LIFETIME

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

Enabling second-life battery production

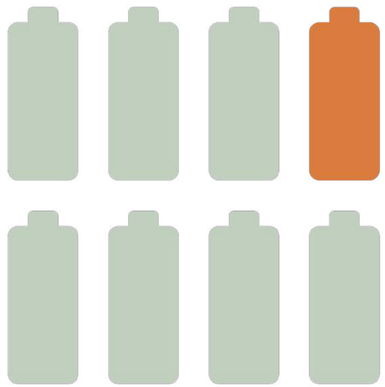
UNIVERSITY OF CAMBRIDGE

Centre for Global Equality

SENSOR CDT

UKRI Engineering and Physical Sciences Research Council

End-of-life Electric Vehicle Batteries



Landfills

95%

Materials recycling

<5%

Reuse

negligible

Problem

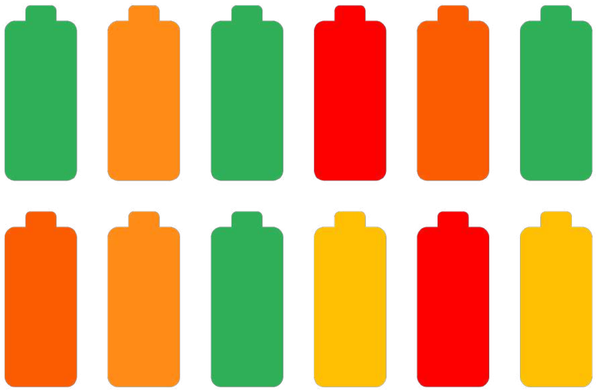
Used **lithium-ion batteries** from **electric vehicles (EVs)** sent to landfill

Solution

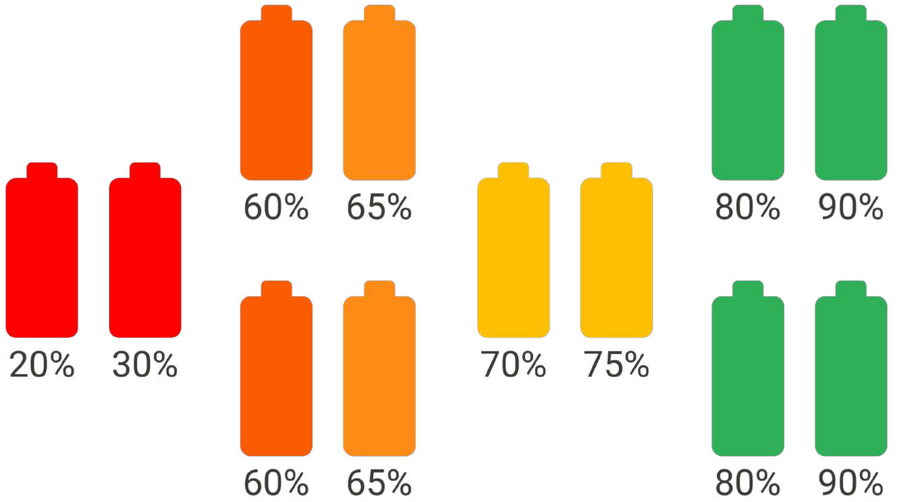
Reuse of EV battery cells for reuse in second-life applications

HOW?

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

- Component availability
- Diversity of battery types
- Battery safety
- Government guidelines
- Time efficiency
- Accuracy

Requirements

- ✓ Cost-effective and accessible materials
- ✓ Open-source
- ✓ Safe
- ✓ User-friendly
- ✓ Portable

Our approach

MARKET RESEARCH

- Industry needs
- End-users
- Impact

HARDWARE

- Capacity measurements
- Charge and discharge
- Cell cycling toolkit

SOFTWARE

- Data-driven modelling approach
- Incremental Capacity Analysis
- Dataset, software package & app

OUTREACH

- Education campaign
- Open-source community
- Co-creation workshops

MARKET RESEARCH

HARDWARE

SOFTWARE

OUTREACH

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Hardware / Outreach

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Hardware

Tomas Paulik

Software

Aparna Kaaraal Mohan

Outreach

Alec Sargood

Modelling

MARKET RESEARCH

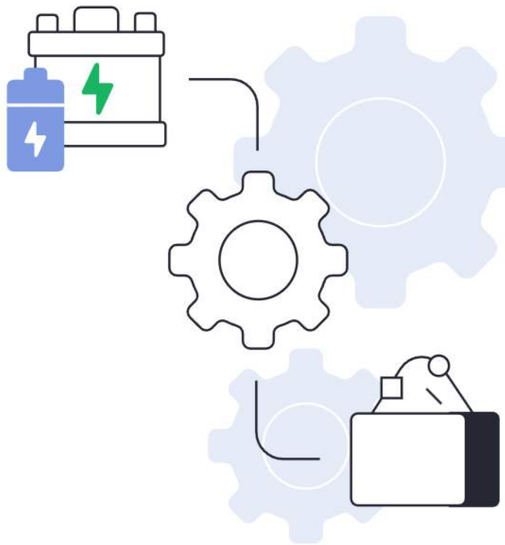
The most common process that used batteries are subjected to is *recycling.*

ACE Green Recycling

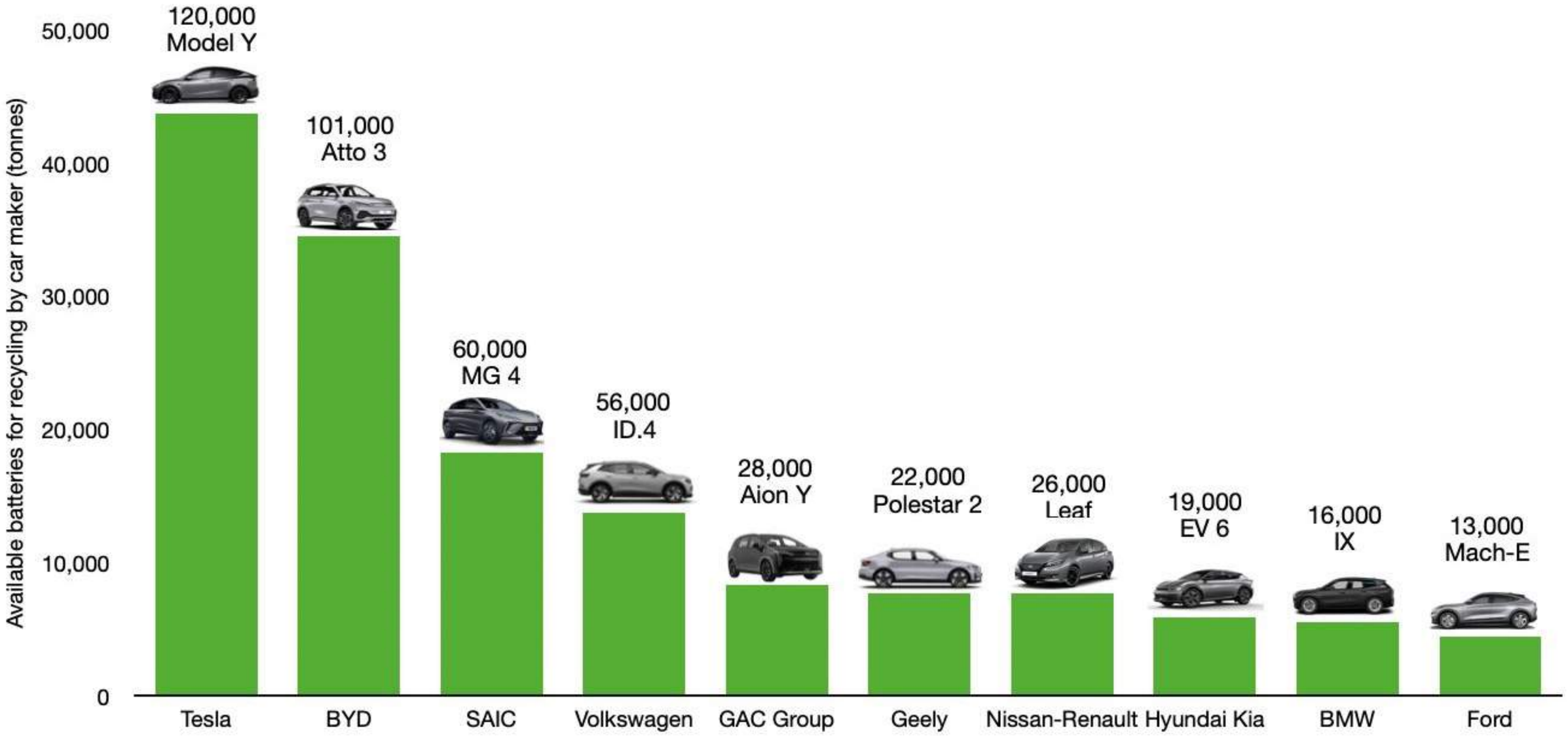
Li-Cycle®

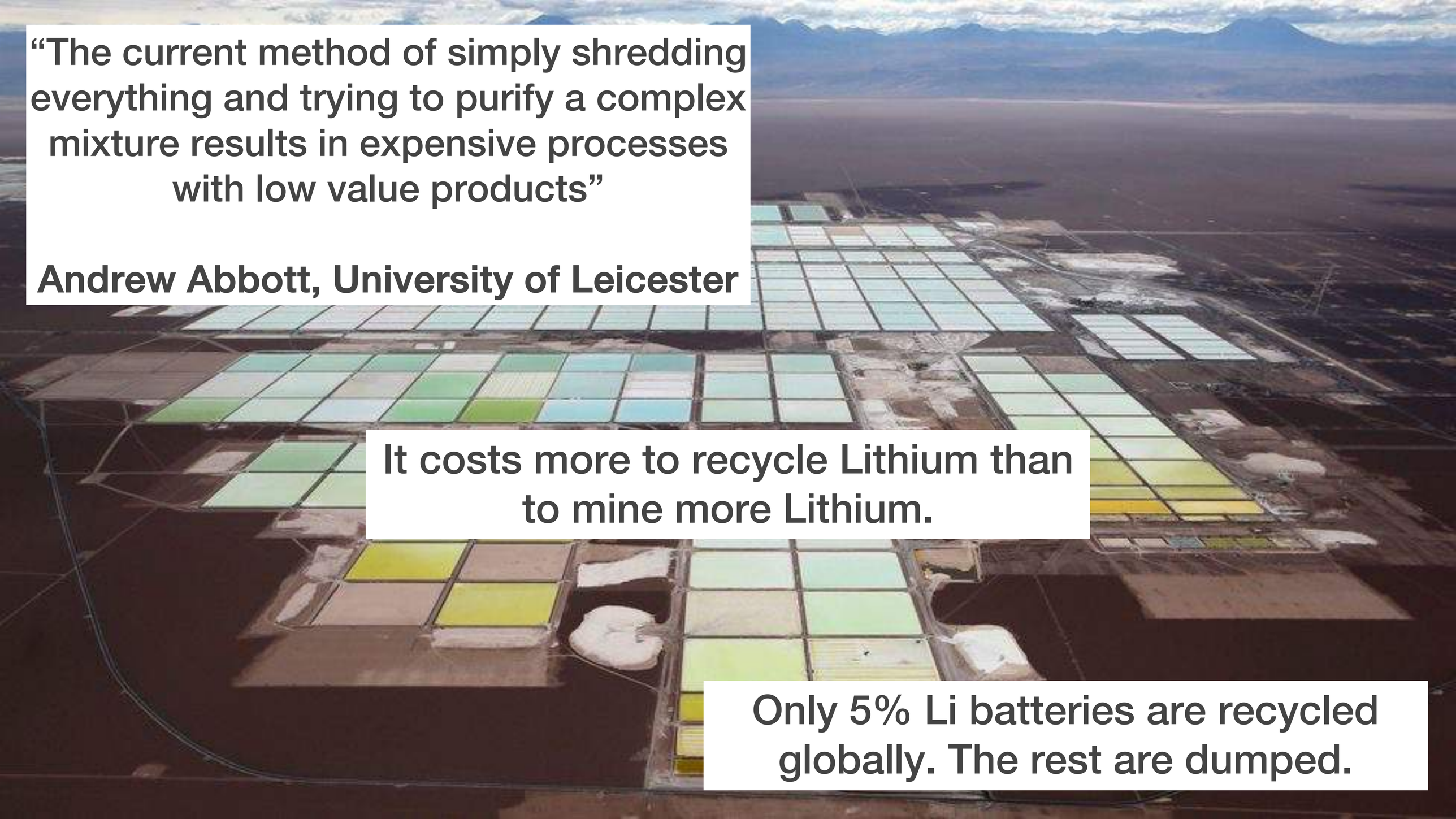
RecycLiCo™
BATTERY MATERIALS

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.

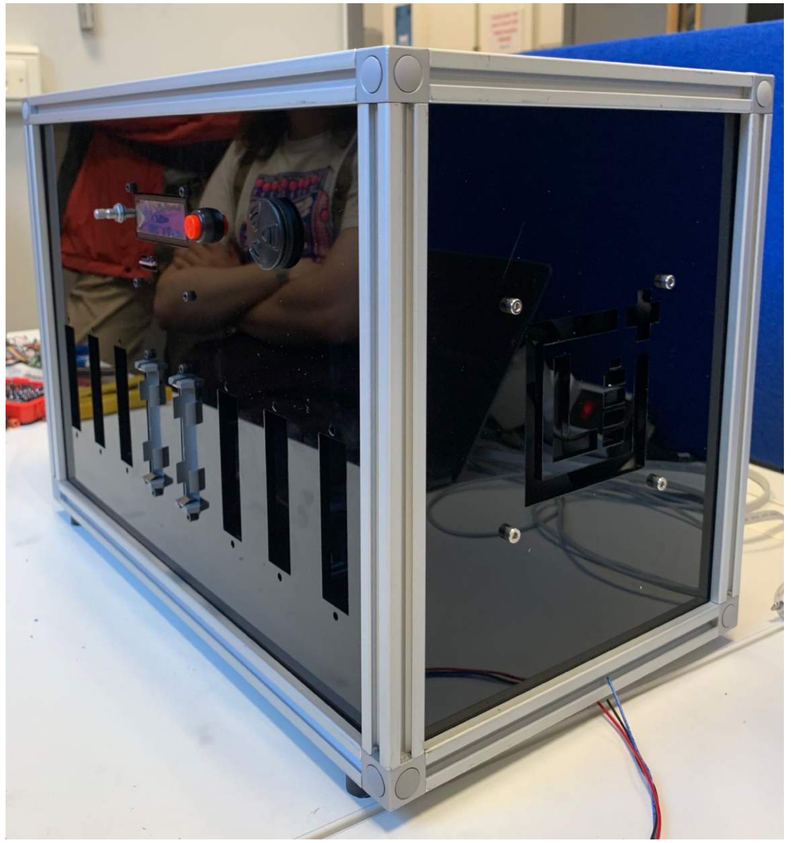
Only 5% Li batteries are recycled globally. The rest are dumped.

The star solution – *Reuse*


HARDWARE

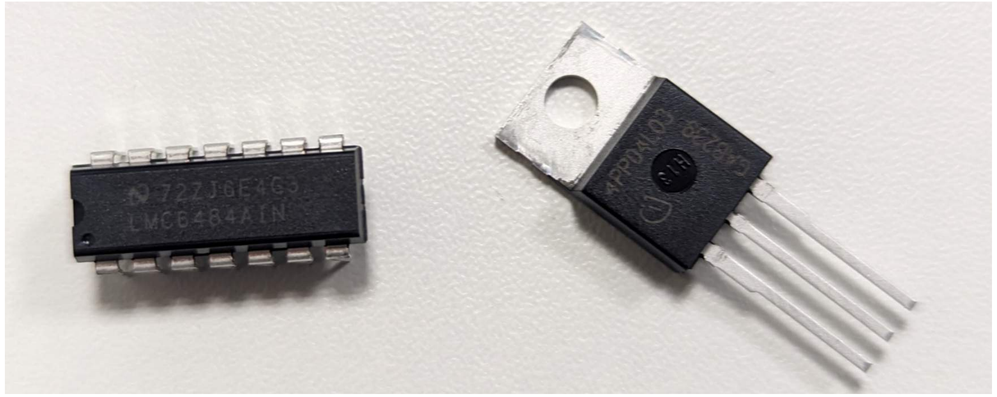
Specification

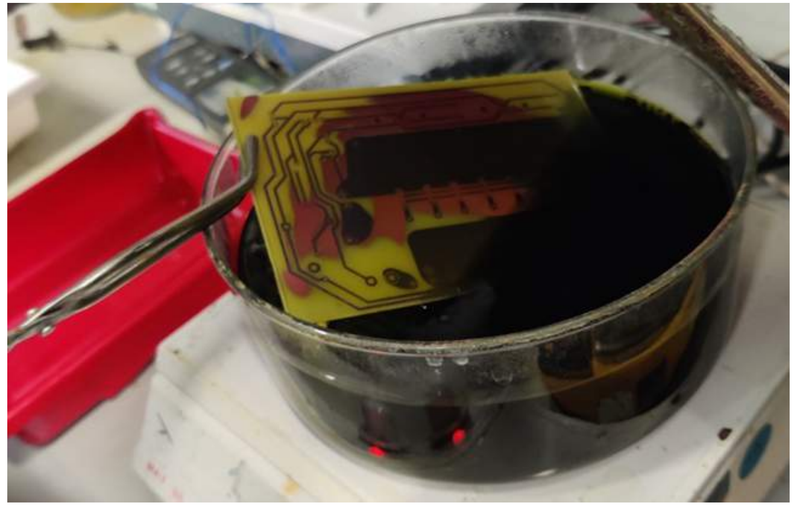
- Pico W microcontroller – on board Bluetooth
- Up to 8 channels (dis)charge with programmable current
- Current and voltage measurement on all cells.
- User interface with physical controls and LCD screen.
- Power supply has capacity for all channels at maximum charge current

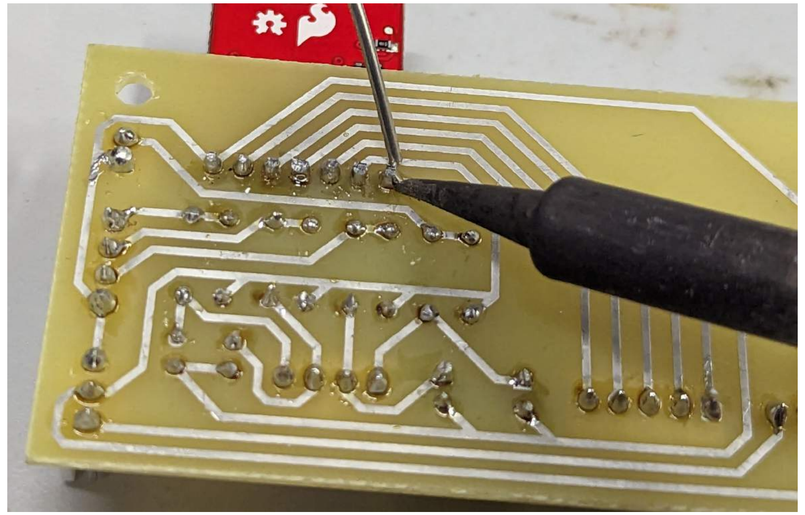


Part & Process Selection

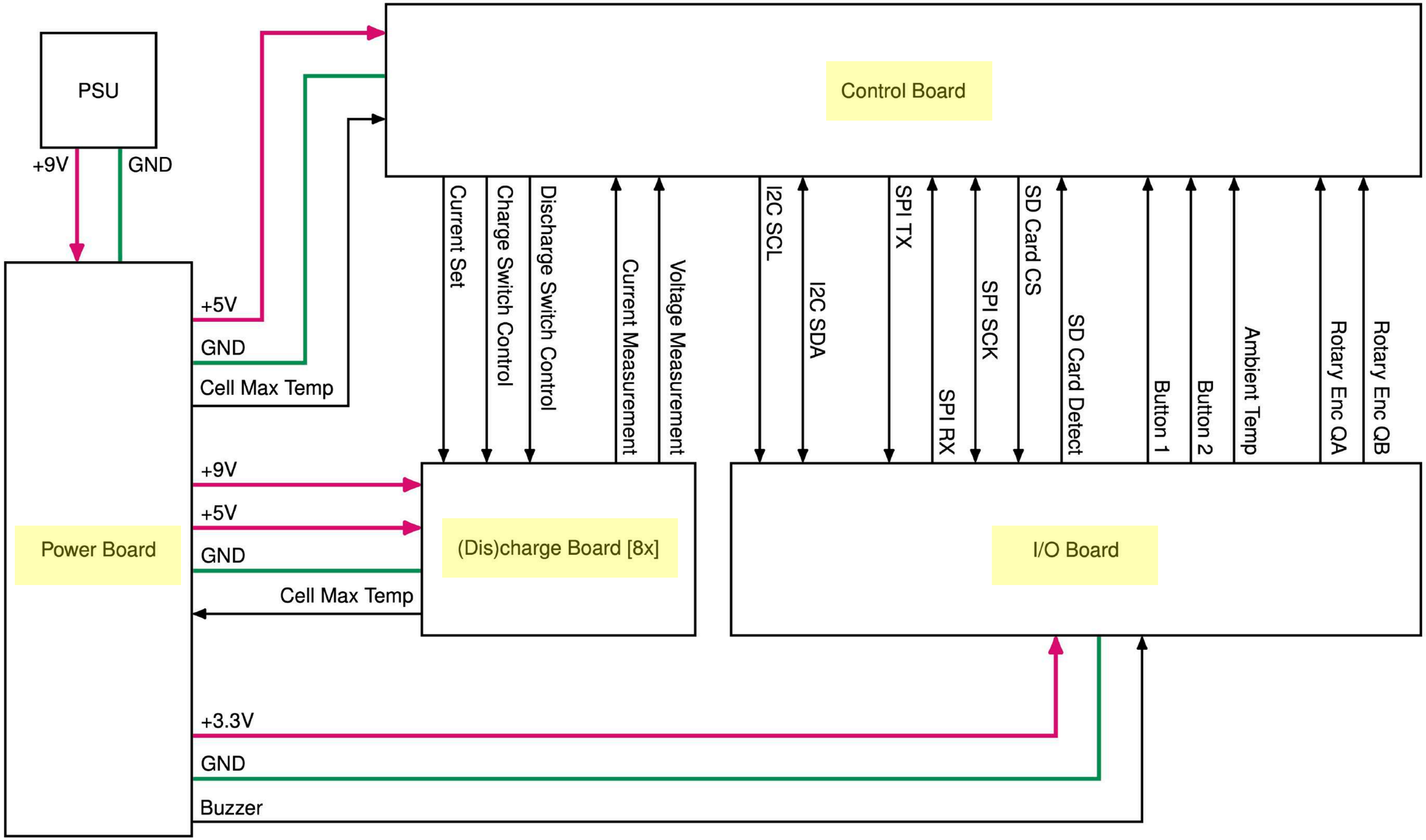
- Parts should be like-for-like interchangeable.
- Through hole rather than surface mount.
- Single sided PCBs, more complicated to route but easier to fabricate.
- Relatively large PCB traces increase tolerance when fabricating.



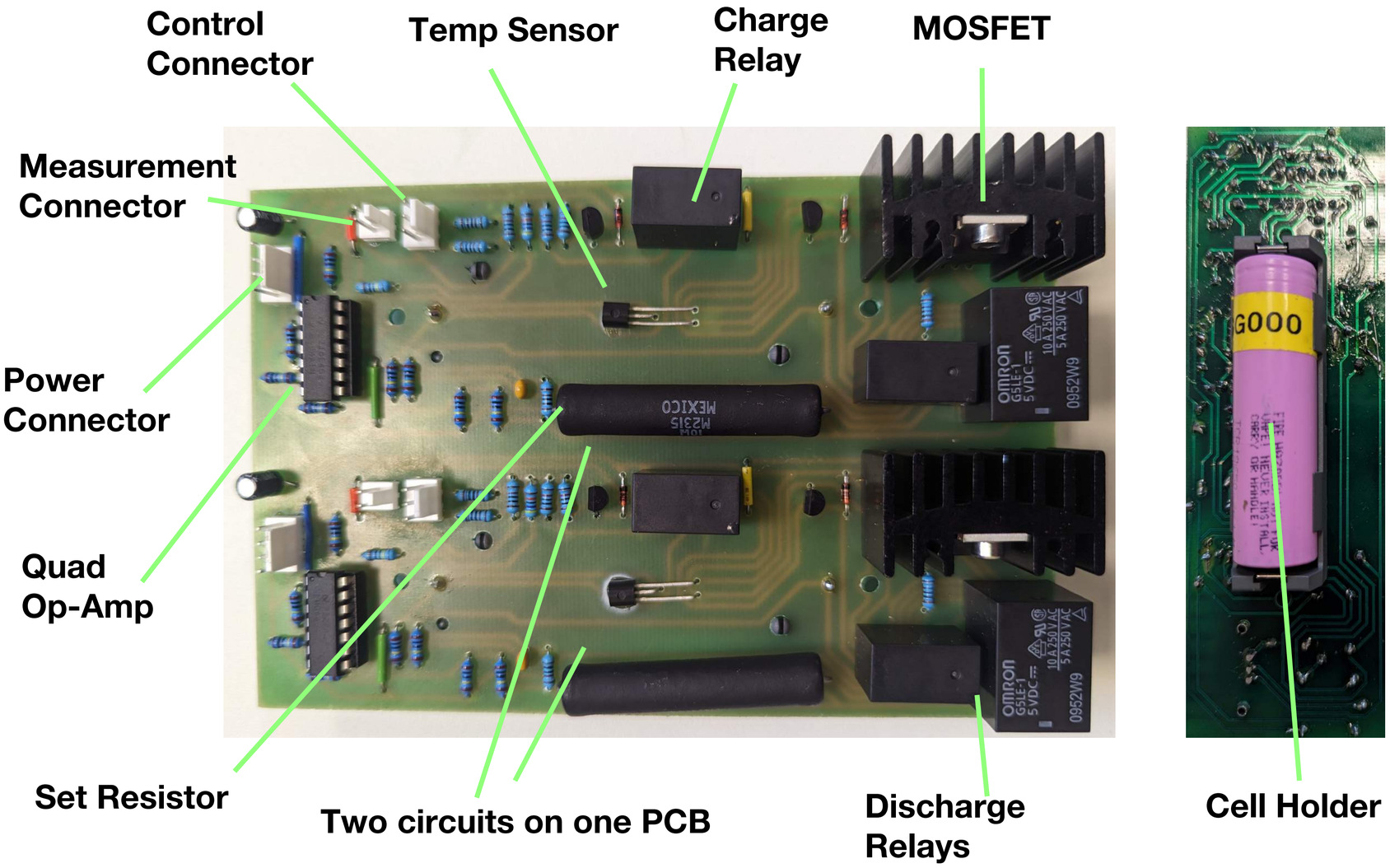




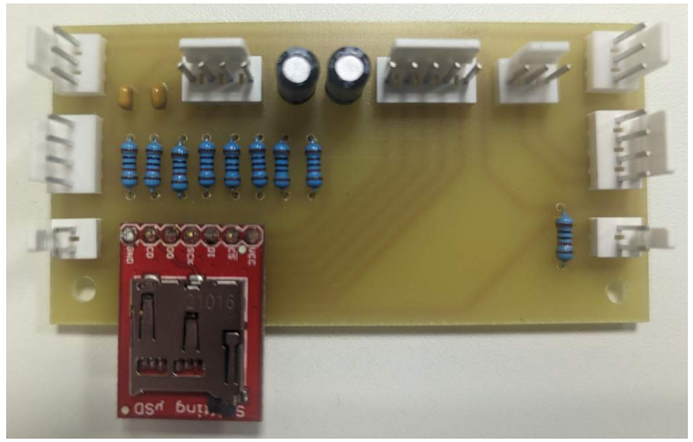
Electronics Overview



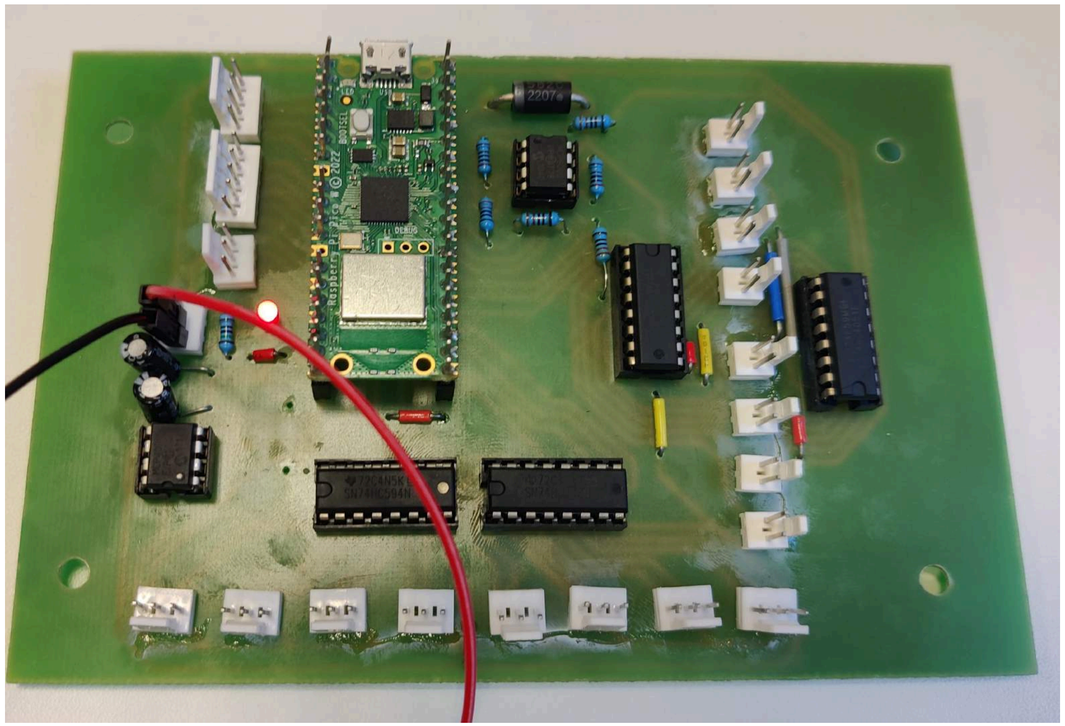
(Dis)charge boards



IO board



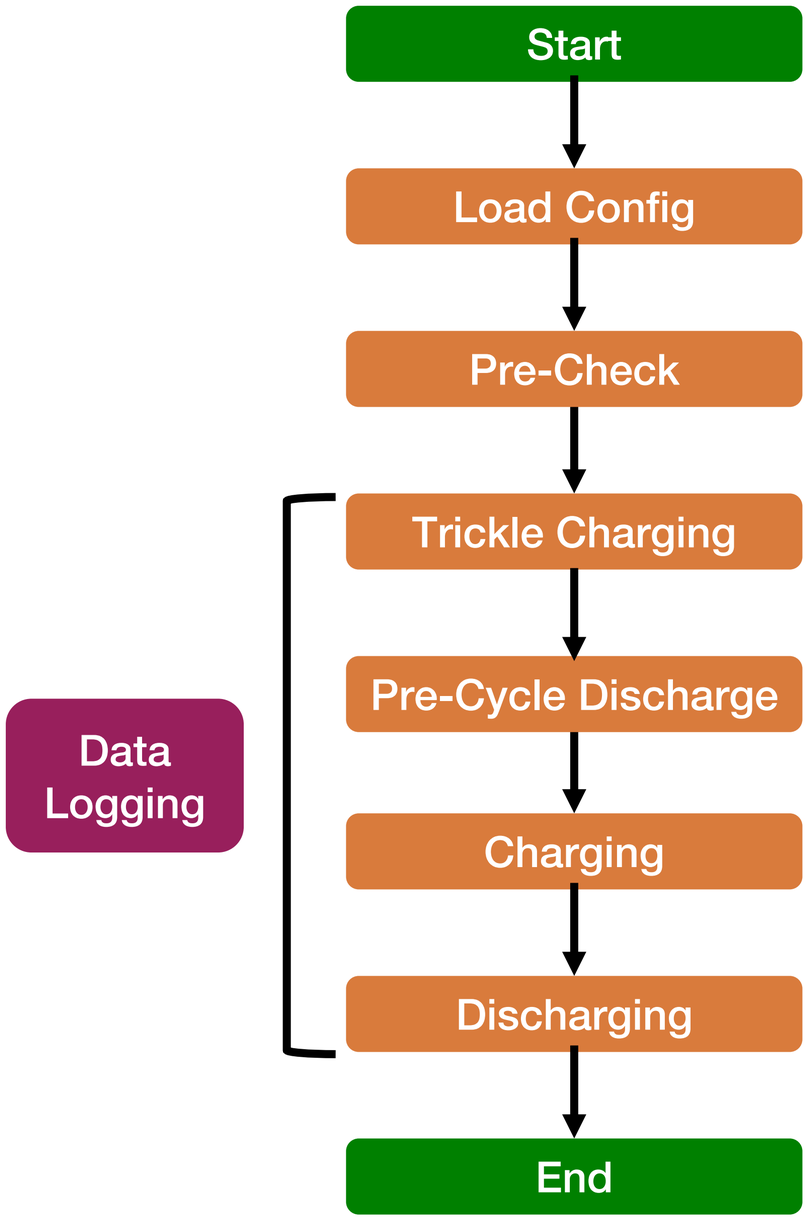
Control board



Power distribution

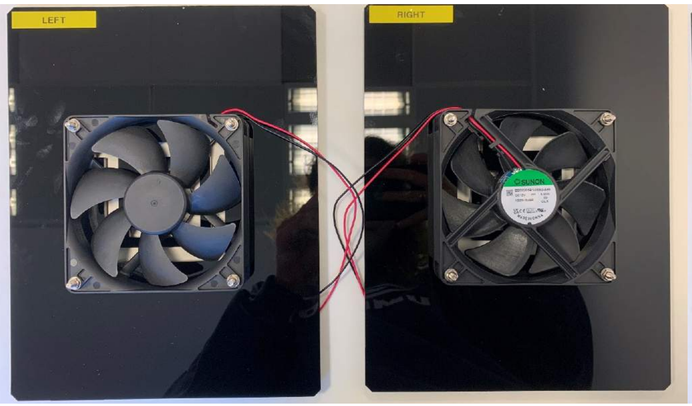
Firmware

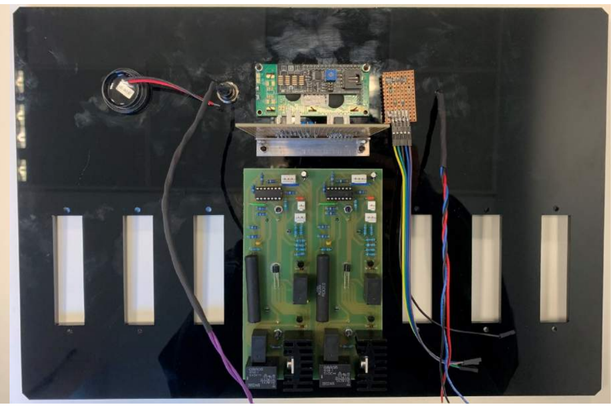
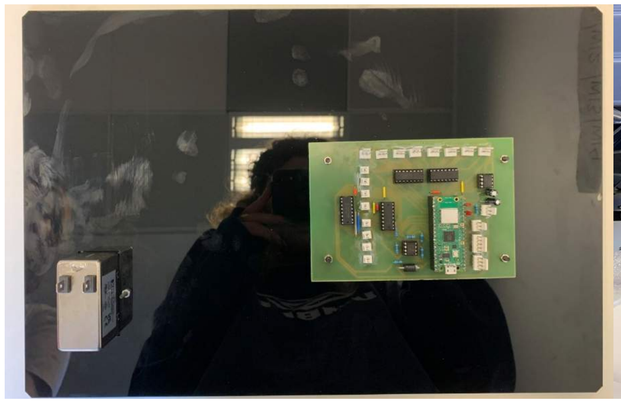
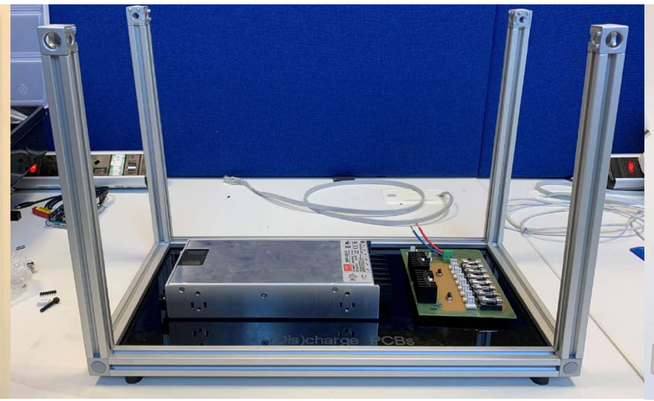
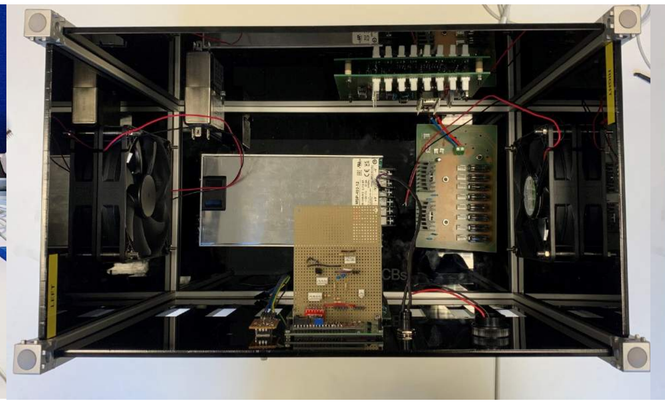
- Structured as a state machine
- Ensures robust, safe, logical operation
- Key parameters set by config file (no coding required)



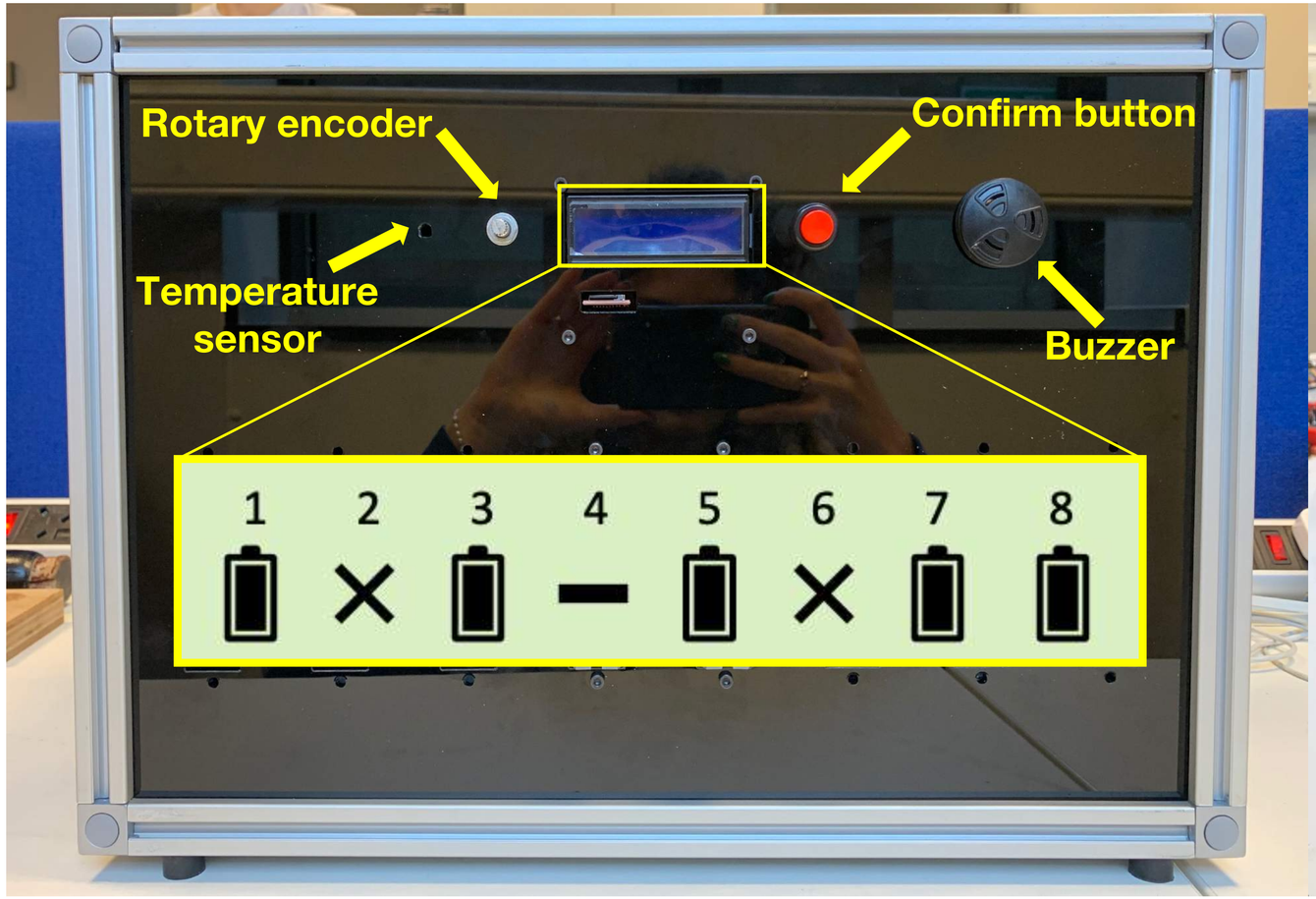
Assembly

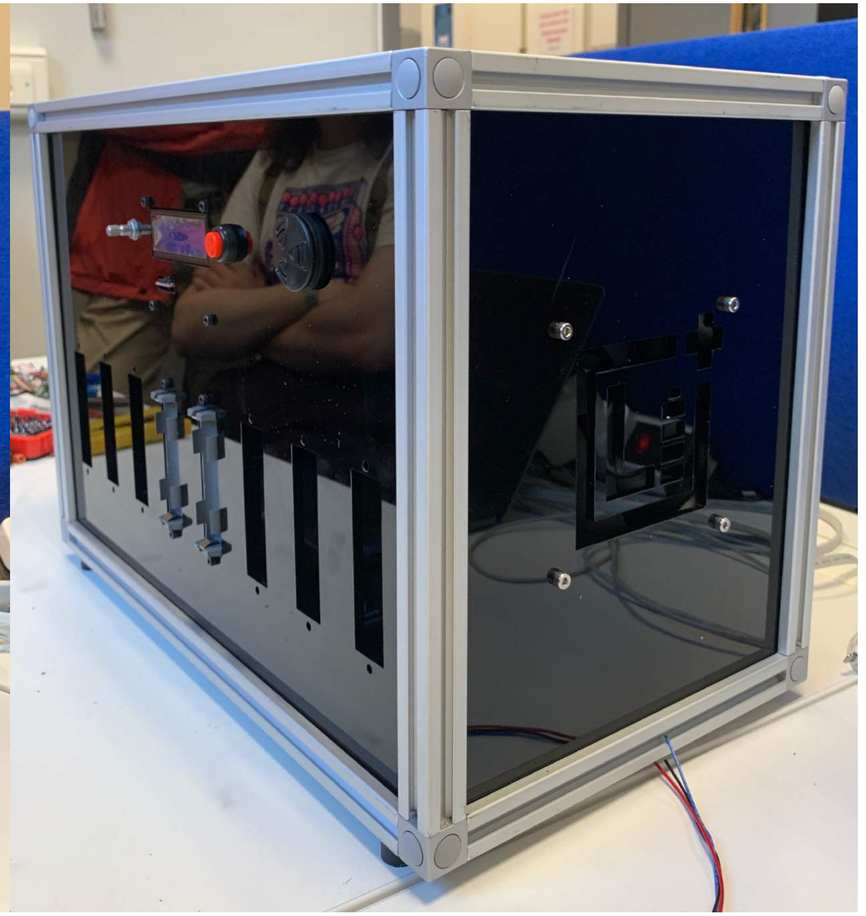





Assembled prototype





*Perspex can be very reflective ☺

Single-cell prototype

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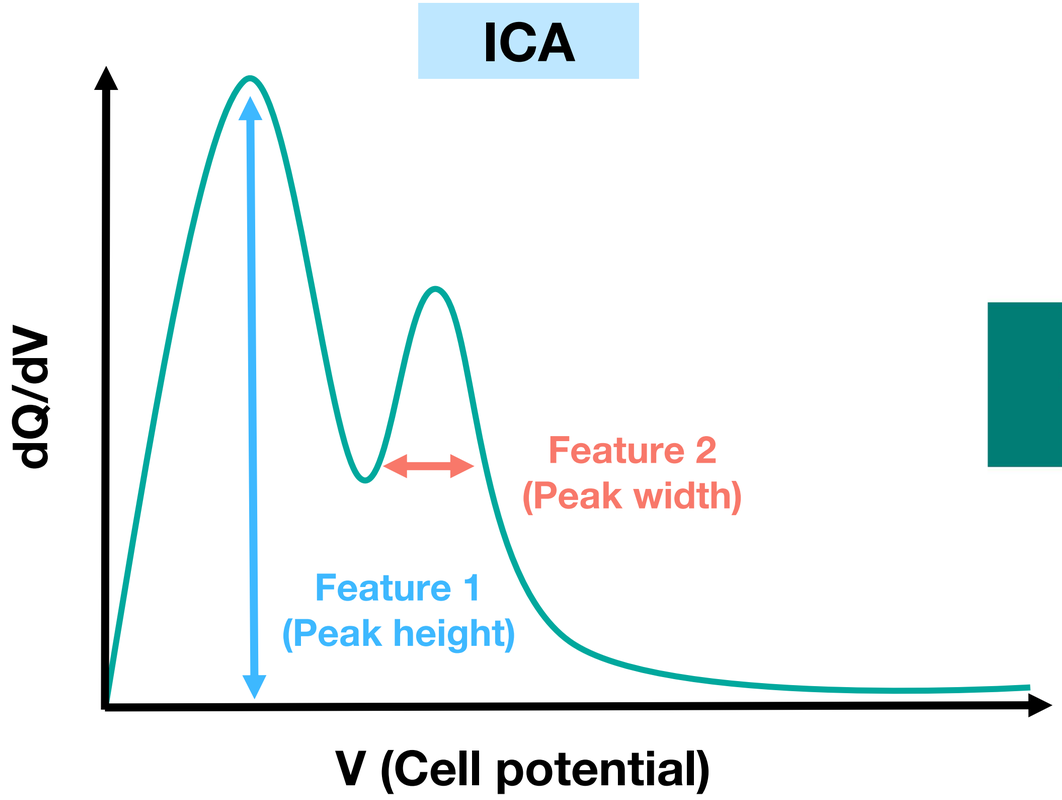
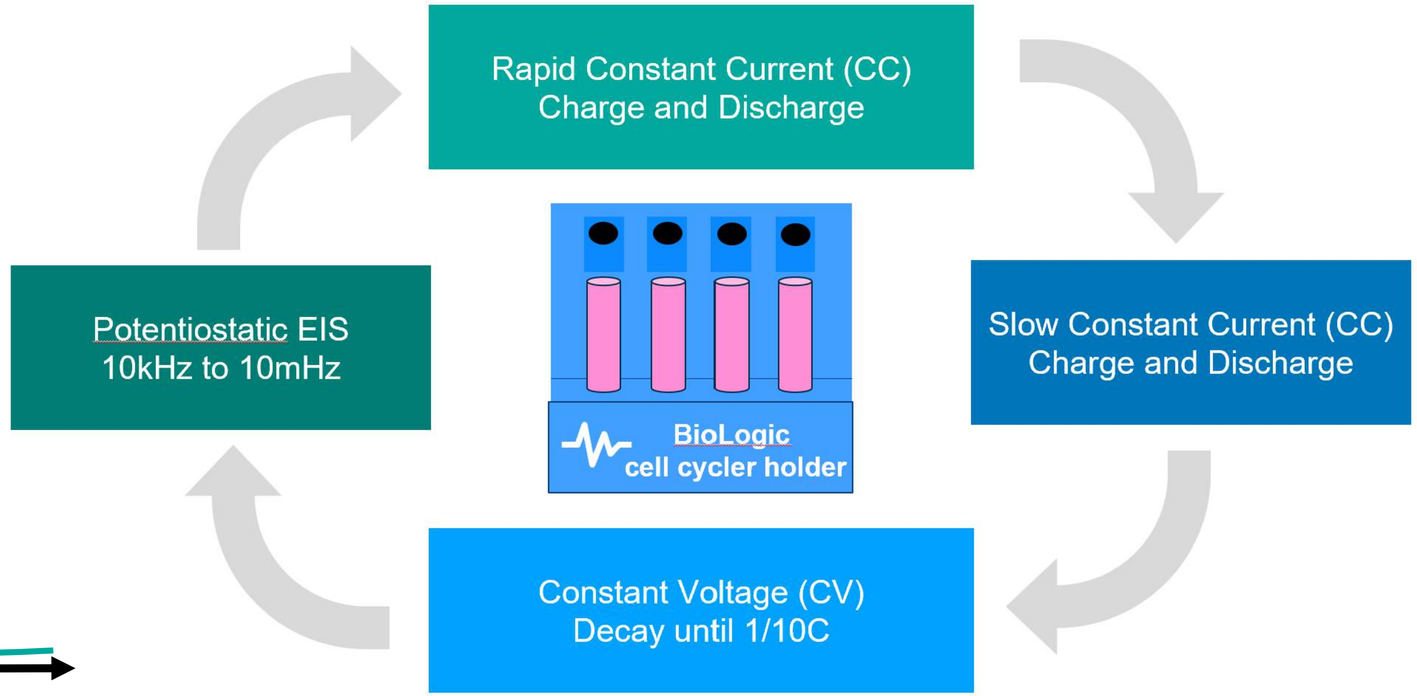
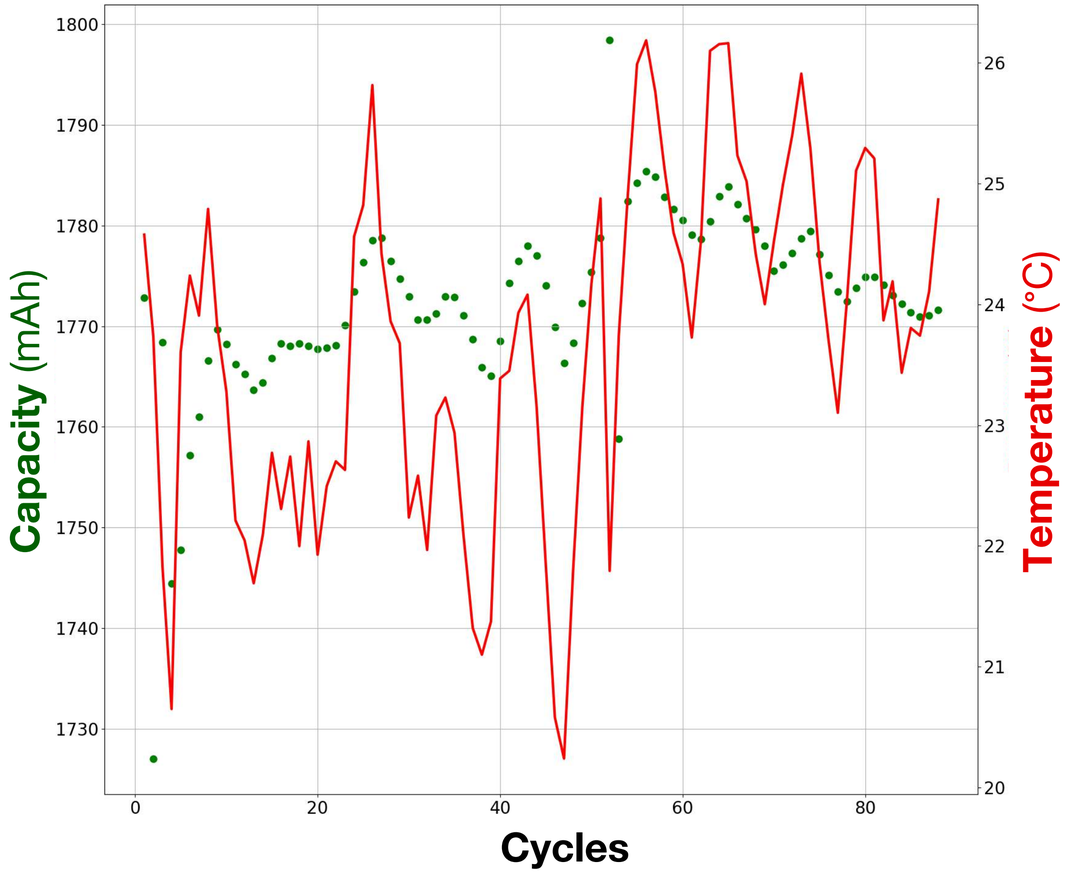
SOFTWARE

Battery cycling



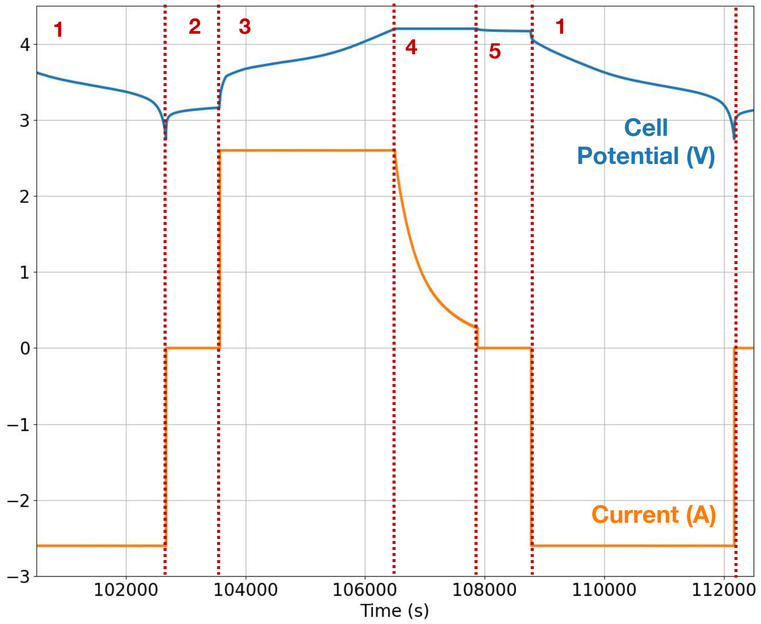


Battery cycling

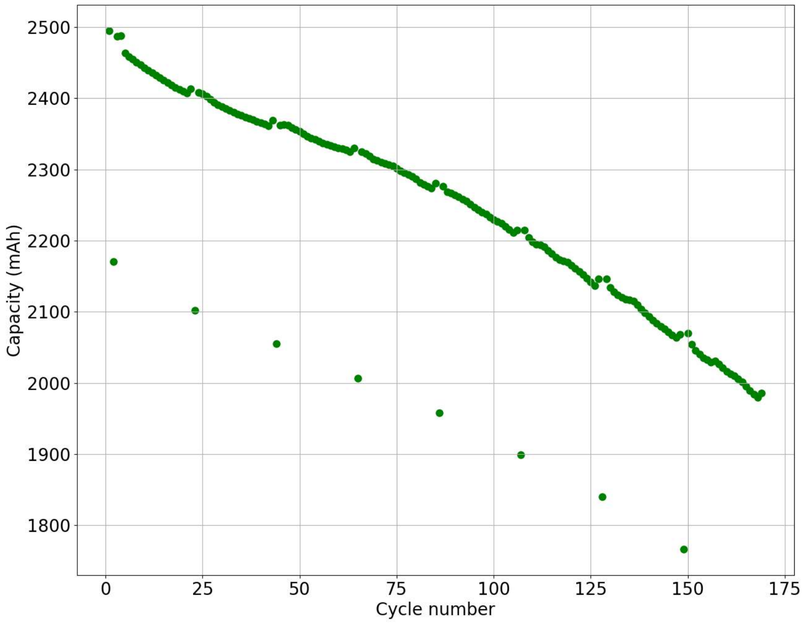


Battery cycling

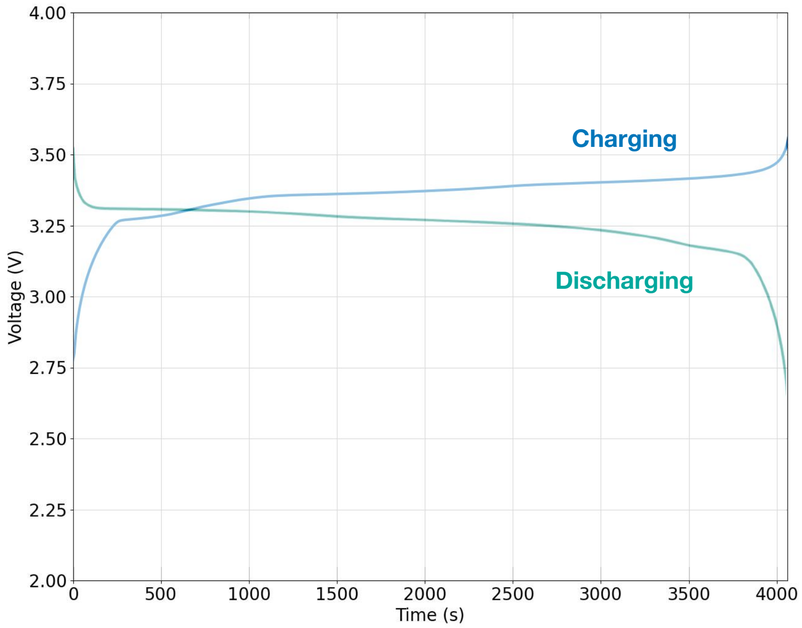
Full Cycle



Capacity

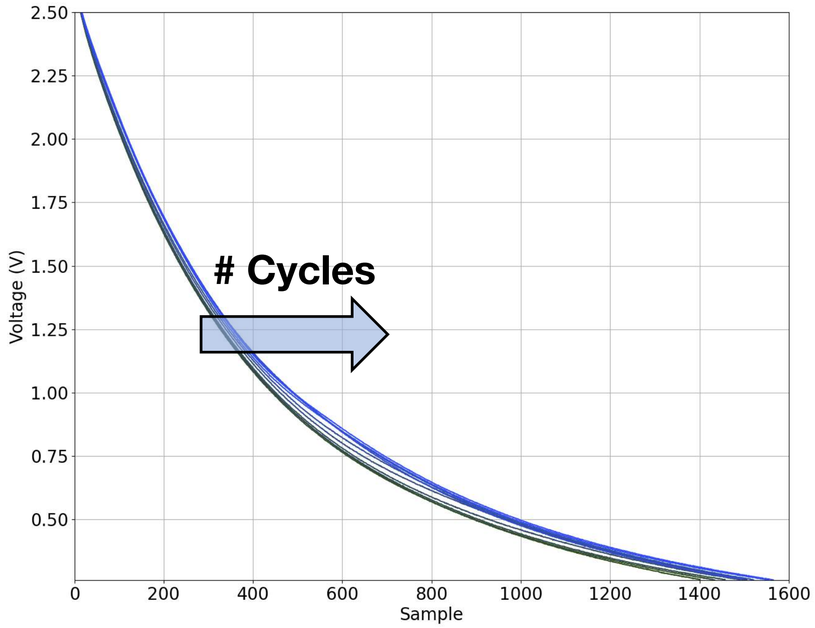


Charge-Discharge

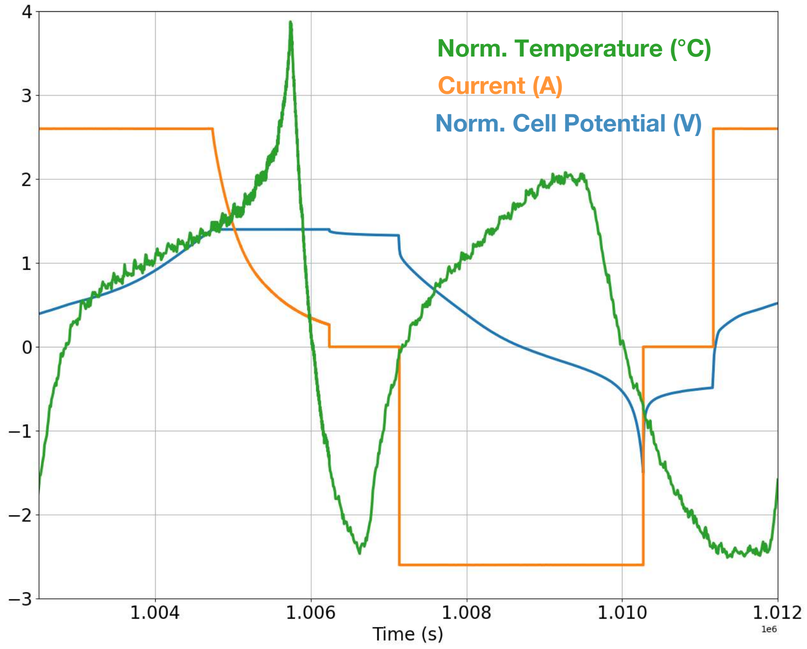


Battery cycling

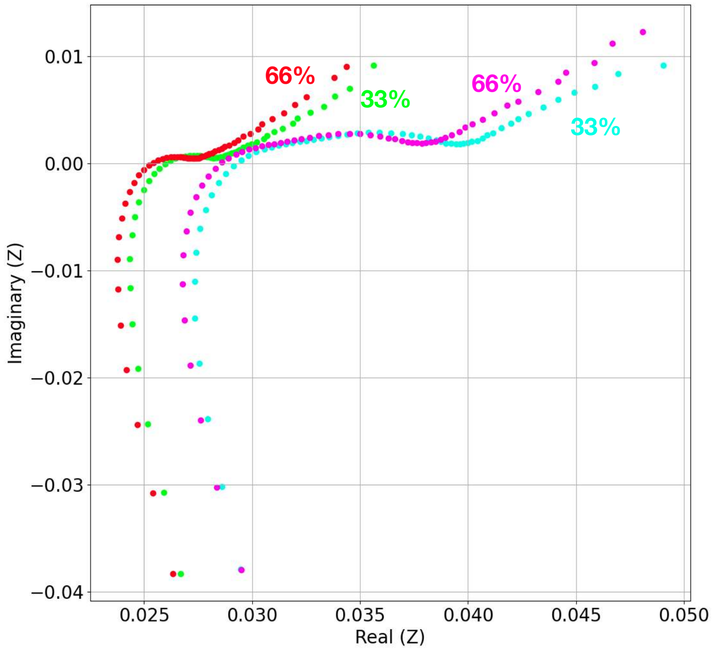
Constant Voltage



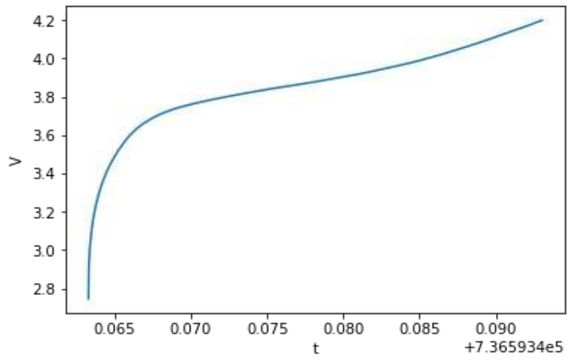
Temperature

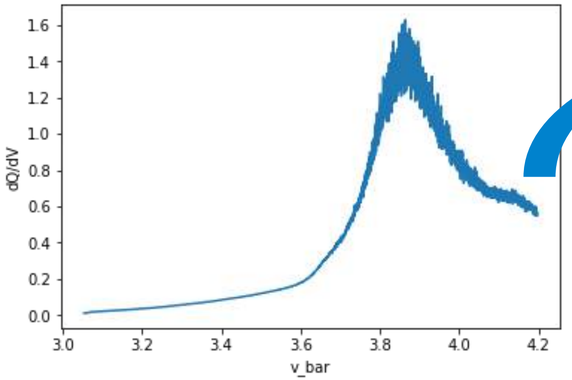


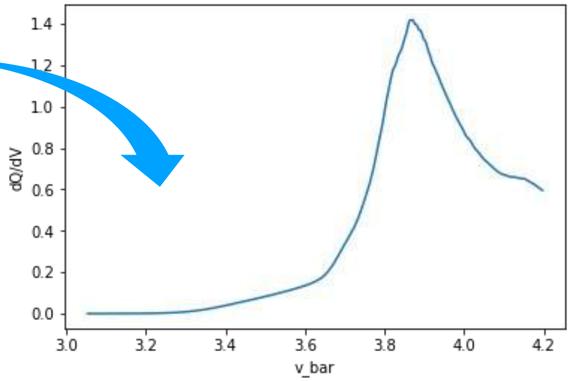
Potentiostatic EIS



Feature Selection







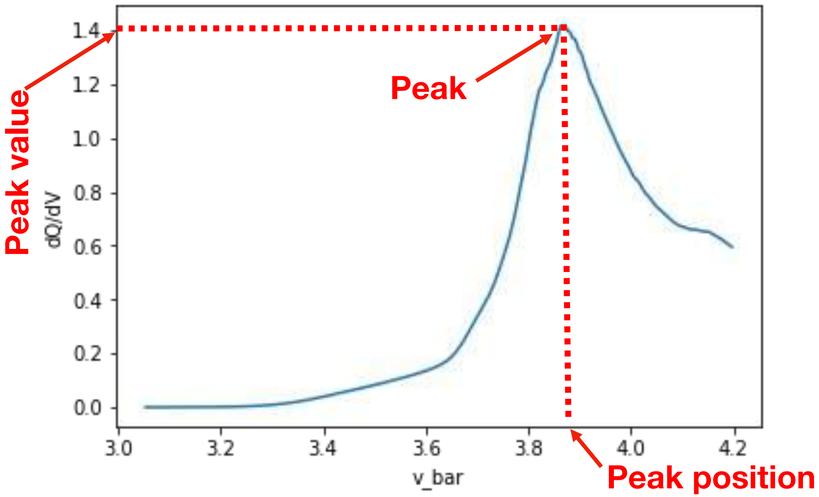
- Charging cycle
- 1st order derivative approx.

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

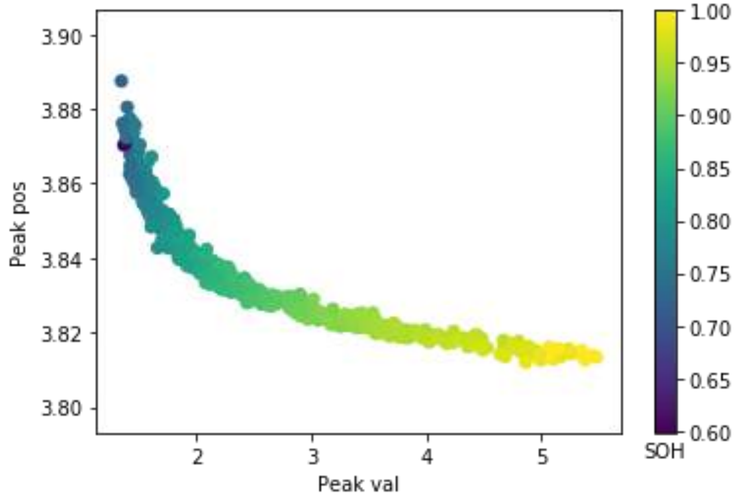
- 1D Gaussian filter

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

Chosen features



Oxford Dataset Features



In Literature?

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

Model Validation

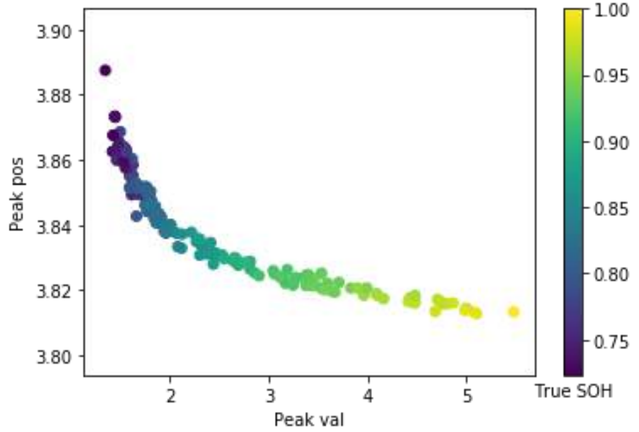
- Gaussian Process model

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

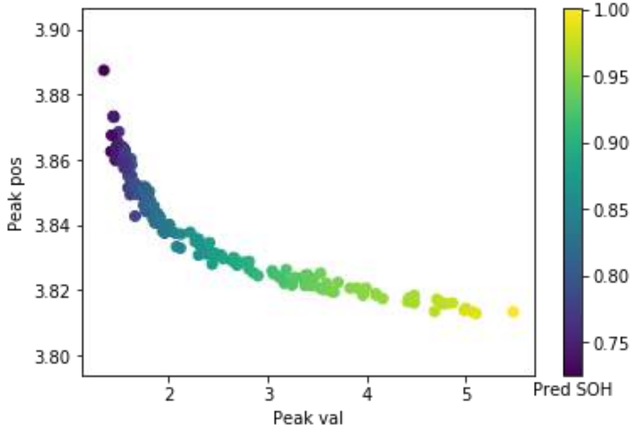
- SE Covariance function - smoothness

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

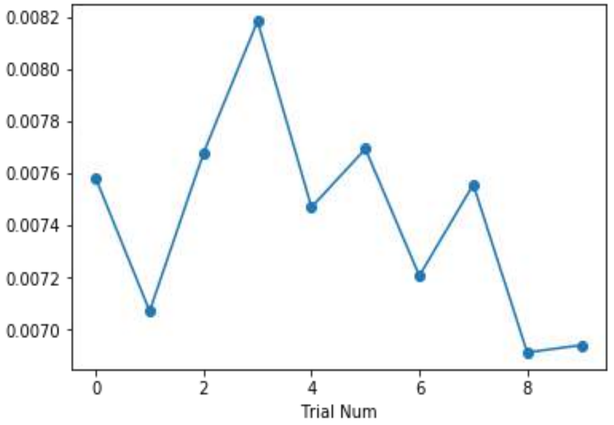
Oxford True



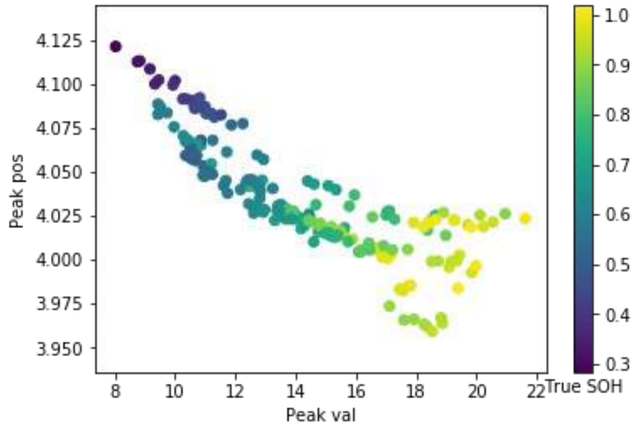
Oxford Predicted



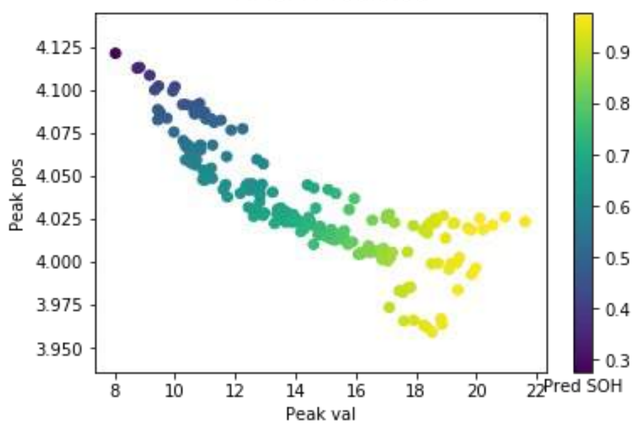
Oxford Mean Error



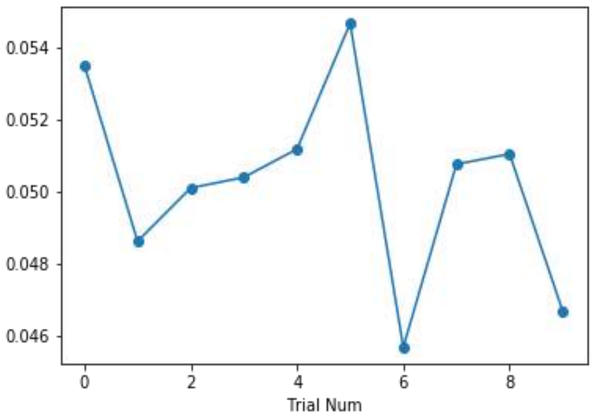
NASA True



NASA Predicted



NASA Mean Error

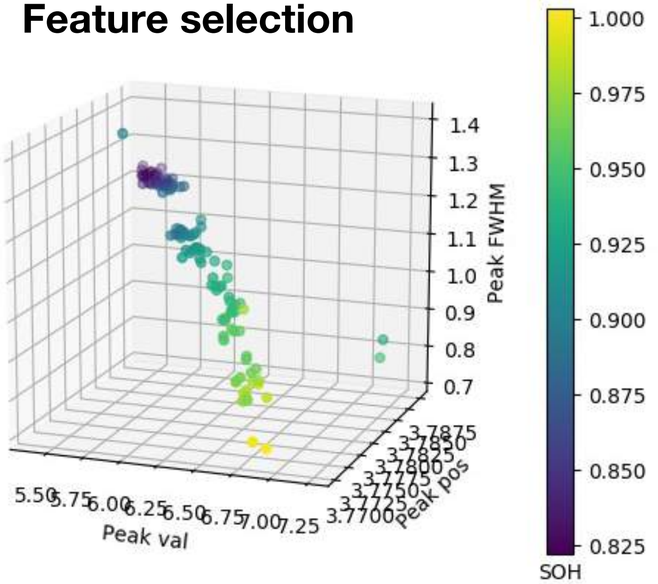


Software Package

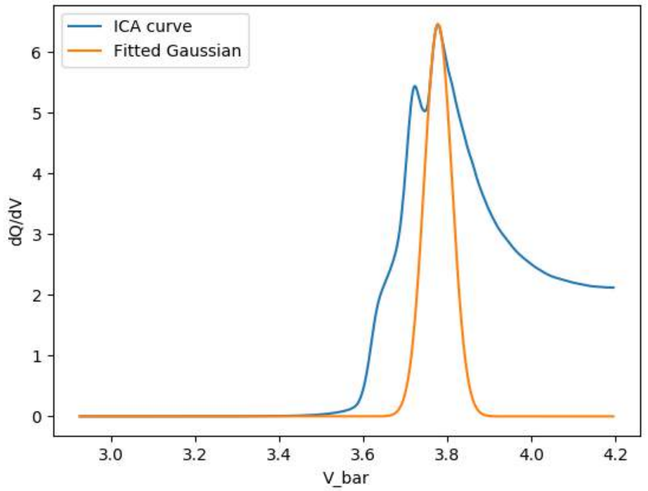
```
from battery_soh.data_processing import DataSet
from battery_soh.gp_model import SEModel

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

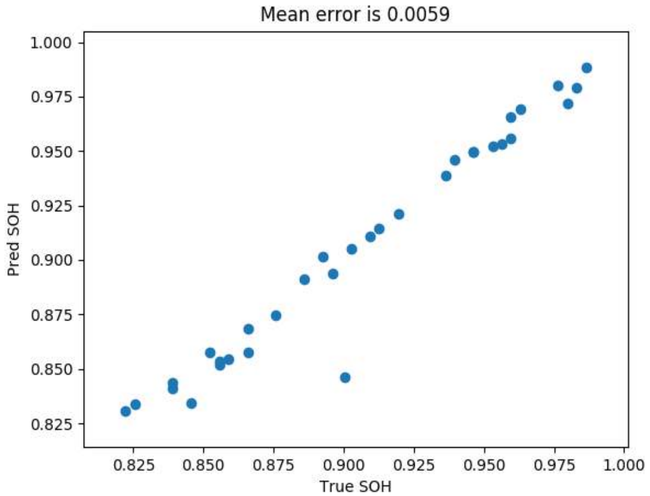



```
from battery_soh.data_processing import DataSet
from battery_soh.gp_model import SEModel

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

GP model training

Error analysis



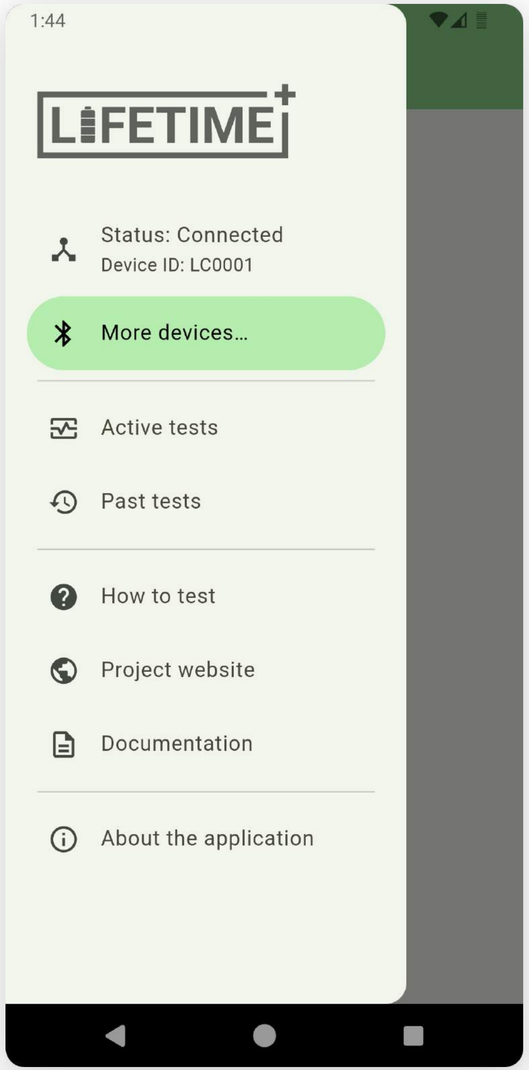
Mobile app – technical considerations

Cross-platform

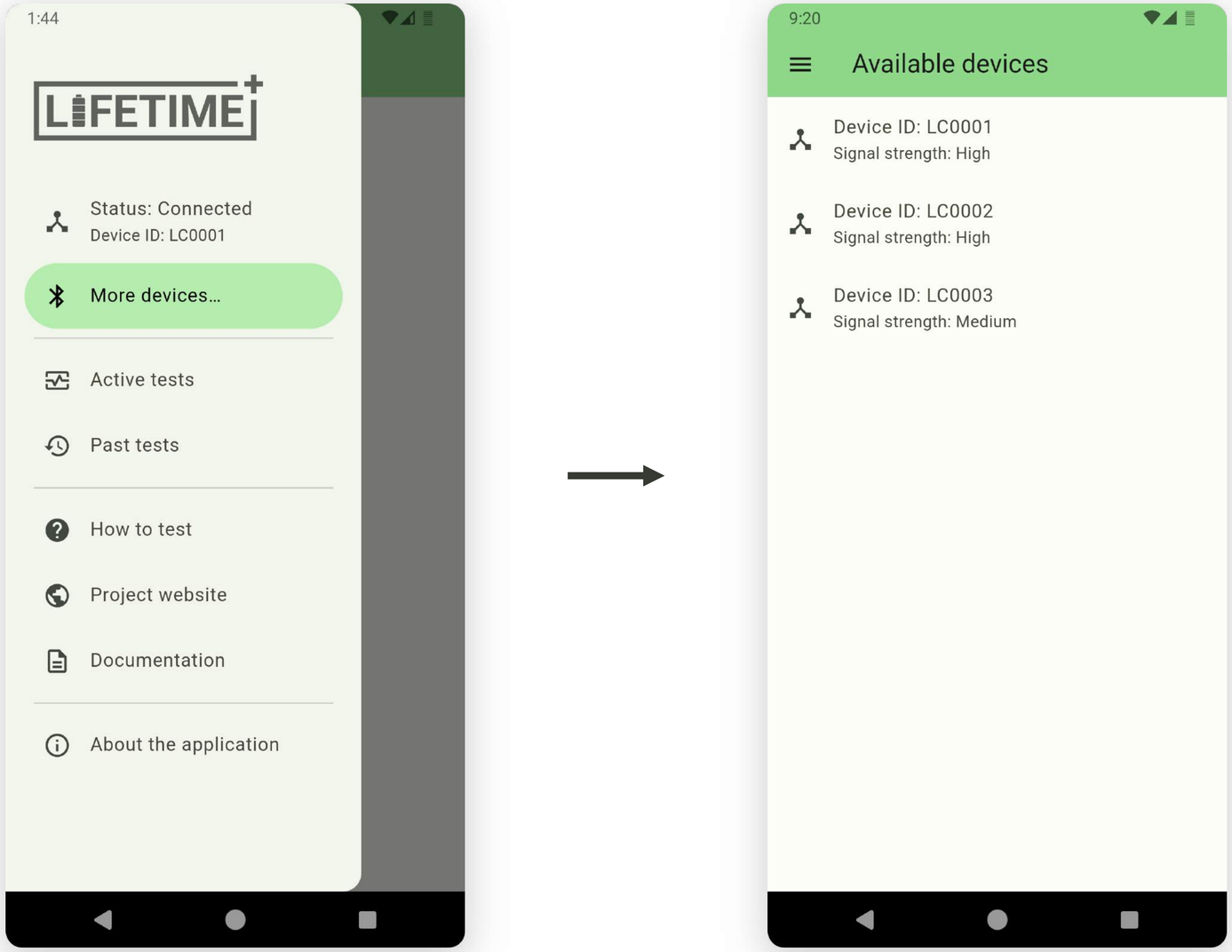
Sub-$100 phones

Customisable

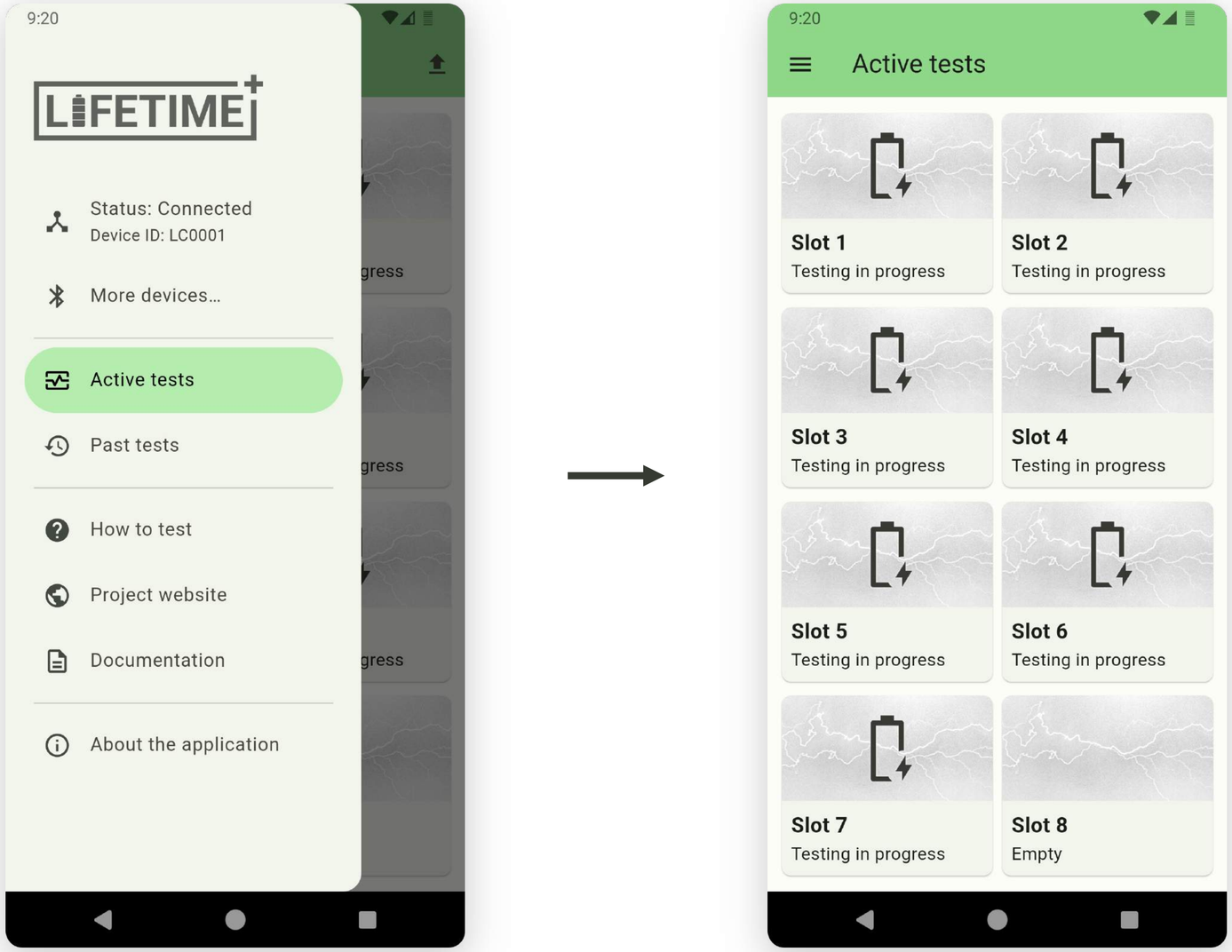
App – Navigation Drawer



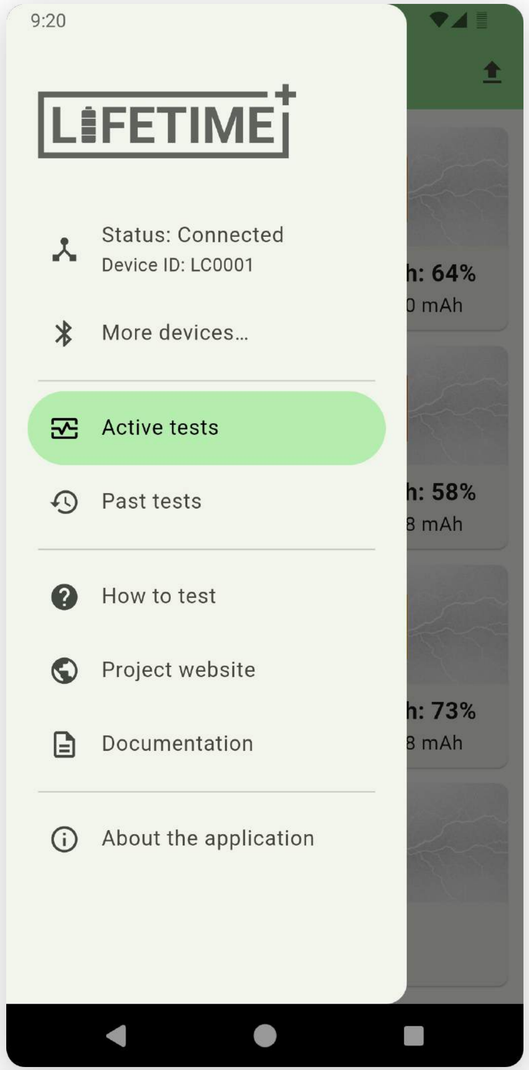
App – Available devices

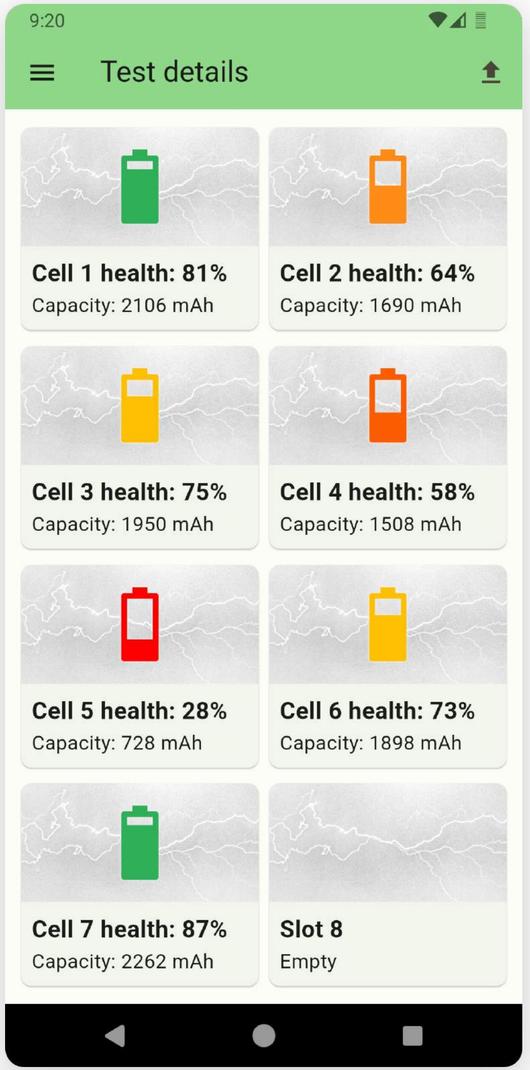


App – Active tests – In progress

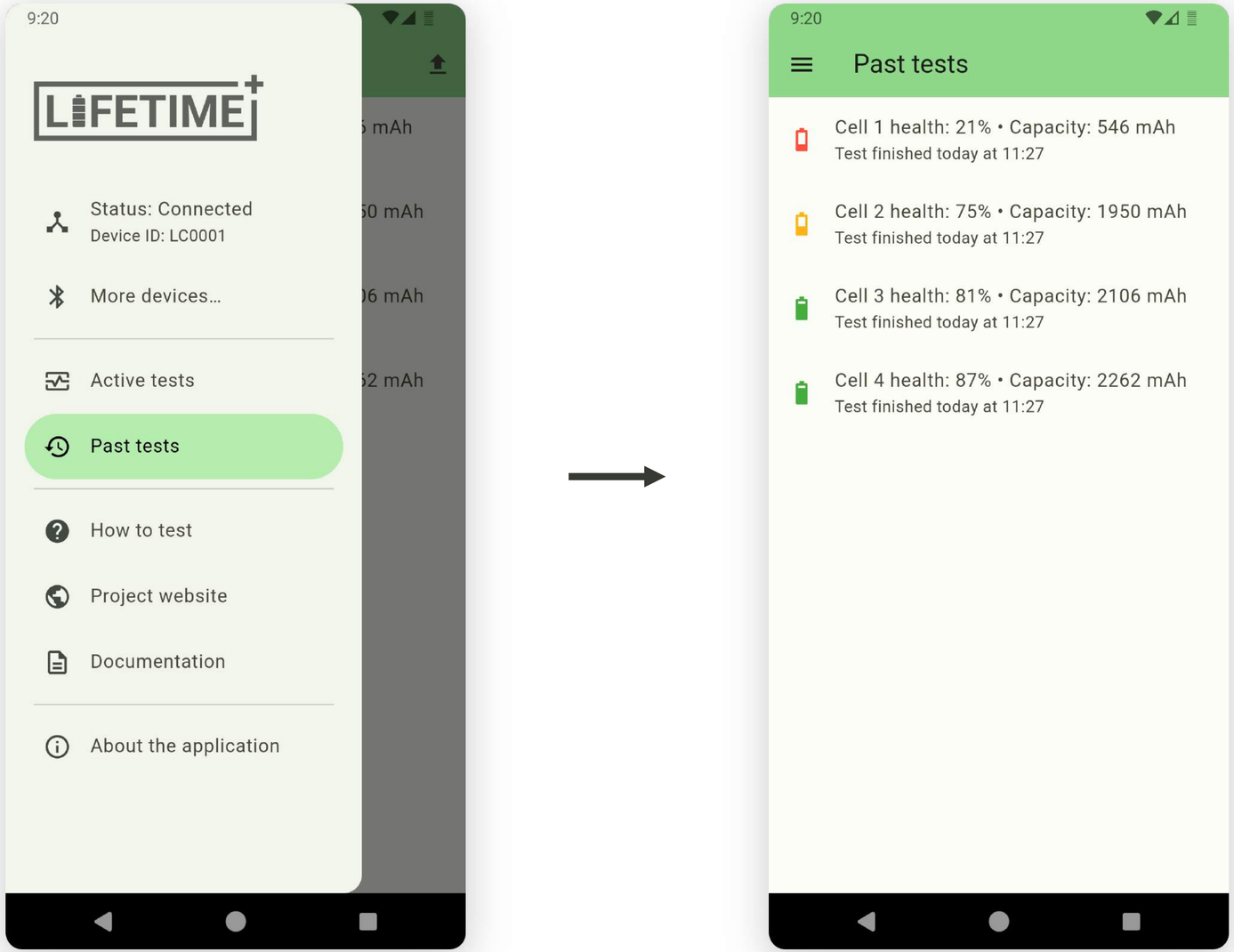


App – Active tests – Done





App – Past tests



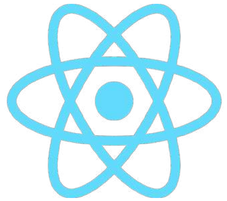
OUTREACH

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

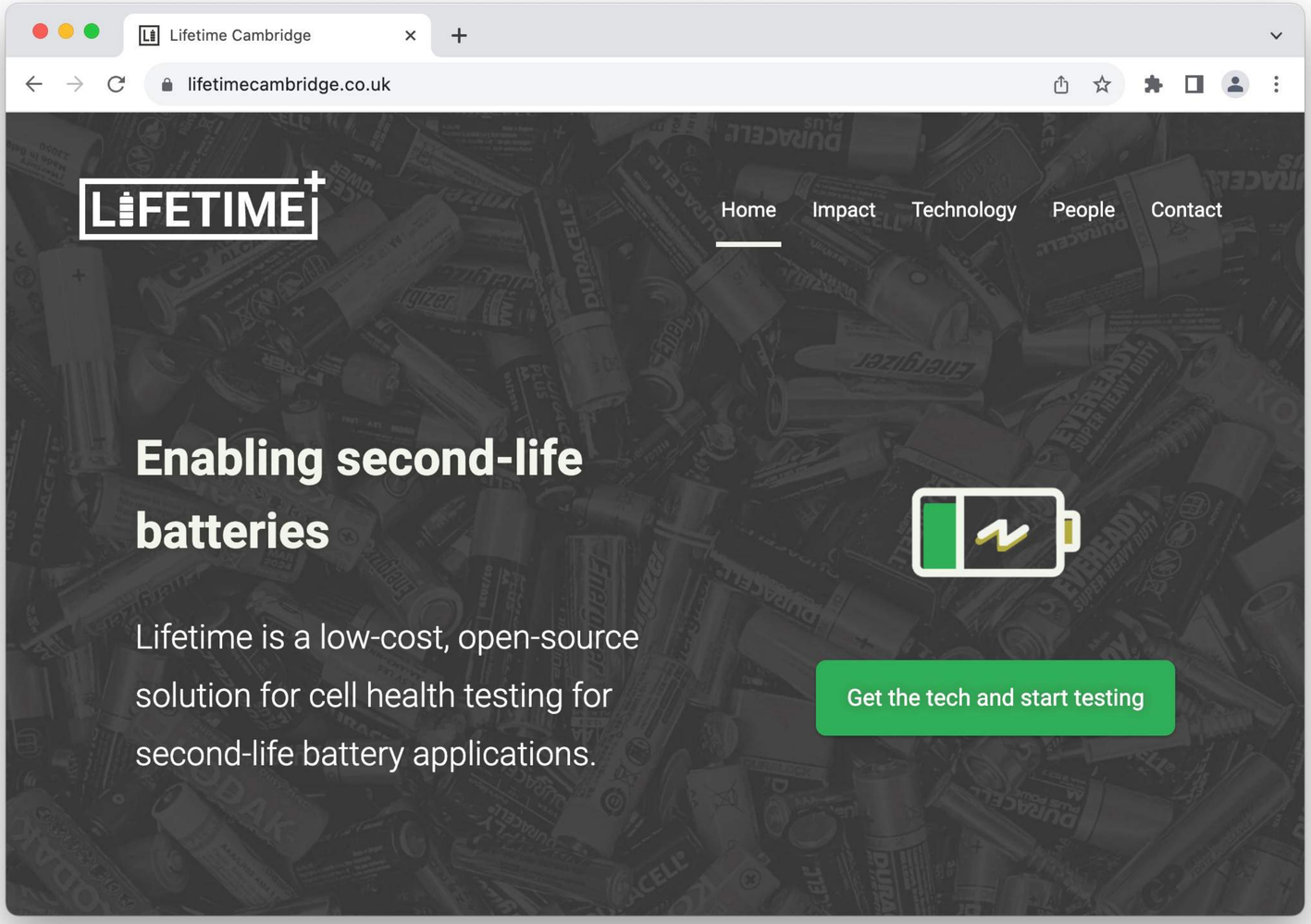


React

Next.JS

Svelte

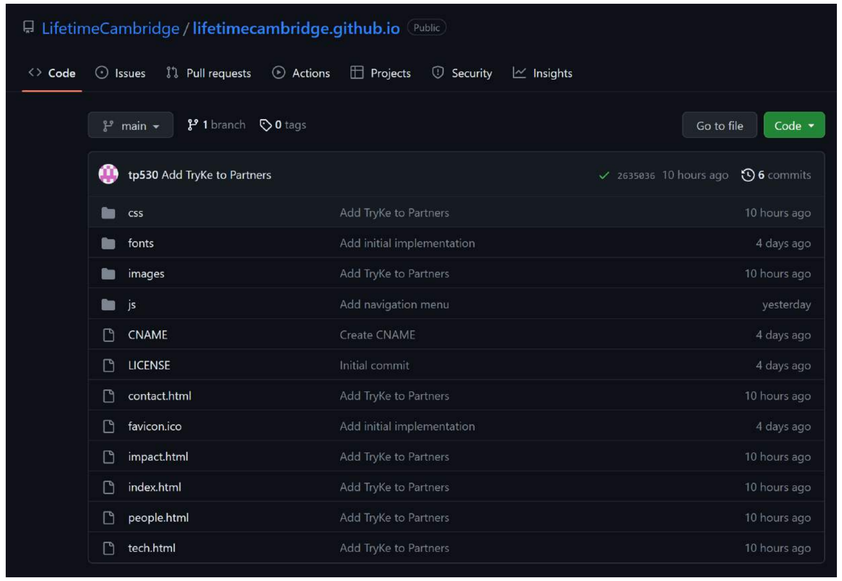
LifetimeCambridge.co.uk



Open-Source Documentation

CERN-OHL-P

GitHub



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

GitBuilding

Step 7: Etching

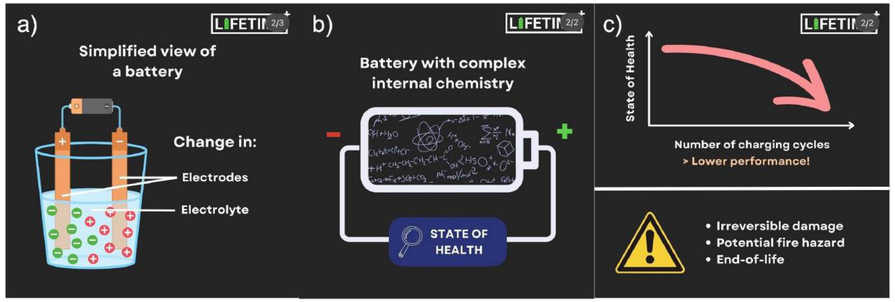
- Place the board inside Ferric Chloride (Fe(III)Cl3), apply heat and constant stirring, which will etch away unwanted copper.

> ⚠ **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!

23

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

LiFETIME
4 followers
4d ·

🔋 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 for energy-intensive applications.

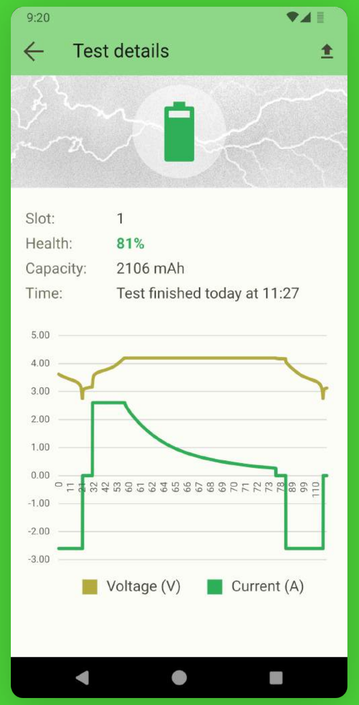
Future work

Hardware

Single cell prototype

Device refinement

App



Software

Improve model with our dataset

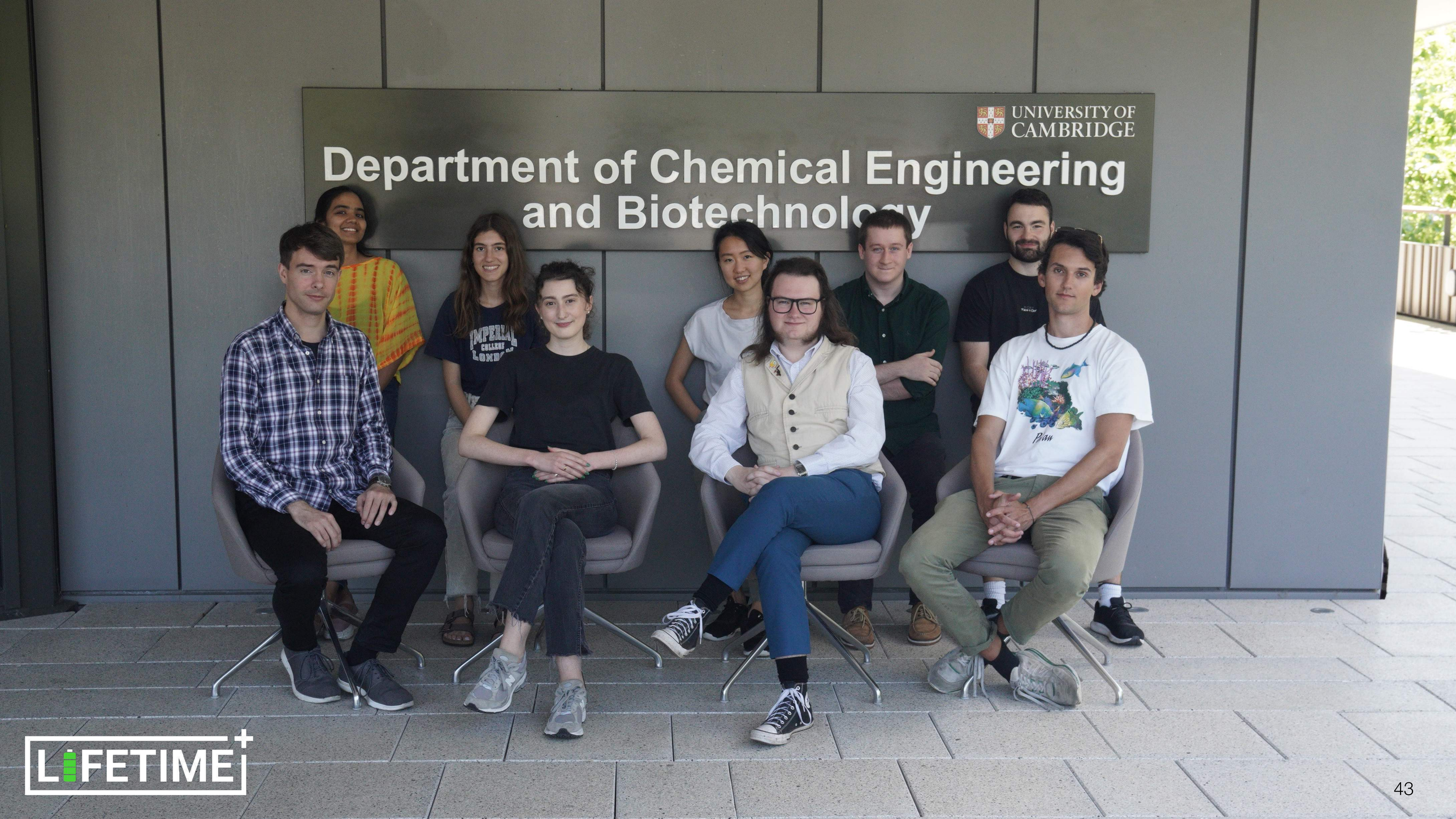
Further cultivate dataset

Outreach

Policy discussions with KEBS

Development i-Teams

Co-creation workshops with collaborators in Kenya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Department of Chemical Engineering
and Biotechnology

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Department of Physics

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Energy Group
Department of Engineering

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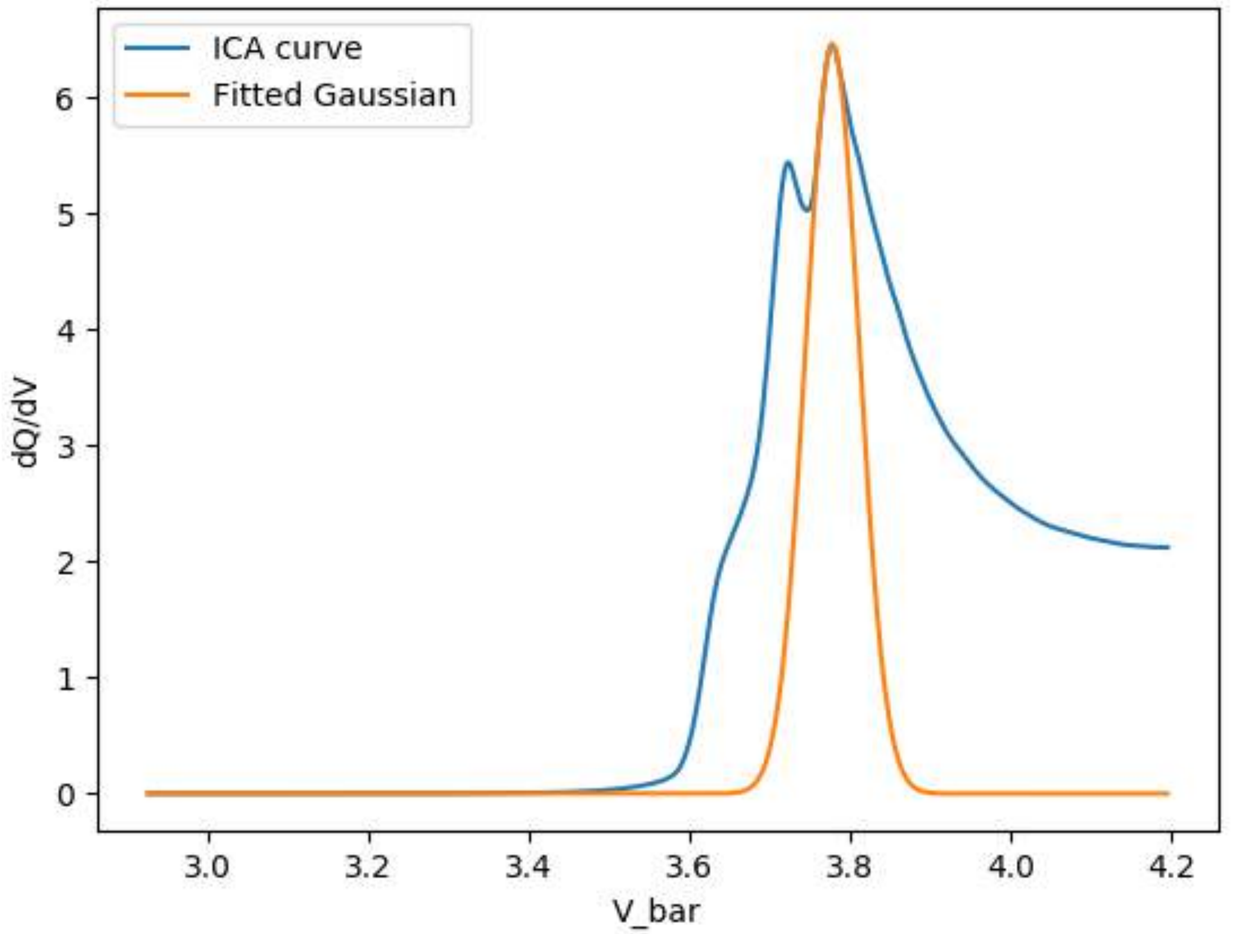
ICA curve
Fitted Gaussian
dQ/dV
V_bar
0
1
2
3
4
5
6
3.0
3.2
3.4
3.6
3.8
4.0
4.2