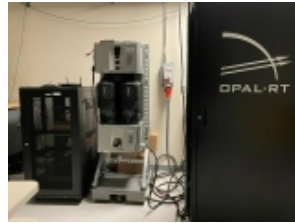




Open-source software to accelerate the development of energy storage systems



PRESENTED BY

Valerio De Angelis, Yuliya Preger

Tech Connect 2022

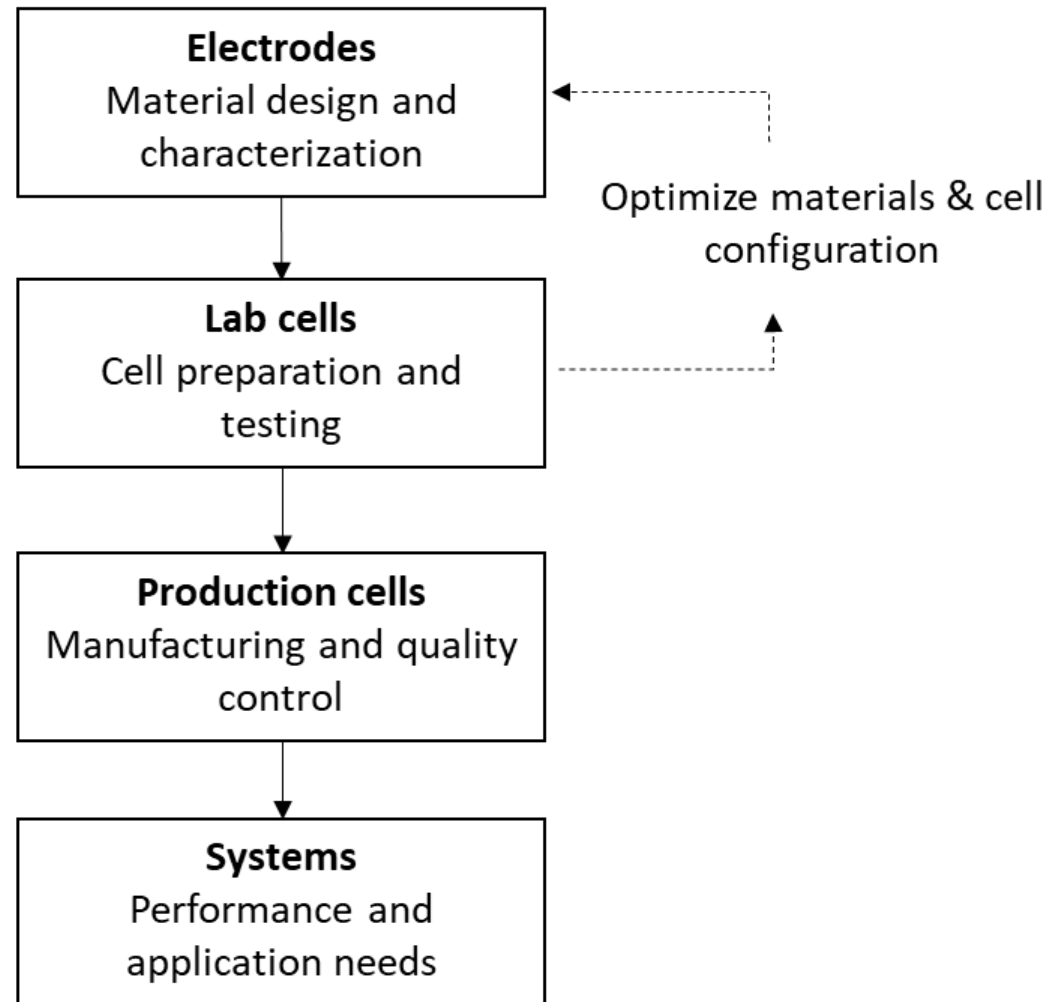
June 14th, 2022

CORE PROJECT MEMBERS

Oindrilla Dutta, Jake Mueller, David Rosewater, Loraine Torres-Castro, and Babu Chalamala



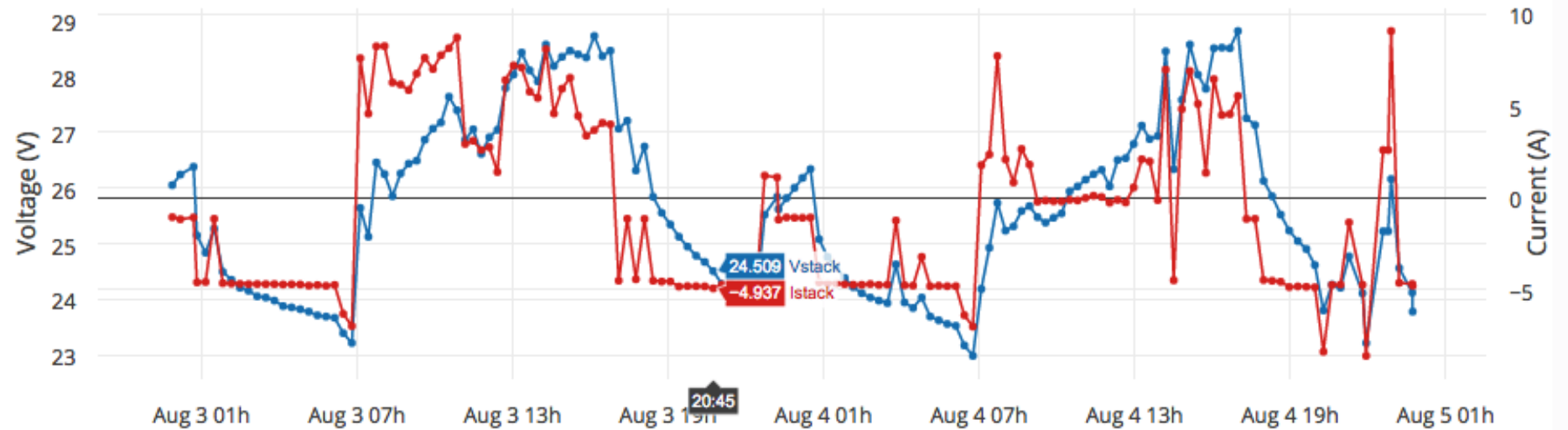
2 Battery development takes time – 10 + years



... But lab test conditions are different from field conditions

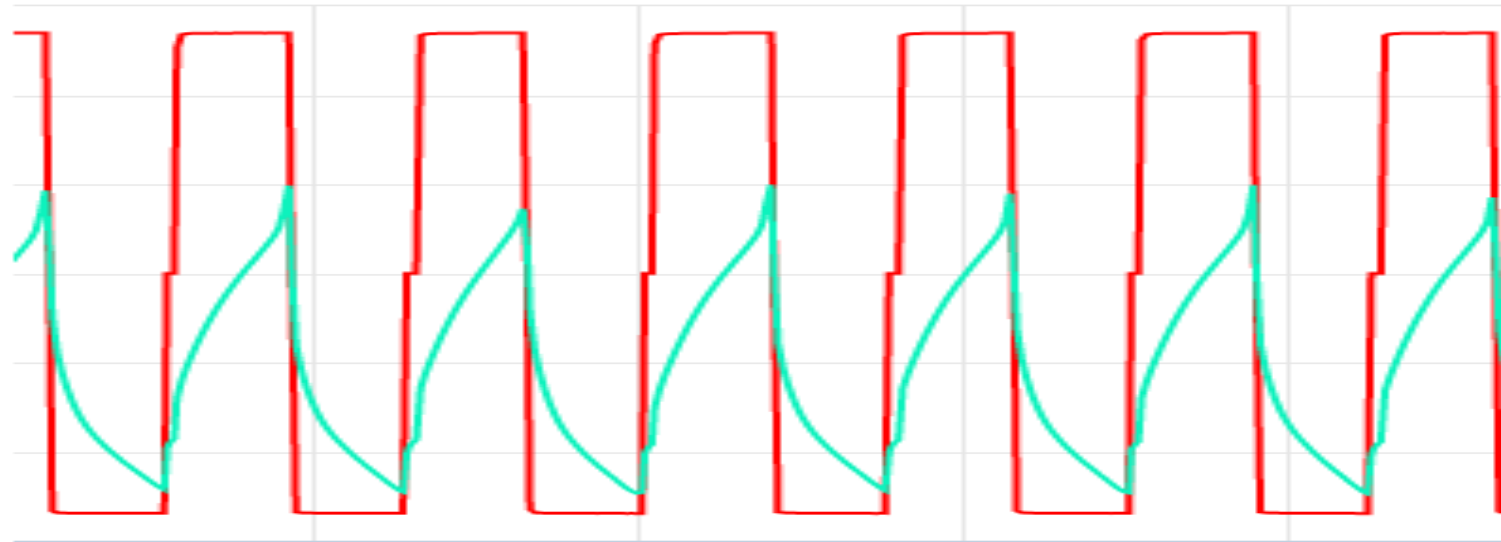


System operation
16 cells in series

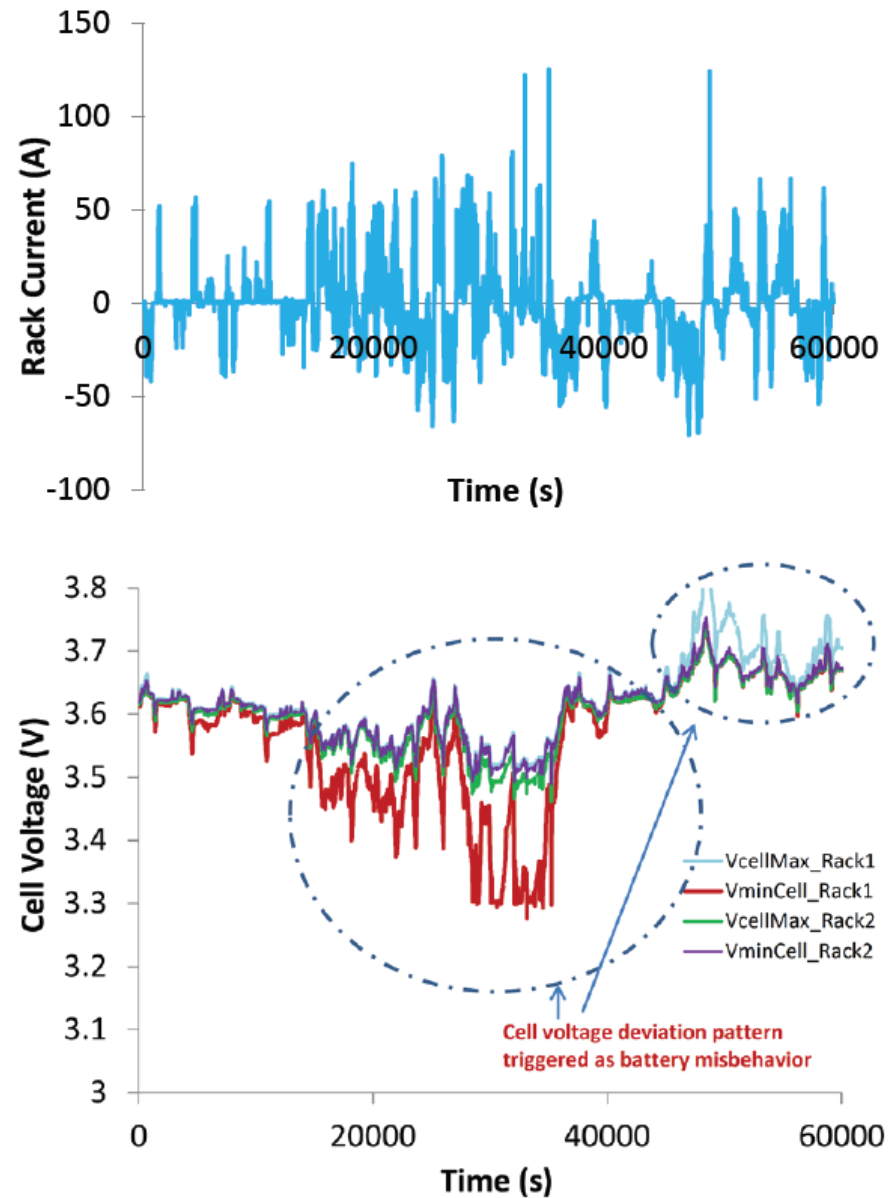


Single-cell testing

Red is current and green
is voltage



.. And sometimes, even mature commercial cells fail without warning



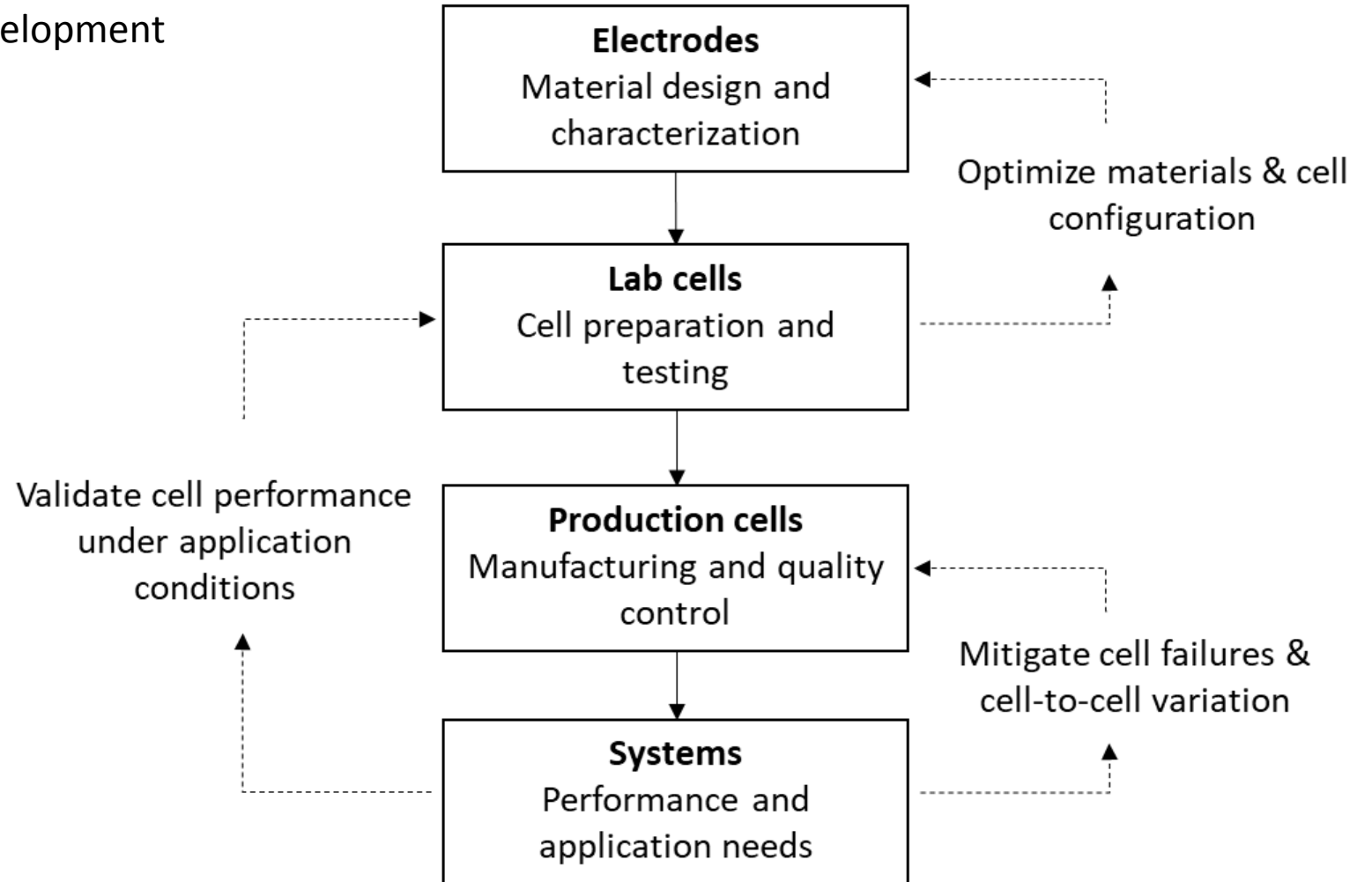
Reference: <https://ieeexplore.ieee.org/document/9228907>



Aggregate data from different stages of development

Access existing cycling and system data

Standardize system data logging



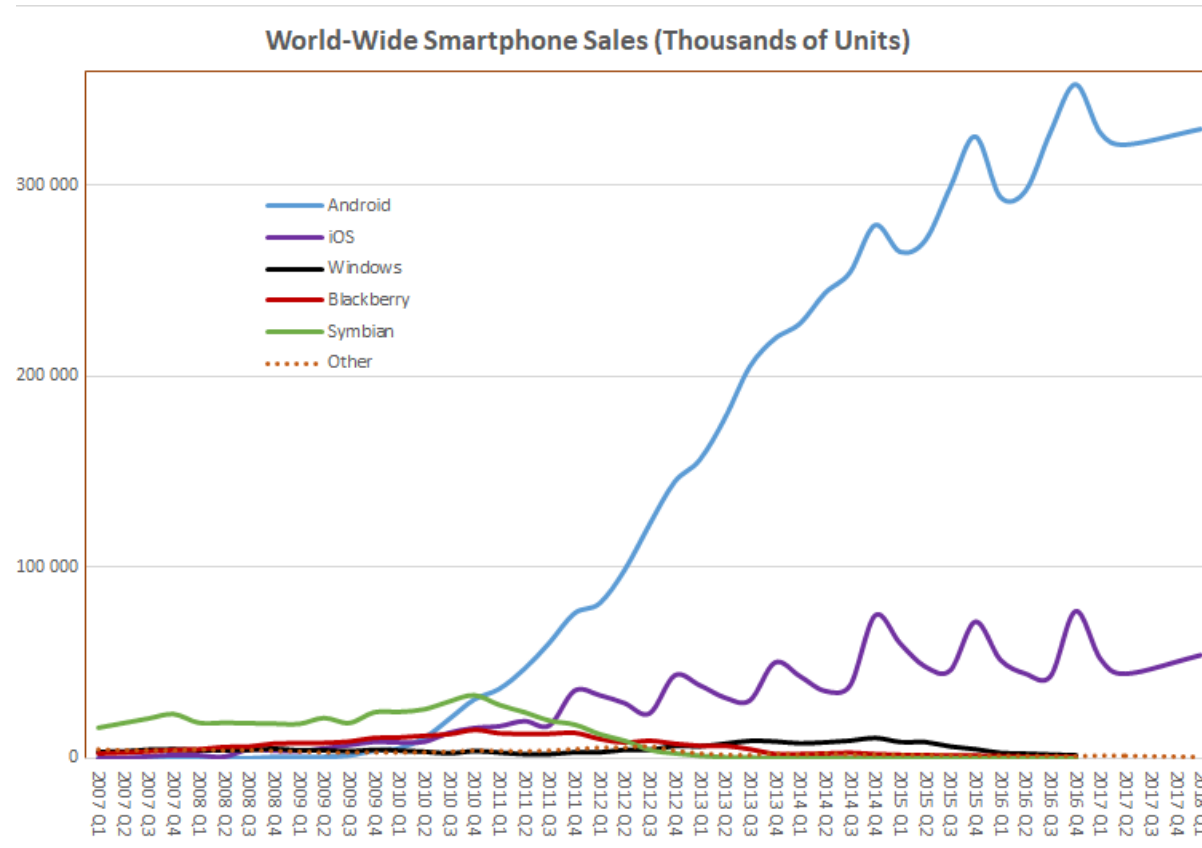
6 ... But no commercial package includes all the tools needed by the battery industry



Open-source software can help: Innovation, Freedom, Integrity, Continuity, Sharing

There are over 2M open source projects on Github, and many contain the building blocks that we need

Open-source software powers smartphones around the world, supercomputing centers, and web servers

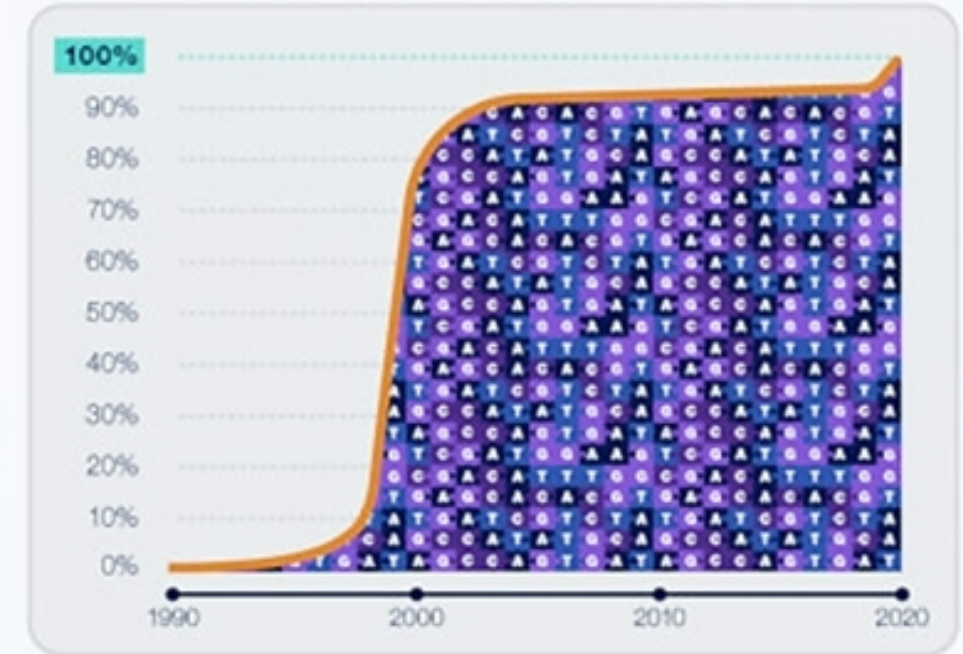


Not even apple can compete with open-source software!



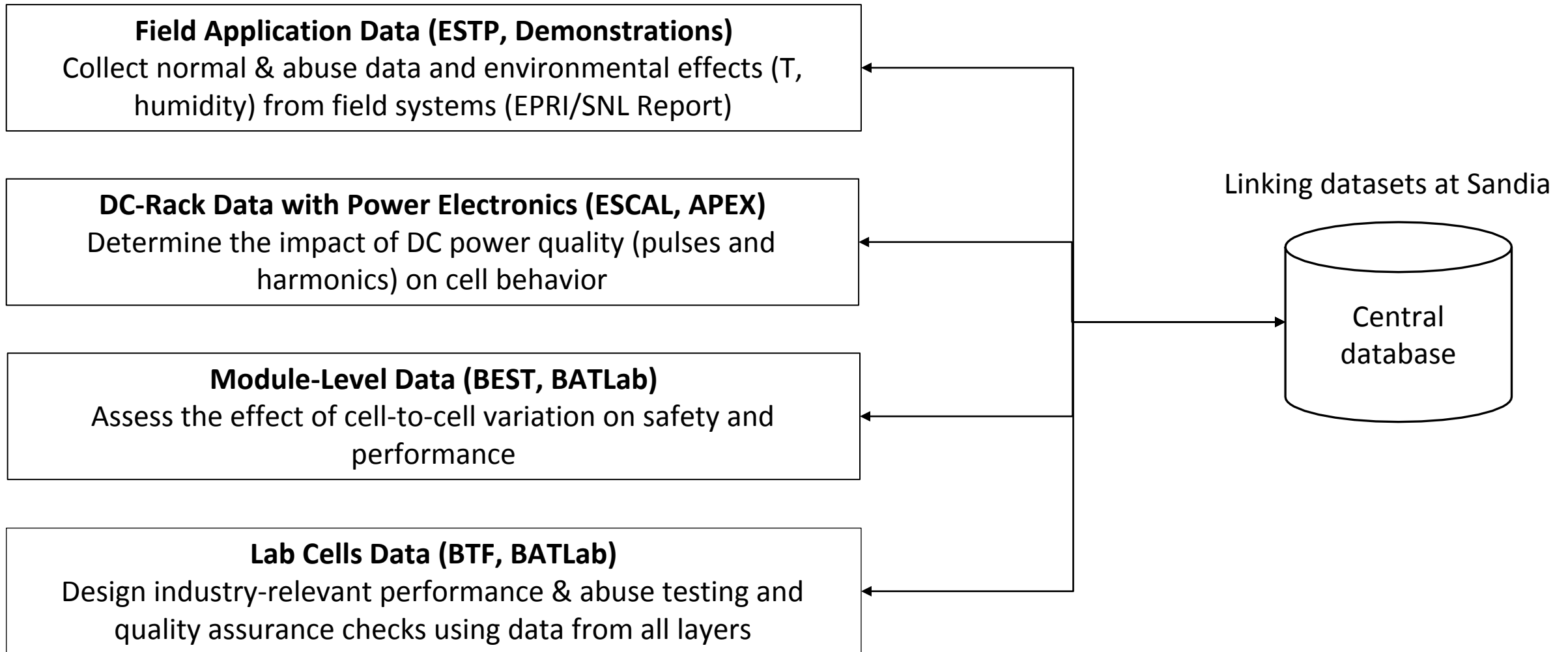
- S: (n) Eskimo dog, husky (breed of heavy-coated Arctic sled dog)
 - direct hypernym / inherited hypernym / sister term
 - S: (n) working dog (any of several breeds of usually large powerful dogs bred to work as draft animals and guard and guide dogs)
 - S: (n) dog, domestic dog, Canis familiaris (a member of the genus Canis (probably descended from the common wolf) that has been domesticated by man since prehistoric times; occurs in many breeds) "the dog barked all night"
 - S: (n) canine, canid (any of various fissioned mammals with nonretractile claws and typically long muzzles)
 - S: (n) carnivore (a terrestrial or aquatic flesh-eating mammal) "terrestrial carnivores have four or five clawed digits on each limb"
 - S: (n) placental, placental mammal, eutherian, eutherian mammal (mammals having a placenta; all mammals except monotremes and marsupials)
 - S: (n) mammal, mammalian (any warm-blooded vertebrate having the skin more or less covered with hair; young are born alive except for the small subclass of monotremes and nourished with milk)
 - S: (n) vertebrate, craniate (animals having a bony or cartilaginous skeleton with a segmented spinal column and a large brain enclosed in a skull or cranium)
 - S: (n) chordate (any animal of the phylum Chordata having a notochord or spinal column)
 - S: (n) animal, animate being, beast, brute, creature, fauna (a living organism characterized by voluntary movement)
 - S: (n) organism, being (a living thing that has (or can develop) the ability to act or function independently)
 - S: (n) living thing, animate thing (a living (or once living) entity)
 - S: (n) whole, unit (an assemblage of parts that is regarded as a single entity) "how big is that part compared to the whole?"; "the team is a unit"
 - S: (n) object, physical object (a tangible and visible entity; an entity that can cast a shadow) "it was full of rackets, balls and other objects"
 - S: (n) physical entity (an entity that has physical existence)
 - S: (n) entity (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))

Percent of human genome sequence released

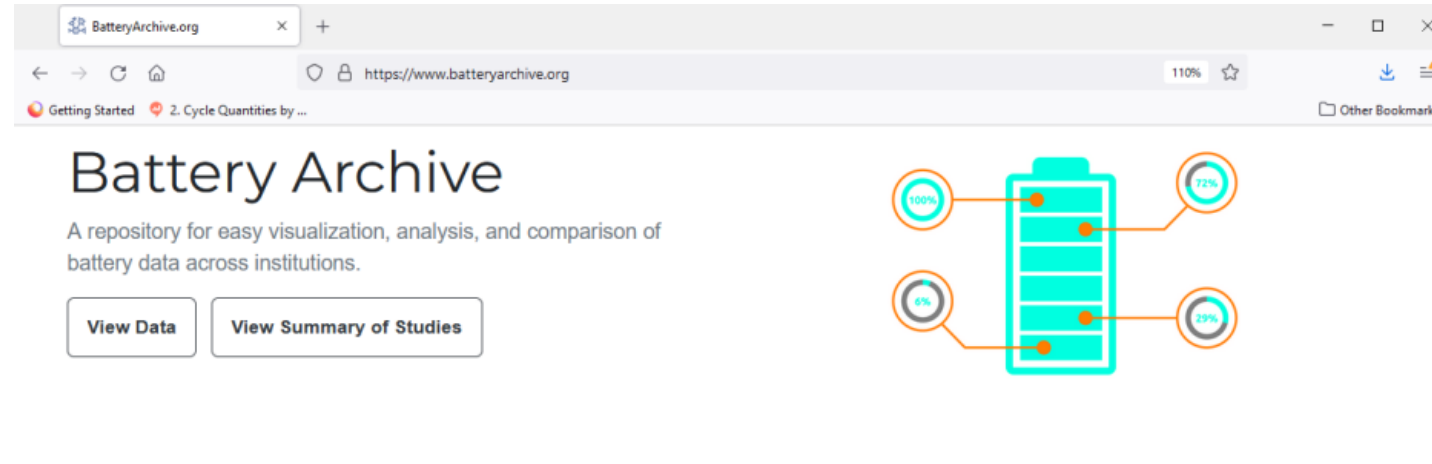


Fei-Fei Li: "Map the entire world of objects" (2009)
 Allowed object classification ability to reach 97.3% (higher than human abilities)

Deeper knowledge of human sequence variation has begun to alter the practice of medicine



9 As a result, we launched the first web-based public battery cycling database



Features

1

Filter battery data

| Name | Capacity | Temperature | Voltage | Discharge Rate |
|--------------|----------|-------------|---------|----------------|
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 0.5 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 1 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 2 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 3 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 4 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 5 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 6 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 7 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 8 C |
| Li-ion 18650 | 2000 mAh | 25 °C | 3.7 V | 9 C |

Query and filter for specific experimental conditions.

2

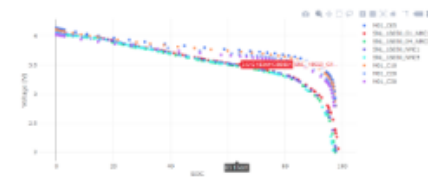
Visualize and compare data



Display battery data, including voltage curves and capacity fade.

3

Compare data with models



Apply performance and degradation models to battery data.

www.batteryarchive.org



Cell list

Cathode

LFP x

NCA x

NMC x



Capacity (Ah)

3.2 x

1.1 x

3 x



Temperature (C)

15 x

25 x

35 x



Min SOC

0 x

20 x

40 x



Max SOC

60 x

80 x

100 x



Discharge C Rate

0.5 x

1 x

2 x

+1 more



[Home](#) > Cell List

Li-ion cell list

| Cell ID | Cycles | Cathode | Capacity (Ah) | Temperature (C) | DOD | MIN SOC | MAX SOC | Discharge C Rate |
|-----------------------------------|--------|---------|---------------|-----------------|--------|---------|---------|------------------|
| SNL_18650_G1_LFP5 | 3,545 | LFP | 1.10 | 25.00 | 100.00 | 0.00 | 100.00 | 1.00 |
| SNL_18650_G1_LFP6 | 3,636 | LFP | 1.10 | 25.00 | 100.00 | 0.00 | 100.00 | 1.00 |
| SNL_18650_G1_NCA1 | 654 | NCA | 3.20 | 25.00 | 100.00 | 0.00 | 100.00 | 1.00 |
| SNL_18650_G1_NCA2 | 522 | NCA | 3.20 | 25.00 | 100.00 | 0.00 | 100.00 | 1.00 |
| SNL_18650_G1_NMC1 | 521 | NMC | 3.00 | 25.00 | 100.00 | 0.00 | 100.00 | 1.00 |

Access standard quantities and download the data



Many different motivations for using Battery Archive



Over 11,000 site users, many return visits, from over 50 countries, academia, and industry

- Representatives of utilities installing energy storage systems who are trying to get a better sense of what conditions exacerbate battery degradation
- Researchers in universities and companies who are trying to validate their battery degradation models with more data + class projects for undergrads
- Battery software start-ups which need data to test their algorithms and product (new data collection would be expensive)
- Individuals at companies that already have battery data and want to compare their results with available technologies
- And more...

More datasets will be made available

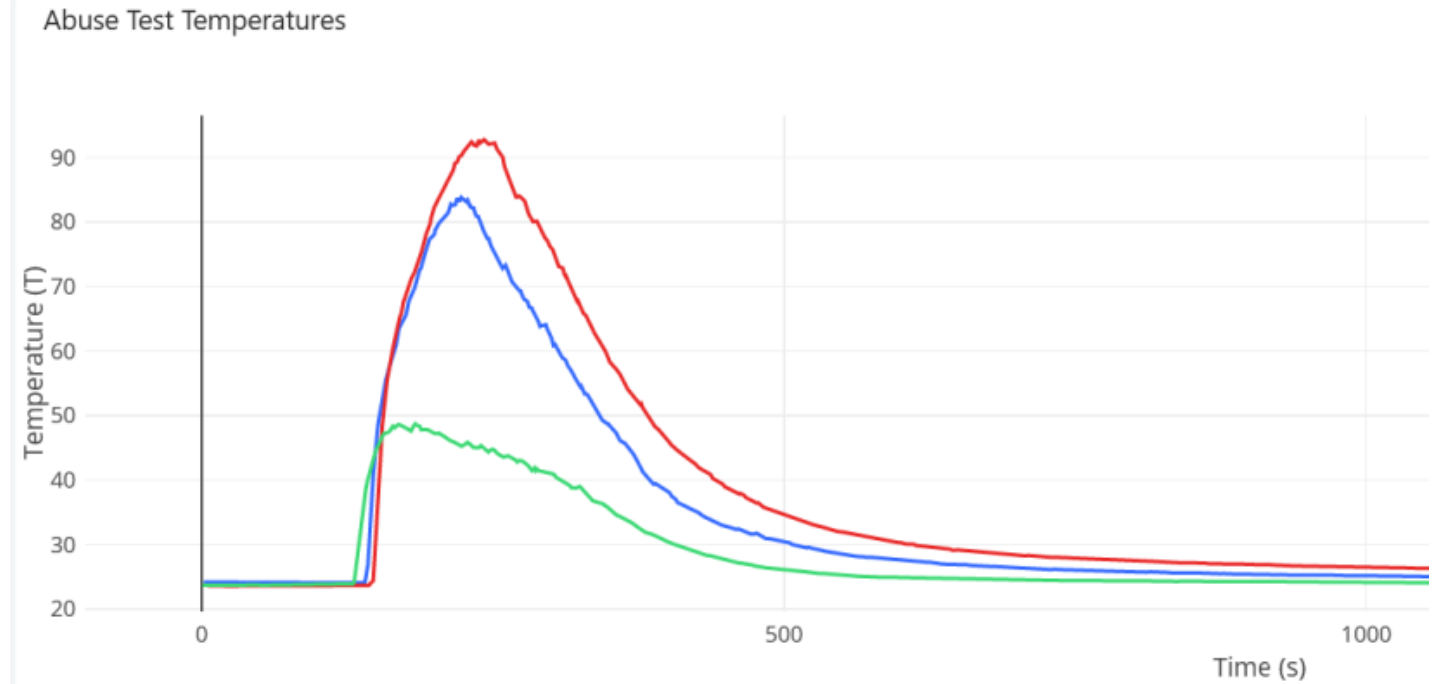
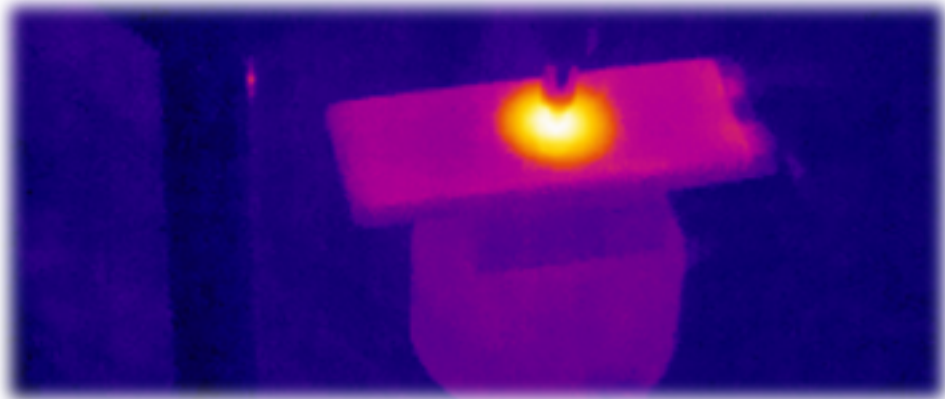


Make battery data easily available for general public use:

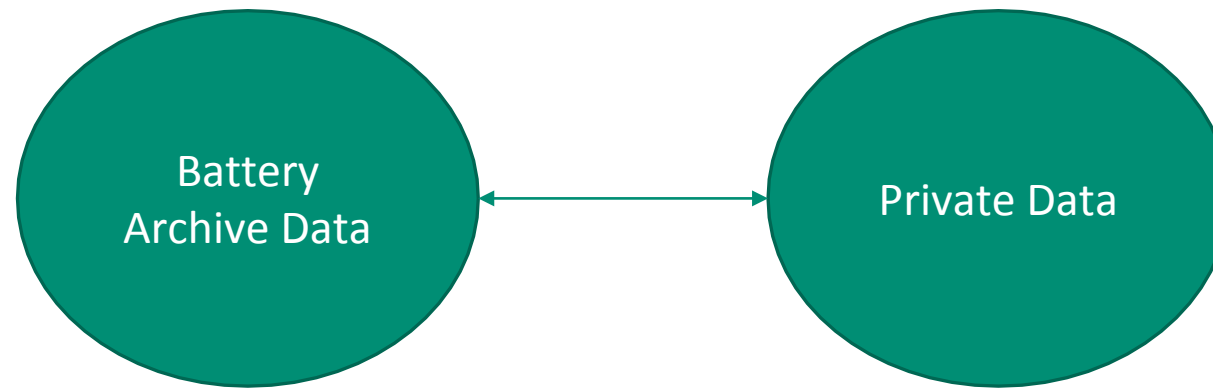
- Current data: single cell Li-ion cycling (UL, SNL, HNEI, Oxford ...)
- In the works: single cell mechanical abuse data and calorimetry (SNL, ORNL)
- Next: module data and system data

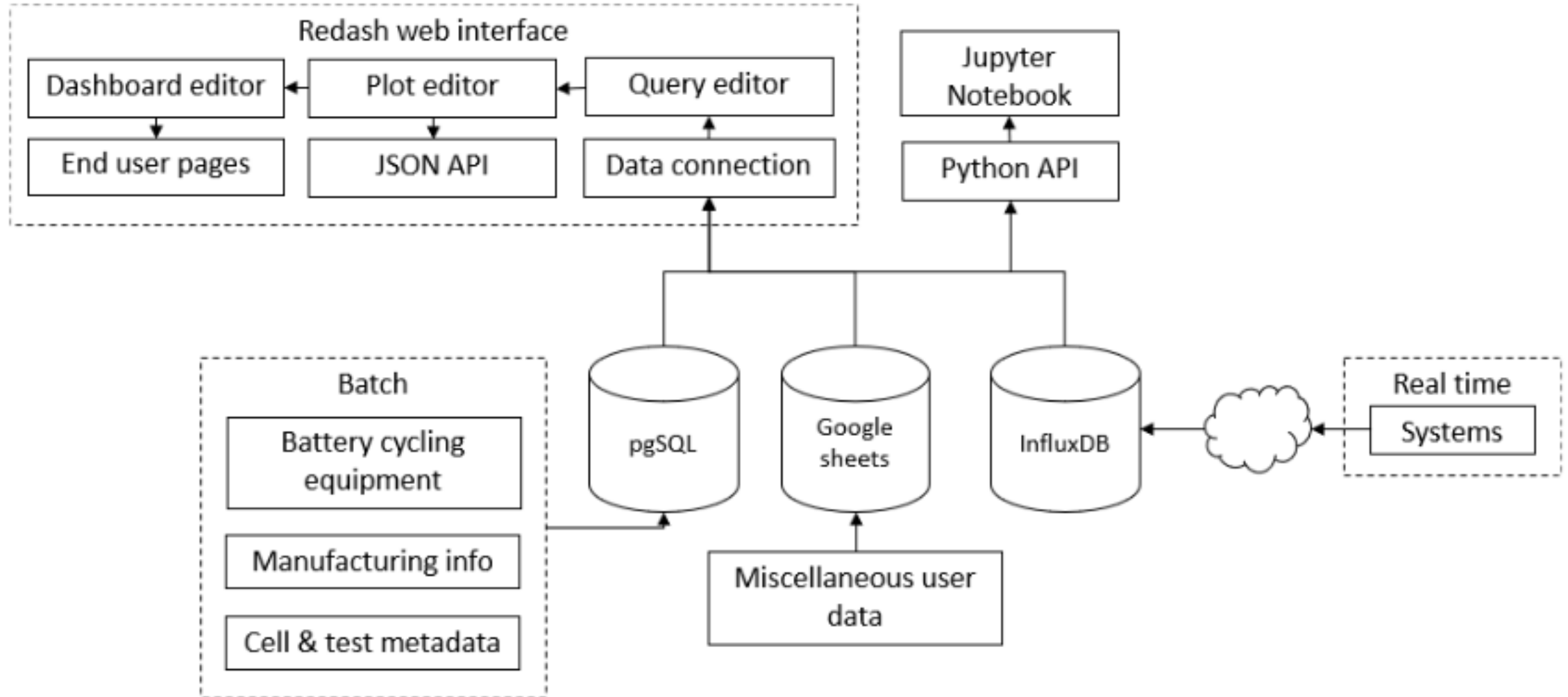
Long term:

- Cell to system for cycling and abuse data for Li-ion and emerging technologies



Aggregating data from a single standard protocol for battery abuse can enable the prediction of thermal runaway risks for new cells.





Researchers interact only with a web interface to browse and plot their data



Dashboard navigation: Dashboards ▾ Queries ▾ Alerts Create ▾

Search queries... 🔍 ? ⚙️ 🌐 admin ▾

☆ Compare Cycle Voltage and Current + Add tag

Show Data Only ⌵

battery_archive ▾

Search schema... 🔍

- abuse_metadata
- abuse_timeseries
- cell_metadata
- cycle_data
- cycle_metadata
- cycle_stats
- cycle_timeseries
- cycle_timeseries_buffer
- test_metadata
- timeseries_data

```
2 SELECT KEY || ':' || r.cell_id AS series_1,
3 KEY || ':' || cycle_index || ':' || r.cell_id AS series_2,
4 r.cycle_index,
5 r.test_time,
6 r.cycle_time,
7 value
8 FROM
9 (SELECT cycle_timeseries.cell_id,
10 cycle_index,
11 test_time,
12 cycle_time,
13 from_build_object('V', v, 'C', c) AS line
```

Save Execute

% Samplings 5 Cell IDs HNEI_18650... Cycle # 1 2 Cycle # 2 5

Table Table × Compare By Cycle Time × + New Visualization

Legend:

- C 2.0: HNEI_18650_NMC_LCO_25C_0-100_0.5/1.5C_a
- V 2.0: HNEI_18650_NMC_LCO_25C_0-100_0.5/1.5C_a
- C 5.0: HNEI_18650_NMC_LCO_25C_0-100_0.5/1.5C_a
- V 5.0: HNEI_18650_NMC_LCO_25C_0-100_0.5/1.5C_a

408 rows 2 minutes runtime

Updated just now

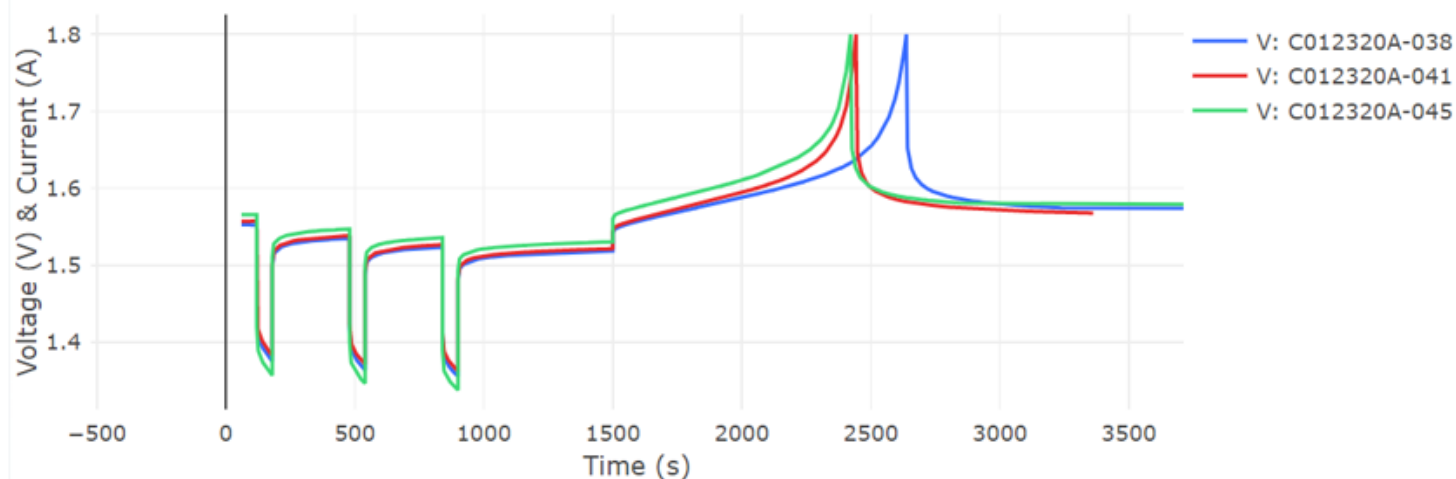
Refresh Schedule Never



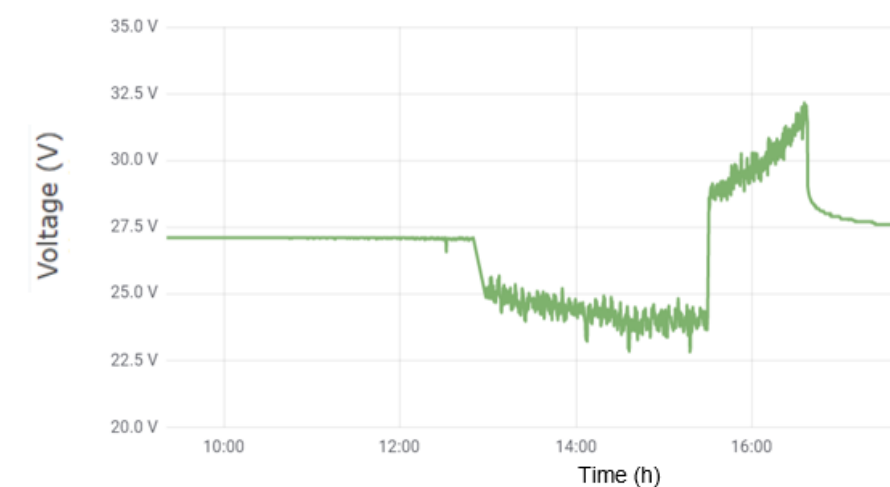
Production Data

| cell_id | study | Anode Batch ID | Cathode Batch ID | Anode Weight (kg) | Cathode Weight (kg) |
|--------------|-------------------------------|----------------|------------------|-------------------|---------------------|
| C012320A-038 | 3-pulse+1-cycle-Battery 1-SBT | A - 011520 | C - 110819 | 0.98 | 1.80 |
| C012320A-041 | 3-pulse+1-cycle-Battery 1-SBT | A - 011520 | C - 110819 | 0.98 | 1.80 |
| C012320A-045 | 3-pulse+1-cycle-Battery 1-SBT | A - 012120 | C - 110819 | 0.96 | 1.86 |

Cell Pulse Testing



System Data

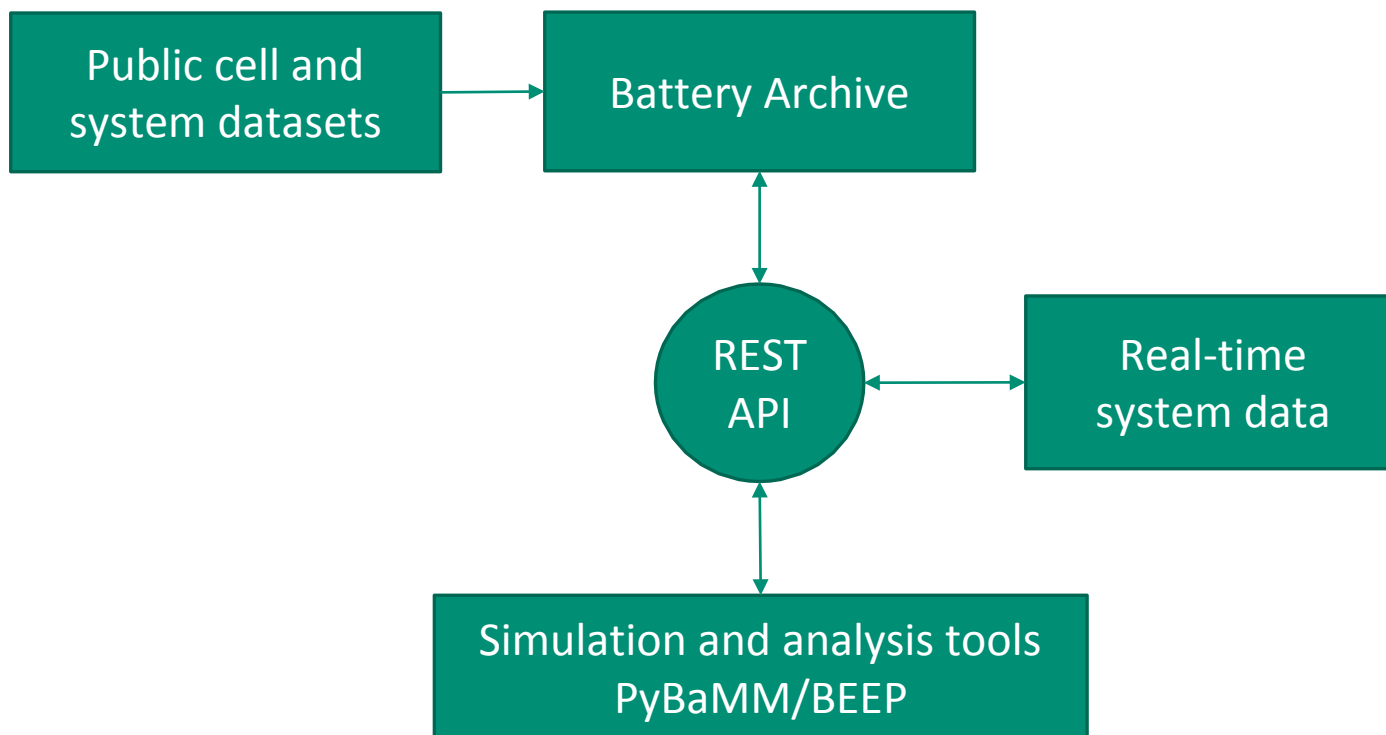


Linking different types of data across the battery lifecycle can accelerate the optimization of materials and cell configurations.

Use our open-source packages through standard REST APIs

Leverage existing resources from the community instead of redeveloping tools

Integrate with other software packages and systems



Comparison with simulation results from PyBaMM

Open source Python library (Faraday Institution) to solve physics-based electrochemical DAE models using DFN and SPM.

Run cycling protocols that match lab profiles.

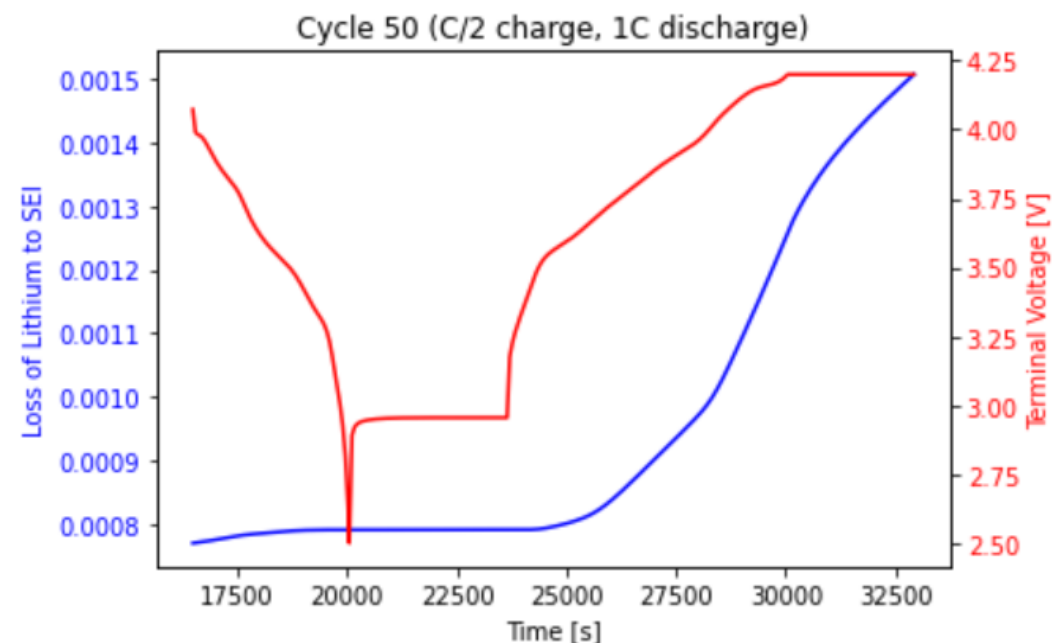
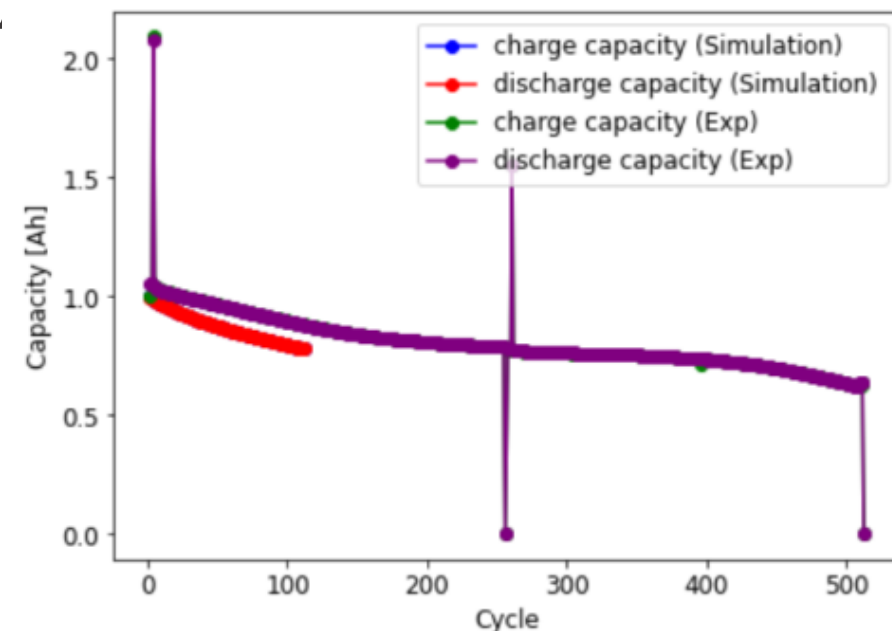
```
[ ] pybamm.set_logging_level("NOTICE")

ncycle = 500 # total number of cycles to run

experiment = pybamm.Experiment([
    (f"Discharge at 1C until {Vmin}V",
     "Rest for 1 hour",
     f"Charge at C/2 until {Vmax}V",
     f"Hold at {Vmax}V until C/50"
    )
] * ncycle,
termination="80% capacity"
)
```

Sulzer, V., et. al. (2021). Journal of Open Research Software, 9(1).

<https://github.com/pybamm-team/PyBaMM>





Provide data and tools to facilitate the progress of new battery technologies

- Starting a repository of public data and building a community of users
- Providing open source tools to maintain private datasets
- Linking data, models, and system control

To join the open-source projects or for more information on how to use the software systems, please contact vdeange@sandia.gov

Acknowledgments

Work in collaboration with Oindrilla Dutta, Jake Mueller, David Rosewater, Loraine Torres-Castro, and Babu Chalamala

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