IMPROVING BATTERY MODELS USING UNCERTAINTY ANALYSIS

Estimating experimental error and investigating propagation in models.

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1. ABSTRACT

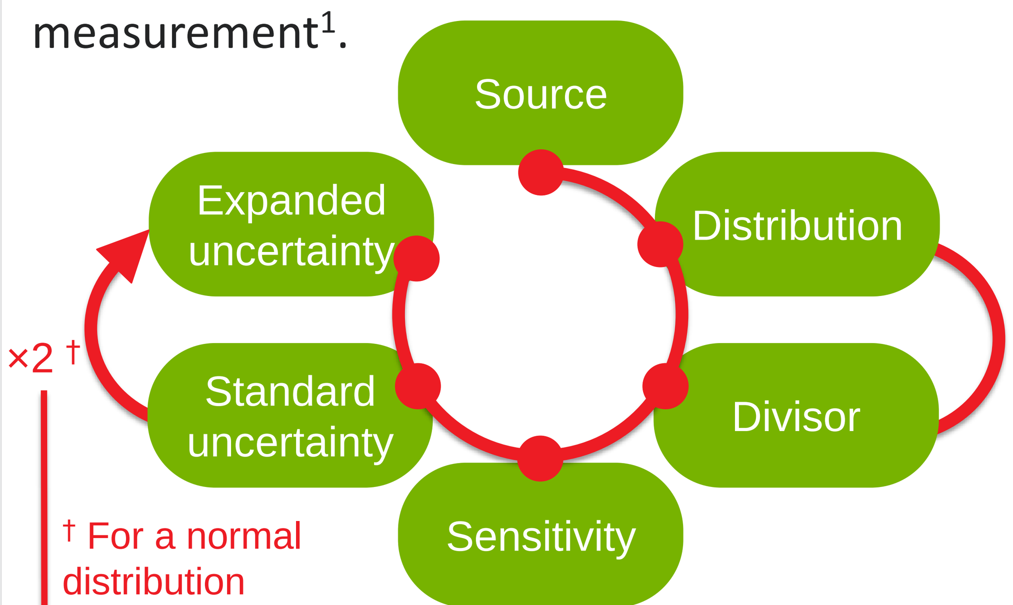
Battery models are increasingly desirable for automotive companies, motorsport and cell manufacturers to **design control systems** based on a particular cell. Models are as reliable as their **input parameters**, which are obtained from **physical measurements** made by tearing down a cell. Quantifying the uncertainty in these measurements and **propagating through the model** has a threefold impact:

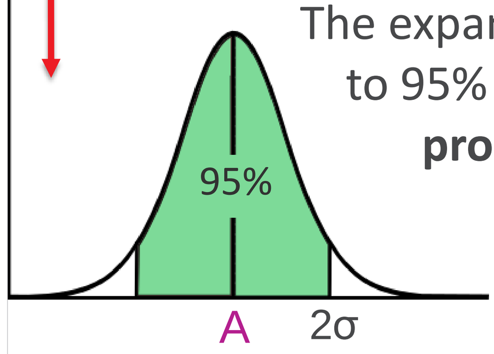
1) The reported data is more **trustworthy** for the customer.
2) The level of uncertainty may **affect decisions** such as amount of billing materials or manufacturing route used.
3) The sources of **uncertainty in the measurement method** are identified and the method can be improved.

Follow along with my website! Look for the magnifying glass symbol on the poster.

2. UNCERTAINTY BUDGETING

Uncertainty is the **quantification of doubt** in a measurement[1].

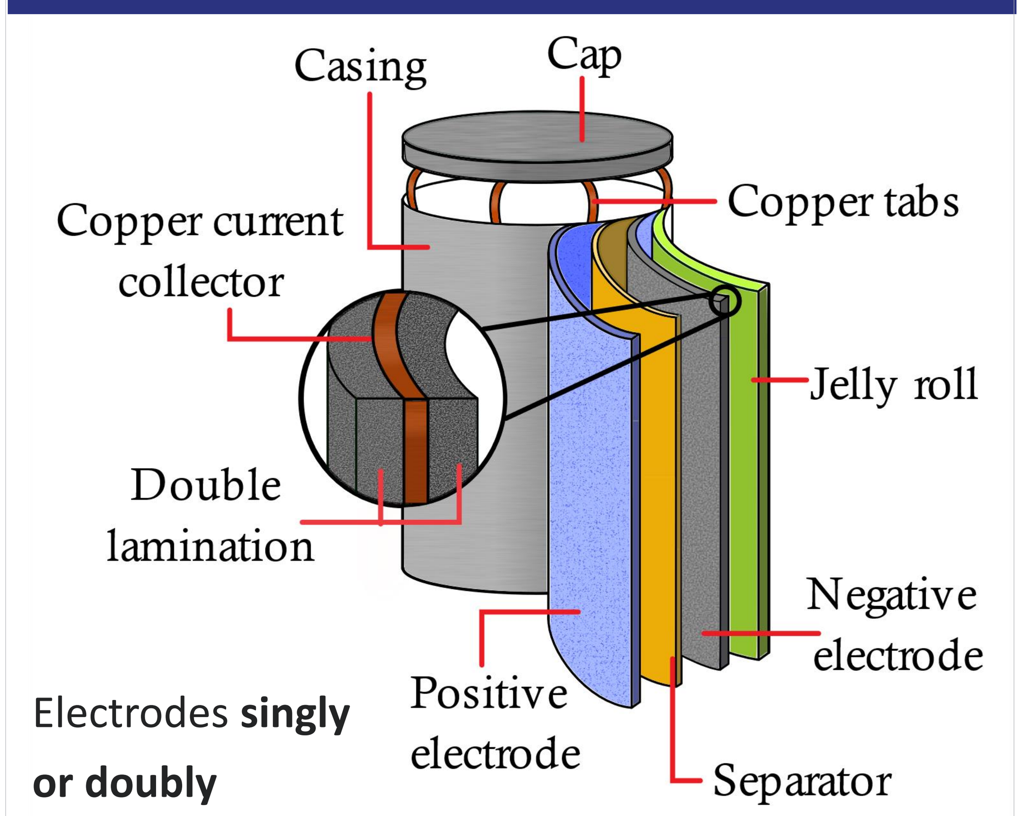




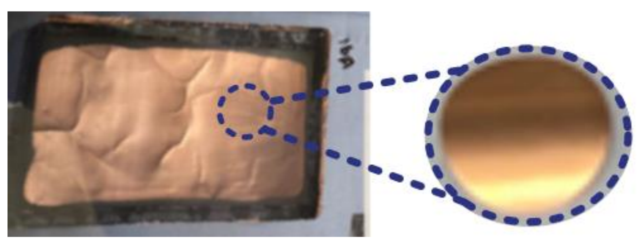
The expanded uncertainty is quoted to 95% confidence; there is **a 95% probability the true value lies within this interval.**

$$A \pm U_A$$

3. TEARDOWN PROCESS



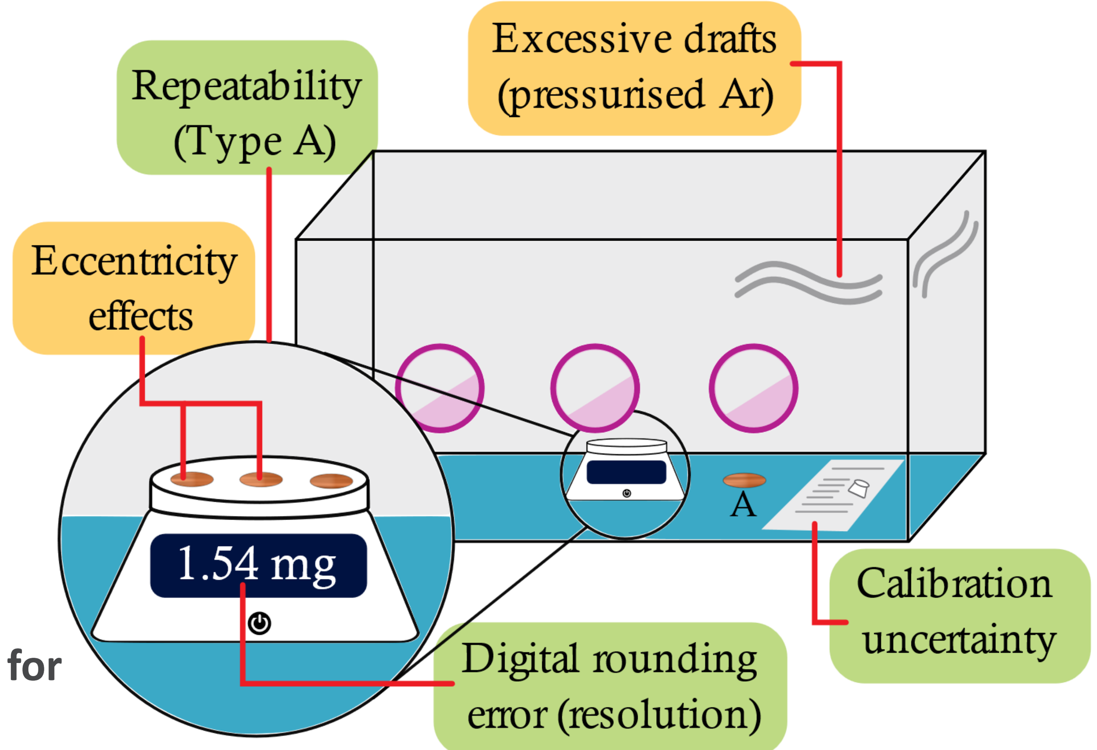
Electrodes **singly or doubly delaminated** using solvent and **punched into discs** for testing.



Picture credit: About:Energy Ltd.

4. SOURCES OF UNCERTAINTY

This diagram shows the **sources of uncertainty** in the mass measurement.



= accounted for in budget

= assumed resolved during calibration

Uncertainty analysis **assumes perfect operation**[2] (impossible!) but can be reduced by methodology improvement such as **regular calibration** or using a **concrete table** to minimise vibrations.

5. MONTE CARLO METHOD

The **standard (not expanded) uncertainty** of mass loading and thickness found in the gravimetric budget was set to be the **standard deviation** of the input values.

Defining the measurand X_i

A **normally distributed array** of values was generated from the mean and deviation found in the budget and using a **quasi-random** sequence.

Perform the calculations N times

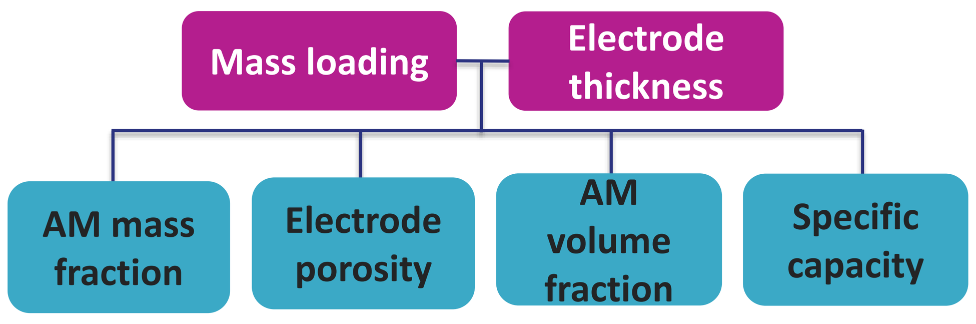
Iterate calculations over array values using **for-loops**.

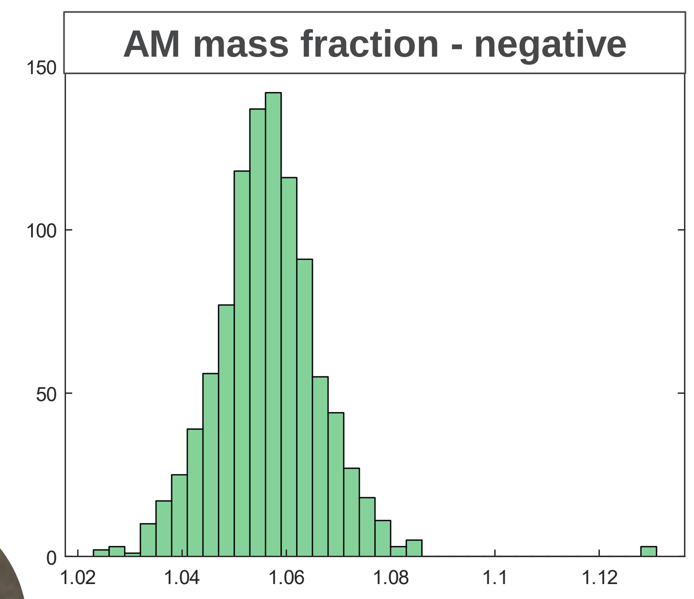
Obtain output Y_i

Fit a normal distribution to Yi histogram to find deviation.

7. CONCLUSIONS

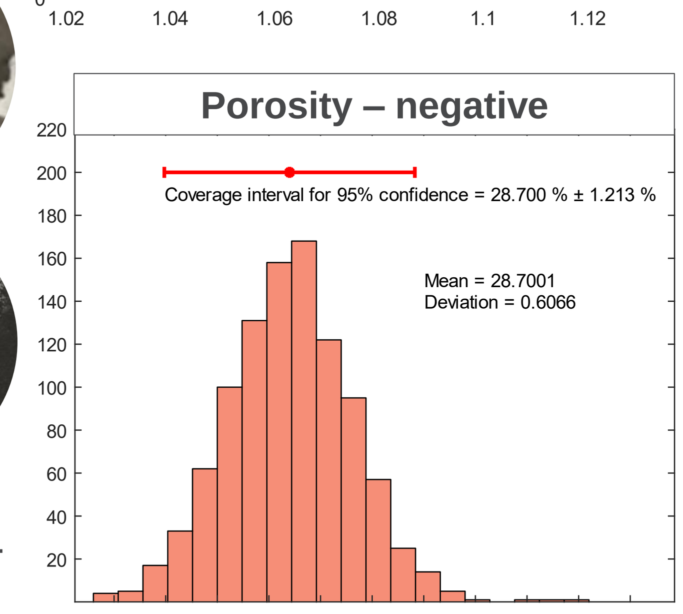
- Between thickness and mass loading of active material (AM), **mass loading was the dominant** uncertainty.





- An uncertainty of 10% in the mass loading resulted in an uncertainty of **38%** in the porosity:
- The uncertainty in the negative electrode parameters was generally greater due to **(A)** some **active material sticking** to the separator and **(B) active material flaking** off as a **powder** and hence, being lost.

Picture credit: About:Energy Ltd.



- Uncertainty tool embedded in spreadsheet:

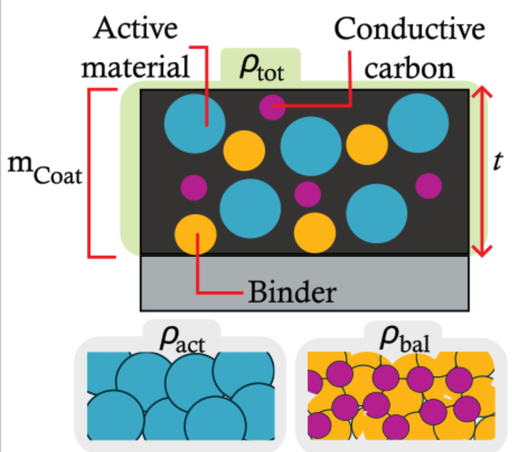
Sample coated on a single side	Diameter / cm	Mass / mg	Thickness / µm	Coat thickess / µm	Coat mass / mg	Mass loading / mg cm^{-2}
Average	1.8	52.420	9.25E+01	84.490	34.28	13.471
Uncertainty 95% confidence	5.40E-03	0.117	3.51E-03	0.005	1.48E-01	0.082

6. EQUATIONS

The equation for **porosity, ε,** is shown on the right. m_{Coat} **is the mass loading** of the electrode layer. ρ_{tot} **is the electrode density** which is calculated from the **active material mass fraction,** w_{act}.

$$\varepsilon = \frac{1 - m_{Coat}}{1000 \times t \times \rho_{tot}}$$

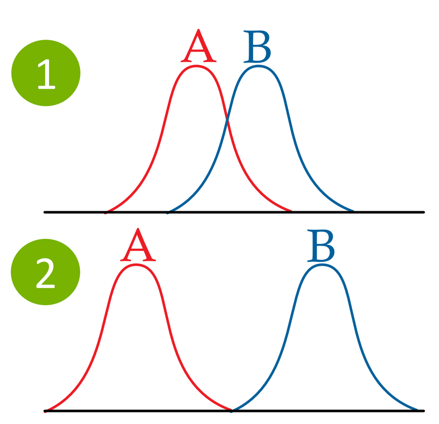
$$\frac{1}{\rho_{tot}} = \frac{w_{act}}{\rho_{act}} + \frac{1 - w_{act}}{\rho_{bal}}$$



w_{act} depends on capacity which is inversely proportional to mass loading. Hence, **porosity is a complex function of mass loading**, and would be tricky to solve analytically.

8. IMPACT / NEXT STEPS

- In both figures the mean of B is greater than the mean of A. However, the **conclusion that B > A cannot be drawn** for (1) due to **significant overlap**.
- Hence, uncertainty analysis enables **quantitative comparison** between measurements under **different conditions**.



Future steps:

a. Improve equipment + setup
b. Electrochemical measurement uncertainties
c. Uncertainty in supply chain

REFERENCES

- (1) Bell, S. (2001) 'A Beginner's Guide to Uncertainty of Measurement', Measurement Good Practice Guide No. 11 (Issue 2), Teddington: National Physical Laboratory.
- (2) Davidson, S., Perkin, M., Buckley, M. (2004) 'The Measurement of Mass and Weight', Measurement Good Practice Guide No. 71, Teddington: National Physical Laboratory.

INTERN BIO

Siddhi is a 3rd year Materials Science student at the University of Cambridge. She hopes to pursue a PhD in the battery sector and transition to industry to make a positive, sustainable impact! She would love to establish a start-up in the future within the energy storage industry.

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