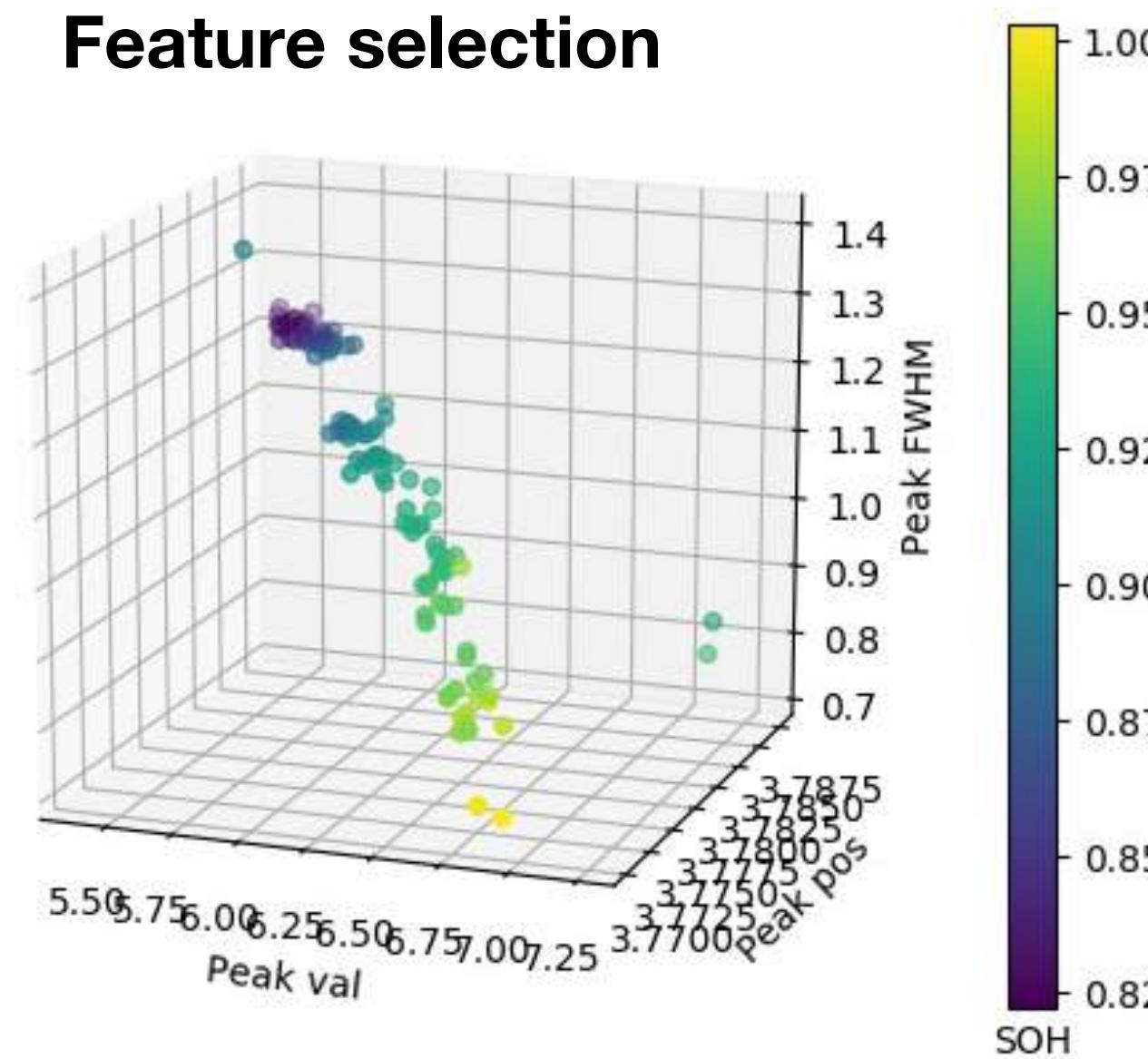


Software Package

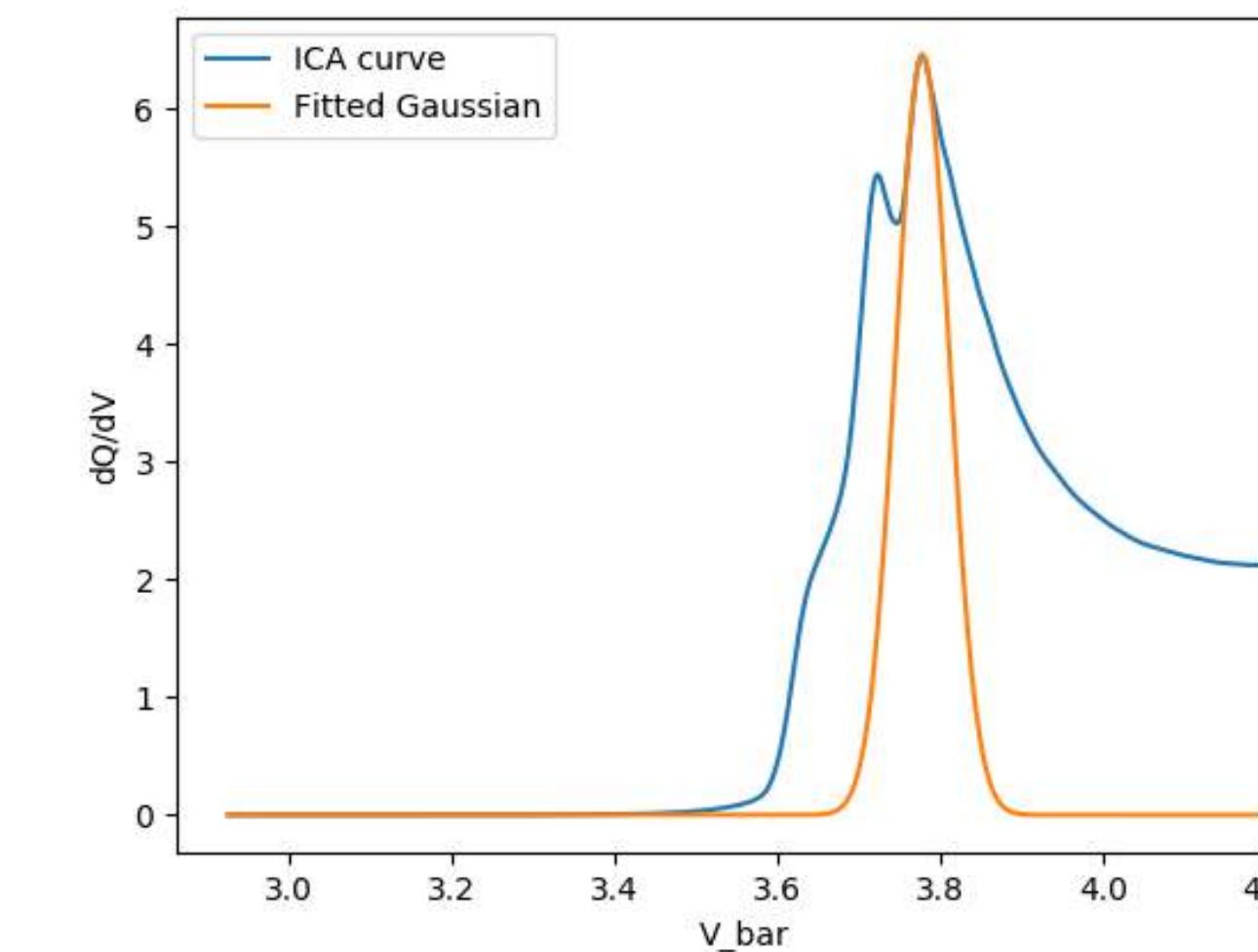
```
from battery_soh.data_processing import DataSet
from battery_soh.gp_model import SModel

test_data = DataSet("test_data.txt", L=20, N=2)
test_data.plot_data()
test_data.plot_ica(20, gauss=1)
```

Feature selection



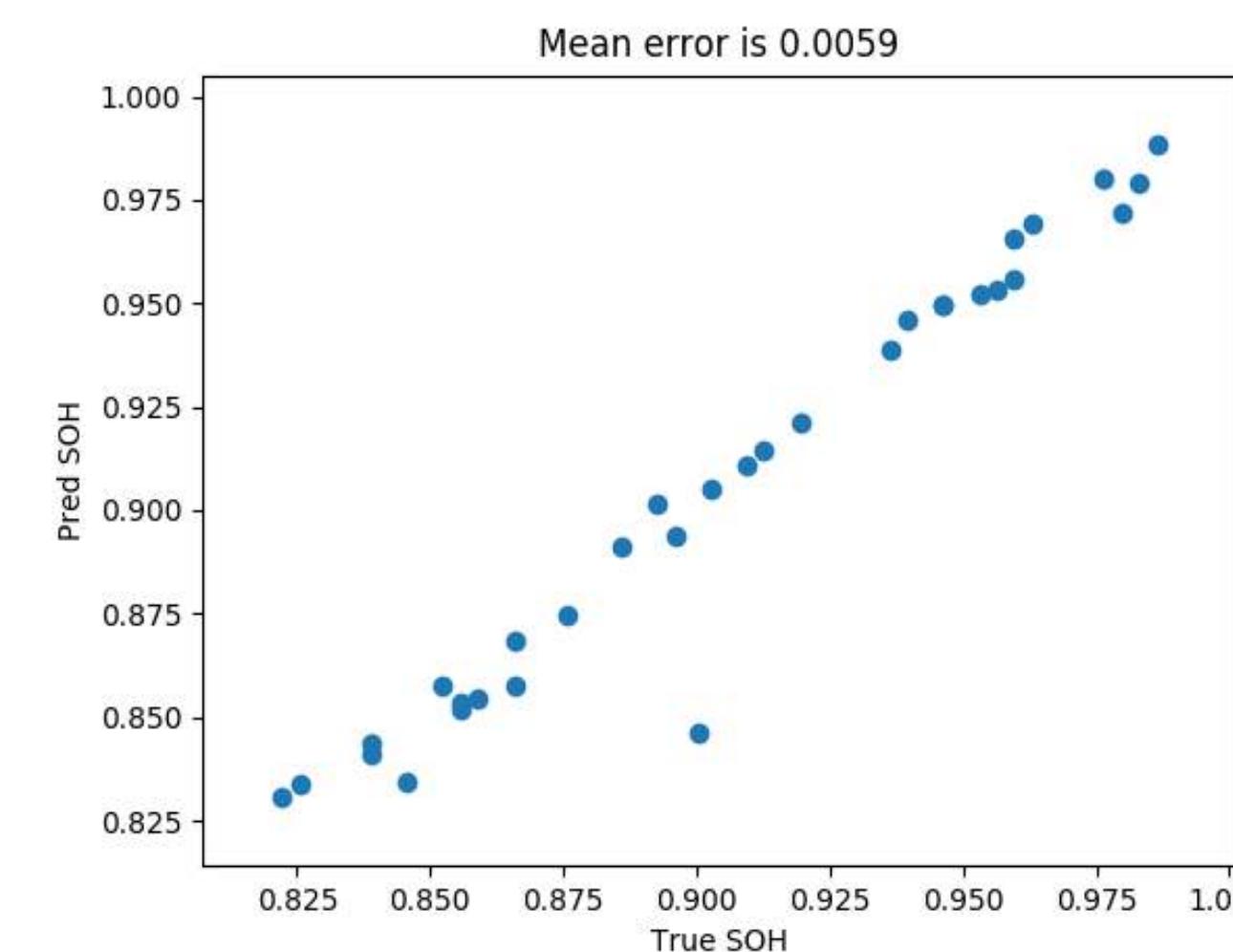
ICA parameters



```
from battery_soh.data_processing import DataSet
from battery_soh.gp_model import SModel

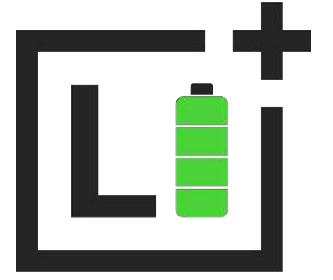
test_data = DataSet("test_data.txt")
test_model = SModel(test_data)
test_model.train(train_prop=0.7)
test_model.predict()
test_model.plot_pred()
```

GP model training



Error analysis

Mobile app – technical considerations



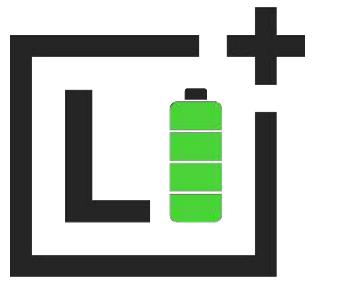
Cross-platform



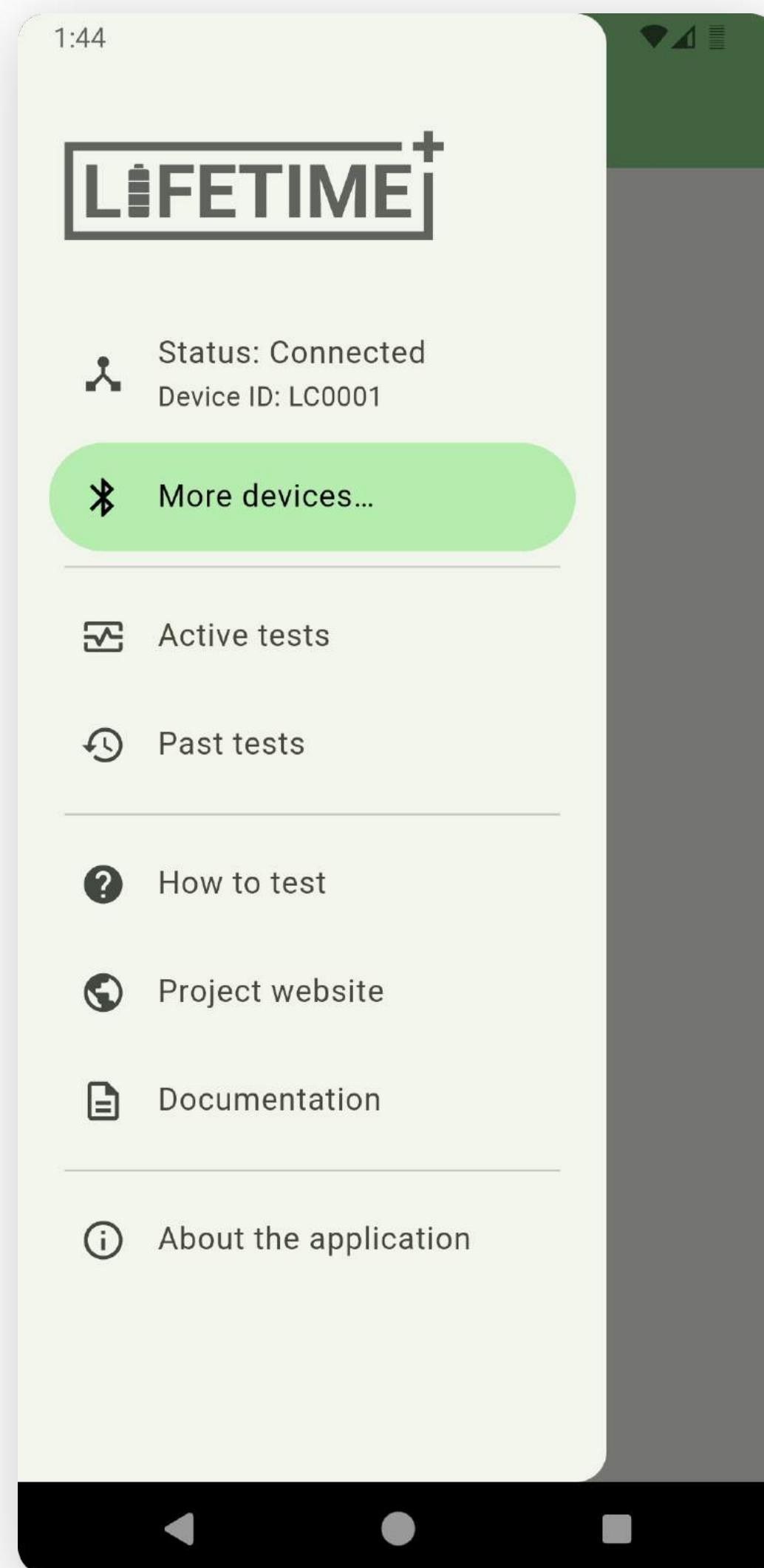
Sub-\$100 phones

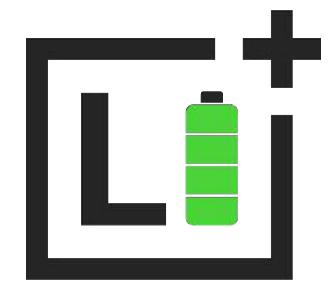


Customisable



App – Navigation Drawer



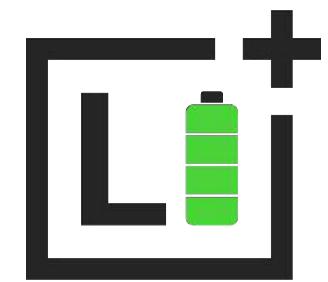


App – Available devices

The image shows two screenshots of the Lifetime+ mobile application. The left screenshot displays the main menu with a connection status message: "Status: Connected" and "Device ID: LC0001". It also features a green button labeled "More devices...". The right screenshot shows a list titled "Available devices" with three entries:

Device ID	Signal strength
LC0001	High
LC0002	High
LC0003	Medium

A large black arrow points from the left screen to the right screen, indicating the transition or flow between the two views.



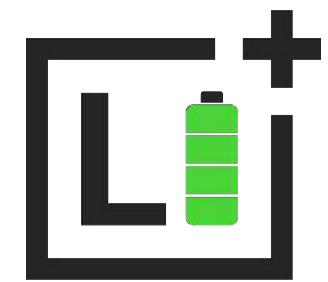
App – Active tests – In progress

The image shows two screenshots of the LIFETIME+ mobile application. The left screenshot displays the main menu with the following options:

- Status: Connected
Device ID: LC0001
- More devices...
- Active tests** (highlighted with a green background)
- Past tests
- How to test
- Project website
- Documentation
- About the application

The right screenshot shows the "Active tests" screen with eight slots, each represented by a map icon and a battery icon with a lightning bolt. The slots are labeled and their status is indicated as follows:

Slot	Status
Slot 1	Testing in progress
Slot 2	Testing in progress
Slot 3	Testing in progress
Slot 4	Testing in progress
Slot 5	Testing in progress
Slot 6	Testing in progress
Slot 7	Testing in progress
Slot 8	Empty



App – Active tests – Done

The image shows two screenshots of the LIFETIME+ mobile application. The left screenshot displays the main menu with a green callout highlighting the 'Active tests' option. The right screenshot shows the detailed results of the active tests.

Left Screenshot (Main Menu):

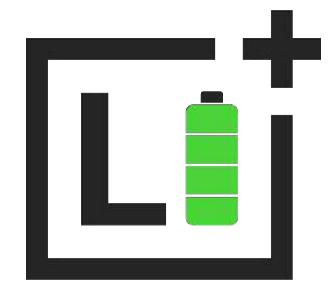
- Status: Connected
- Device ID: LC0001
- More devices...
- Active tests** (highlighted in green)
- Past tests
- How to test
- Project website
- Documentation
- About the application

Right Screenshot (Test Details):

9:20

Test details

Cell	Health (%)	Capacity (mAh)
Cell 1	81%	2106 mAh
Cell 2	64%	1690 mAh
Cell 3	75%	1950 mAh
Cell 4	58%	1508 mAh
Cell 5	28%	728 mAh
Cell 6	73%	1898 mAh
Cell 7	87%	2262 mAh
Slot 8		Empty



App – Past tests

The image shows two screenshots of a mobile application interface. The left screenshot displays the main menu with options like 'Status: Connected', 'More devices...', 'Active tests', and 'Past tests'. The 'Past tests' option is highlighted with a green background. The right screenshot shows a list of past test results for four cells, each with a battery icon, health percentage, capacity, and a timestamp indicating it finished today at 11:27.

9:20

LIFETIME+

Status: Connected
Device ID: LC0001

More devices...

Active tests

Past tests

How to test

Project website

Documentation

About the application

9:20

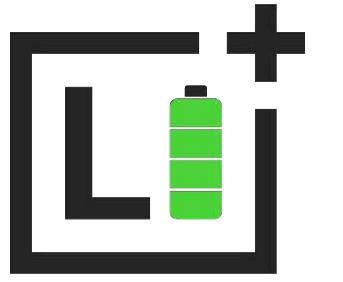
Past tests

Cell 1 health: 21% • Capacity: 546 mAh
Test finished today at 11:27

Cell 2 health: 75% • Capacity: 1950 mAh
Test finished today at 11:27

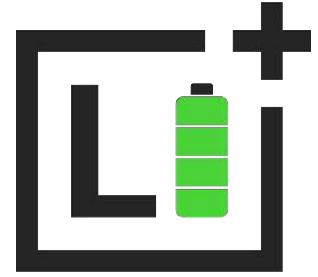
Cell 3 health: 81% • Capacity: 2106 mAh
Test finished today at 11:27

Cell 4 health: 87% • Capacity: 2262 mAh
Test finished today at 11:27



OUTREACH

The website – technical considerations



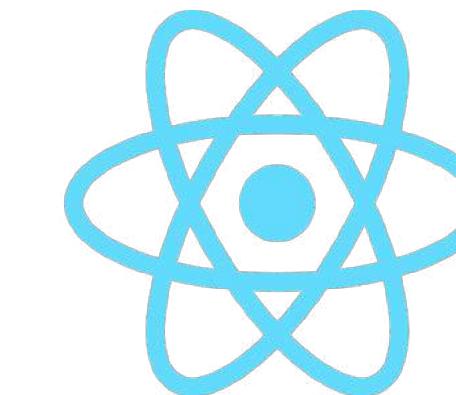
- Must look professional and include engaging visual elements
- Must work on both mobile and desktop devices (i.e., responsive design)
- Must be easy to edit by a non-professional software developer



Plain HTML, CSS,
and JS



TypeScript
and Vite



React

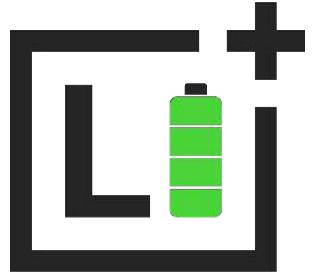
NEXT



Next.JS

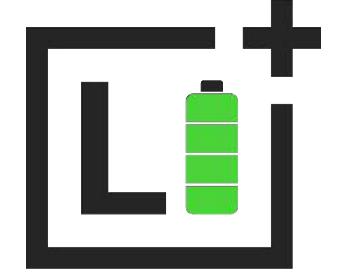
Svelte

LifetimeCambridge.co.uk



The screenshot shows a web browser window for 'Lifetime Cambridge' at 'lifetimecambridge.co.uk'. The page has a dark background featuring a collage of various battery brands like Duracell and Energizer. The 'LIFETIME+' logo is in the top left. A navigation bar at the top right includes 'Home', 'Impact', 'Technology', 'People', and 'Contact'. The main headline 'Enabling second-life batteries' is in large white text on the left. Below it is a paragraph about the service: 'Lifetime is a low-cost, open-source solution for cell health testing for second-life battery applications.' To the right is a green button with the text 'Get the tech and start testing' and a battery icon. The browser interface shows standard controls and a lock icon.





Open-Source Documentation

CERN-OHL-P

GitHub

LifetimeCambridge / [lifetimecambridge.github.io](#) (Public)

Code Issues Pull requests Actions Projects Security Insights

main · 1 branch · 0 tags

tp530 Add TryKe to Partners 2635036 10 hours ago 6 commits

- css Add TryKe to Partners 10 hours ago
- fonts Add initial implementation 4 days ago
- images Add TryKe to Partners 10 hours ago
- js Add navigation menu yesterday
- CNAME Create CNAME 4 days ago
- LICENSE Initial commit 4 days ago
- contact.html Add TryKe to Partners 10 hours ago
- favicon.ico Add initial implementation 4 days ago
- impact.html Add TryKe to Partners 10 hours ago
- index.html Add TryKe to Partners 10 hours ago
- people.html Add TryKe to Partners 10 hours ago
- tech.html Add TryKe to Partners 10 hours ago

PCB Fabrication

Power Distribution Board

Parts

- 1 [Copper Board](#)

Tools

- 1 [Drill](#)
- 1 [Inkjet Printer](#)
- 1 [Tongs](#)
- 1 [UV Box](#)

Chemicals

- 1 [Alkaline Solution \(NaOH\)](#)
- 1 [Ferric Chloride \(Fe\(III\)Cl3\)](#)
- 1 [Green Protective Coating](#)
- 1 [Tinning Solution](#)

Step 7: Etching

- Place the board inside [Ferric Chloride \(Fe\(III\)Cl3\)](#), apply heat and constant stirring, which will etch away unwanted copper.

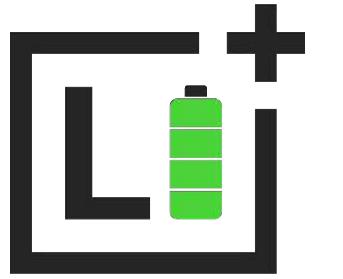


Caution

Ferric Chloride is toxic, so keep the container closed at all times.

- Etch for 20 minutes or until all the exposed copper is washed away.

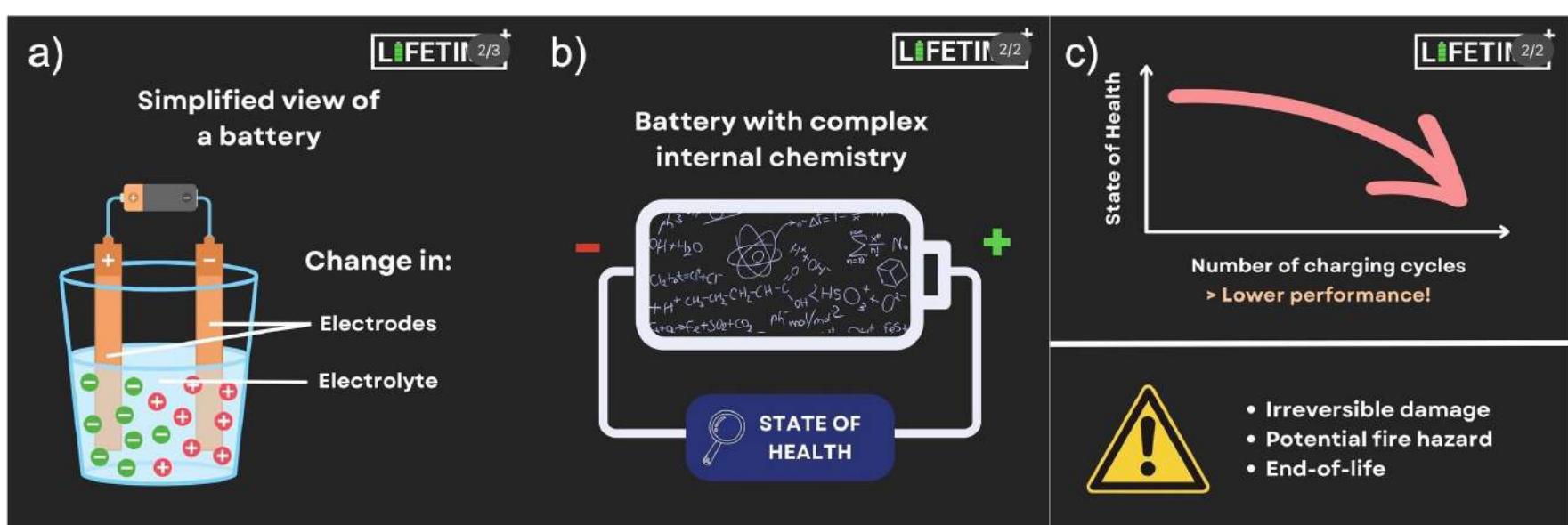




Social media



@lifetimecambridge



@lifetimecamb



LIFETIME @Lifetimecamb · 4d

💡 Our hardware team has been busy building the #PCB for our #battery cycler. Stay tuned for more posts explaining the exact workings of our device!



<https://www.linkedin.com/company/lifetimecambridge/>



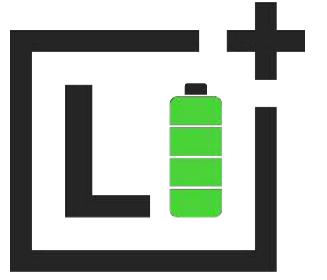
LIFETIME
4 followers
4d · 0

🔋 The performance of #batteries deteriorates with use, which is due to mechanisms that alter a battery's interior #chemistry. With an increasing number of #charging cycles, the #stateofhealth of a battery decreases until it cannot be used for energy-intensive applications.



What is battery health, and why is it important?

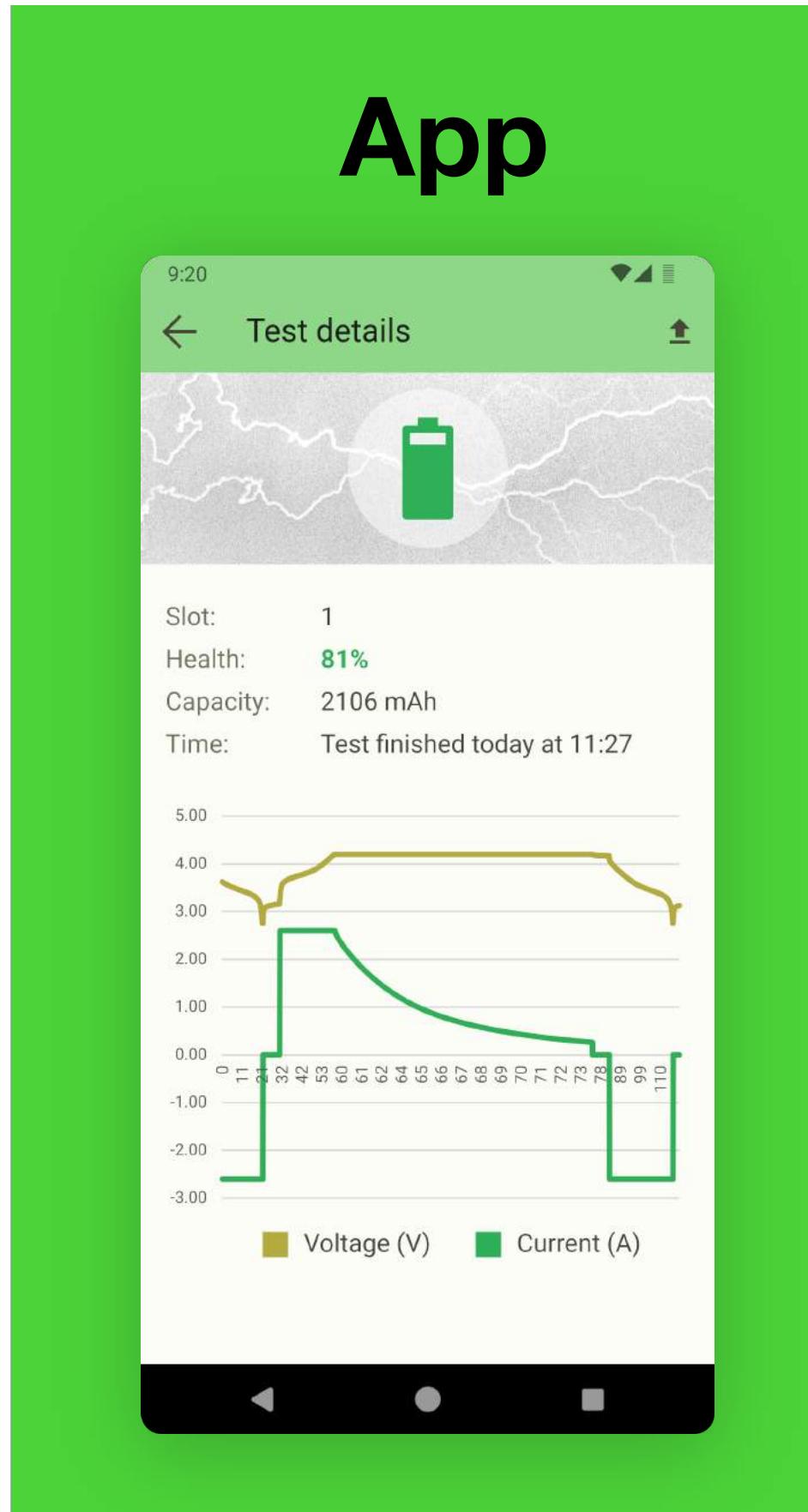
Future work



Hardware

Single cell
prototype

Device refinement



Software

Improve model with
our dataset

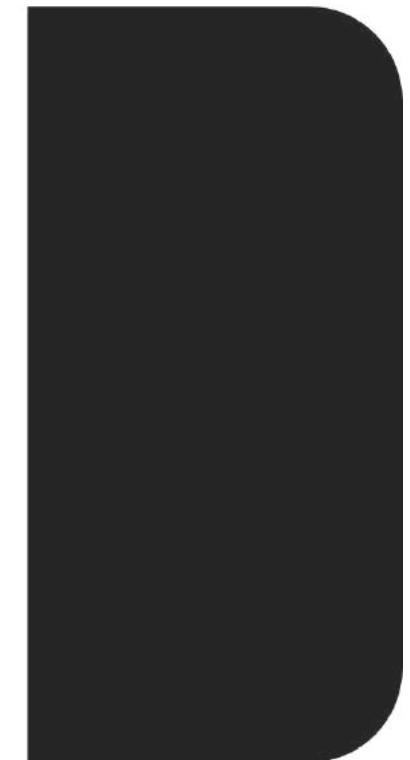
Further cultivate
dataset

Outreach

Policy discussions
with KEBS

Development i-
Teams

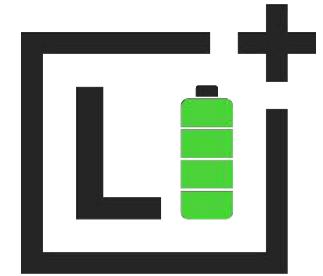
Co-creation
workshops with
collaborators in
Kenya



Department of Chemical Engineering and Biotechnology

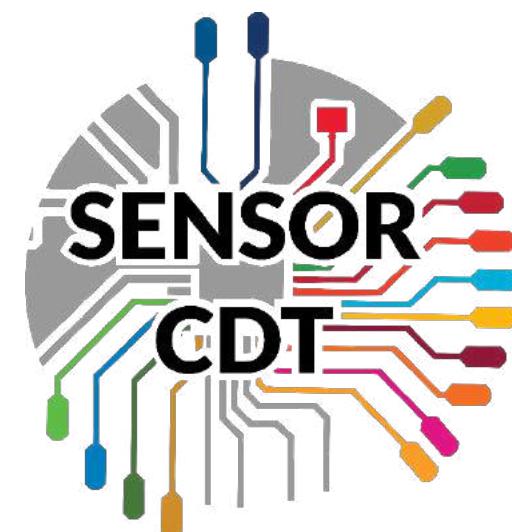


Acknowledgements



This project would not have been possible without the support and advice from:

Sensor CDT administration



Lara Allen
Centre for Global Equality



**All our collaborators and advisors,
with special thanks to:**



EPSRC

Engineering and
Physical Sciences
Research Council



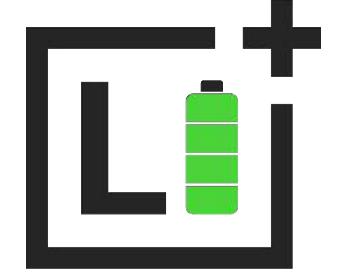
Mark Scudder & Josh Easy
Makerspace

Svetlana Menkin Bachbut
Department of Chemistry

Tijmen Euser
Department of Physics

Adam Boies & Maurits Houck
Energy Group
Department of Engineering





References

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https://www.cas.org/sites/default/files/documents/%7B653f1a27-cad6-41ad-b065-c6e0bfb38ebf%7D_CASGENENGWHP100560220101-LIB_Recycling-White-Paper.pdf

