Lithium-Ion Batteries

1. History of batteries.
2. Research that led to the development of lithium-ion batteries.
3. Working of Lithium-Ion batteries
4. History of Anode and Cathode optimisations
5. Solid Electrolyte Interface (SEI) formation

Tesla's approach of optimising Lithium-Ion batteries[2]

Plan to halve the cost per kWh
1. Cell Design
2. Cell Factory
3. Anode Materials
4. Cathode Materials
5. Cell Vehicle Integration

Cell Design

Elements of a battery cell
1. Can (negative terminal of the cell)
2. Cap (positive terminal of the cell)

When you open that cell -> Tab connected to those terminals, Jellyrolls - wound electrodes on the inside (if you unwind it, it is over 1m)
3 sheets - Anode, Separator, Cathode
Discharge = Lithium moves from Anode to Cathode
Charge = Lithium moves back to Anode
Moved from 18650 form factor to 2170 form factor (Bring 50% more energy into the cells).
Form Factor Convention: First two digits -> diameter, Second Two digits -> Length.
No reason for extra 0, so they changed the convention from 5 digits to 4 digits.
They mapped cell outer diameter vs the improvement in the range of the cars (and found a sweet spot)
If you increase the form factor, supercharging and thermals in a cell become difficult to manage.
To solve this, they came up with a tabless architecture

Tabless Architecture

Took the existing foils -> Laser Powdered Them -> Enabled dozens of connections into the active material through shingled spiral
1. Simple Manufacturing
2. Fewer Parts
3. 5x Reduction in electrical paths (50mm vs 250mm)
   a. Distance that the electrons have to travel is much less
   b. Shorter Path length in a large tabless cell than in the smaller cell with tabs.
   c. More power to weight ratio
4. Production POV

    a. When the cell goes through the system it has to keep stopping where all the tabs are
    b. You can’t do continuous production if you have tabs. There is rate at which you start and stop and accelerate again.
    c. Slows down the rate of production
    d. Sometimes you get the tabs wrong, lose active area, etc.
5. 5x Energy, 16% range increase, 6x Power

Cell Factory

Inspiration

- Paper and Bottle industry, continuous motion, mass scaled manufacturing -> Very low cost

What’s in a cell factory

1. Electrode Process
    a. Active materials are coated into films onto foils
2. Winding Process
    a. Those coated foils are wound. (If you have tabs then you have to start and stop a lot)
3. Assembly Process
    a. Jellyroll is assembled into the can.
    b. It’s sealed with electrolyte
4. Formation Process
    a. Cell is charged for the first time
    b. Electrochemistry is set
    c. Quality of cell is verified

Wet process of the electrode coating

1. Mixing
    a. Powders are mixed with either water or solvents (solvents for cathode)
2. Coat and Dry
    a. That mix goes into a large coat and dry oven (huge 10m long) where the slurry is
        i. coated onto the foil
        ii. Dried
        iii. Solvent has to be recovered
3. Compress
    a. The coated foil is compressed to the final density

This is a lot of iron involved in just one process
This whole processed is optimised using the dry process

Dry process of the electrode coating

Mix, Dry Coat (watch the video for more info on this (54:14) -

- 10x footprint reduction
- 10x energy reduction

Anode Materials

Silicon as anode

1. Most abundant element in the earth's crust after oxygen
2. Stores 9x more lithium than graphite

Why isn't everybody using it?

1. It expands 4x when fully charged with lithium.
2. All that expansion stress on the particle results in the cracking of particle, electrical isolation of particles
3. You lose capacity -> energy retention of the battery starts to fade
4. It gums up with a passivation layer that has to keep reforming as the particles expand

Current approach to silicon are highly engineered expensive materials

1. Silicon structured in SIO glass (6.6 KW/h)
2. Silicon structured in graphite (10.2 KW/h)
3. Silicon in nano wires (>100 KW/h)

Tesla's approach:
Tesla Silicon

1. Raw metallurgical silicon
2. Stabilize the surface (through elastic ion conducting polymer coating)
    a. No chemical vapour deposition
    b. No highly engineered, high capacity solution
3. Integrate in the electrode, through a robust network formed out of a highly elastic binder.
4. Costs 1USD per KWh (Cheaper and longer range)

Cathode Materials

Cathode is like book shelves

1. Metals (Nickel/Cobalt/Aluminium) are shelf
2. Lithium is the book

What sets apart these different metals is how many books of lithium they can fit on the shelves and how steady the shelves are.
You need a stable structure to contain the ions. You want a structure that doen't crumble or get gooey. Basically that holds the shape in both the cathode and the anode. As you're moving these ions back and forth, it needs to retain it's structure.
If it doesn't retain its structure then you lose cycle life and your battery capacity drops very quickly

Dollar / KWh metals
Cobalt > Nickel > Iron
Energy Density
Nickel > Cobalt > Iron

Tesla's goal is to increase Nickel (high ED and low cost). Cobalt is very stable hence it is highly used.
Maximise Nickel, Remove Cobalt using novel coating and dopants -> 15% reduction in cost of cathode (dollar / KWh)

3 tier approach for developing EVs

1. Iron-Based - Long Cycle Life
2. Nickel + Manganese - Long Range
3. High Nickel - Mass Sensitivity (Trucks and all)

Cathode Cost Breakdown

1. Nickel - 35%
2. Lithium - 25%
3. Cobalt - 5%
4. Processing - 35%

Traditional Cathode Process

1. Metal Sulfate Production
    a. Metal
    b. Sulphuric Acid
2. Raw Materials Input
    a. Metal Sufate
    b. Chemicals
    c. A lot of water
3. Cathode Production
4. Final Product
    a. Cathode
    b. Large amount of waste water + byproducts

Tesla Cathode

1. Raw material input
    a. Metal
    b. Water
2. Cathode Production
3. Final Product
    a. Cathode

66% reduction in investment, 76% reduction in process cost, 0 wastewater

A similar reduction in Lithium cost. They use sodium chloride to extract lithium from the core

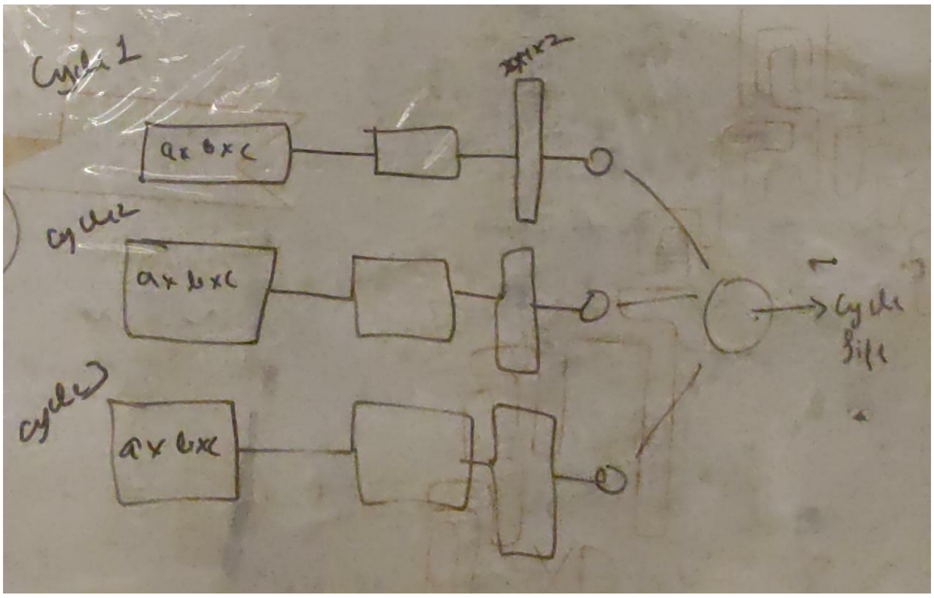
Neural Network Architectures

1. Convolutional Neural Networks
    a. Convolution Layers
    b. Pooling Layers
    c. Fully Connected Layer
    d. Famous architectures that we can use
        i. LeNet-5
        ii. AlexNet
        iii. VGG-16
        iv. ResNet

    v. Network in Network (1x1 Convolution)
    vi. Inception Net
    vii. Mobile Net
    viii. Efficient Net
2. Recurrent Neural Networks
3. I will add more about how and when can we use these architectures.

Plan

The data I analysed is mostly 3 dimensional.
We'll collect data for every cycle (total 5 cycles) and process it like it's an image (probably a 3-dimensional matrix). Eventually compress the dimensions using convolution, pooling techniques. Create a small 1-dimensional matrix out of all those steps. Build a simple regression model to generate a single feature for each cycle. Then train a network to predict cycle life from those 5 features we generated.



Problems

Any questions that we have maybe written here. We can try to answer them!

1. CNN require a lot of data -> So we need to collect a lot of data.
    a. Different parameters (like depth of discharge, max Soc, etc.) for a dataset may lead to ambiguity. The dataset should be as consistent as possible.
2. What do we mean by
    a. Potentiostatic Charging (Sup Fig 2 - Severson et. al.)
    b. Galvanostatic Charging (Sup Fig 2 - Severson et. al.)
3. Questions for data analysis
    a. What are Qd, Qv, Qdlin, discharge_dQdV, Tdlin (Are they really measured?)
    b. What are the 3 phases which have occurred in a complete cycle (T, V, Qd + Qv)

Next Steps

1. Learn about more NN architectures
    a. This statement is very vague, I will narrow it down.
2. Prepare dataset to feed into the model.
    a. This doesn't require us to develop a model first.
    b. We can do this parallelly
    c. The main task is to identify the data used in most of the research papers.
    d. Add the data source in the section down below
    e. Identify the factors which should be consistent across all the datasets
        i. For example, the form factor.
        ii. The temperature at which the batteries were operated
        iii. etc.
    f. Cc: prashiv_s@ch.iitr.ac.in parth_b@ch.iitr.ac.in shivshankar_s@ch.iitr.ac.in
3. Learn about factors that affect battery health.
    a. Learn about all the battery terminologies and see how we can collect data for all those features.

References

1. Xiaopeng Tang, Kailong Liu, Kang Li, Widanalage Dhammika Widanage, Emma Kendrick, Furong Gao. Recovering large-scale battery ageing dataset with machine learning.
2. Kristen A. Severson, Peter M. Attia, Norman Jin, Nicholas Perkins, Benben Jiang, Zi Yang, Michael H. Chen, Muratahan Aykol, Patrick K. Herring, Dimitrios Fraggedakis, Martin Z. Bazant, Stephen J. Harris, William C. Chueh & Richard D. Braatz. Data-driven prediction of battery cycle life before capacity degradation.
3. Vijay Mohan Nagulapati, Hyunjun Lee, DaWoon Jung, SalaiSargunan S Paramanantham, Boris Brigljevic, Yunseok Choi, Hankwon Lim. A novel combined multi-battery dataset based approach for enhanced prediction accuracy of data-driven prognostic models in capacity estimation of lithium-ion batteries.
4. Laisuo Su, Mengchen Wu, Zhe Li, Jianbo Zhang. Cycle life prediction of lithium-ion batteries based on data-driven methods.
5. Meru A. Patil, Piyush Tagade, Krishnan S. Hariharan, Subramanya M. Kolake, Taewon Song, Taejung Yeo, Seokgwang Doo. A novel multistage Support Vector Machine based approach for Li-ion battery remaining useful life estimation.
6. Preger, Yuliya & Barkholtz, Heather & Fresquez, Armando & Campbell, Daniel & Juba, Benjamin & Romàn-Kustas, Jessica & Ferreira, Summer & Chalamala, Babu. (2020). Degradation of Commercial Lithium-Ion Cells as a Function of Chemistry and Cycling Conditions. Journal of the Electrochemical Society. 167. 10.1149/1945-7111/abae37.
7. Press Release. The Nobel Prize in Chemistry 2019. NobelPrize.org. Nobel Prize Outreach AB 2022. Tue. 15 Feb 2022.
8. Tesla. “Tesla Battery Day”. YouTube video, 2:11:29.

9. A. Jhunjhunwala et. al. NPTEL Course, Title: "NOC: Fundamentals of Electric vehicles: Technology & Economics.” Indian Institute of Technology Madras, Chennai, Tamil Nadu.