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# Title: Internal Structure of Lithium-Ion Batteries

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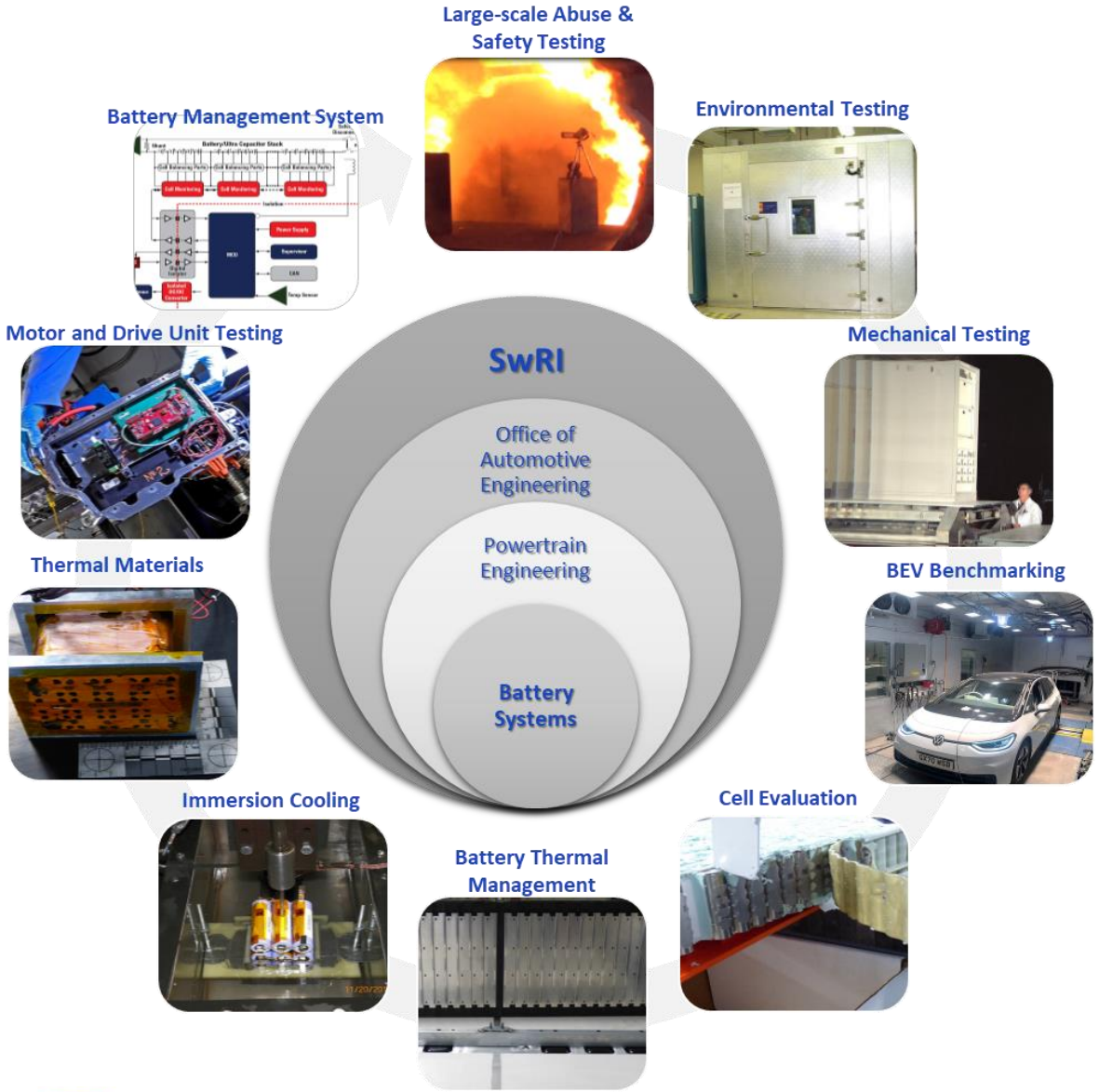
# SwRI Technical Divisions

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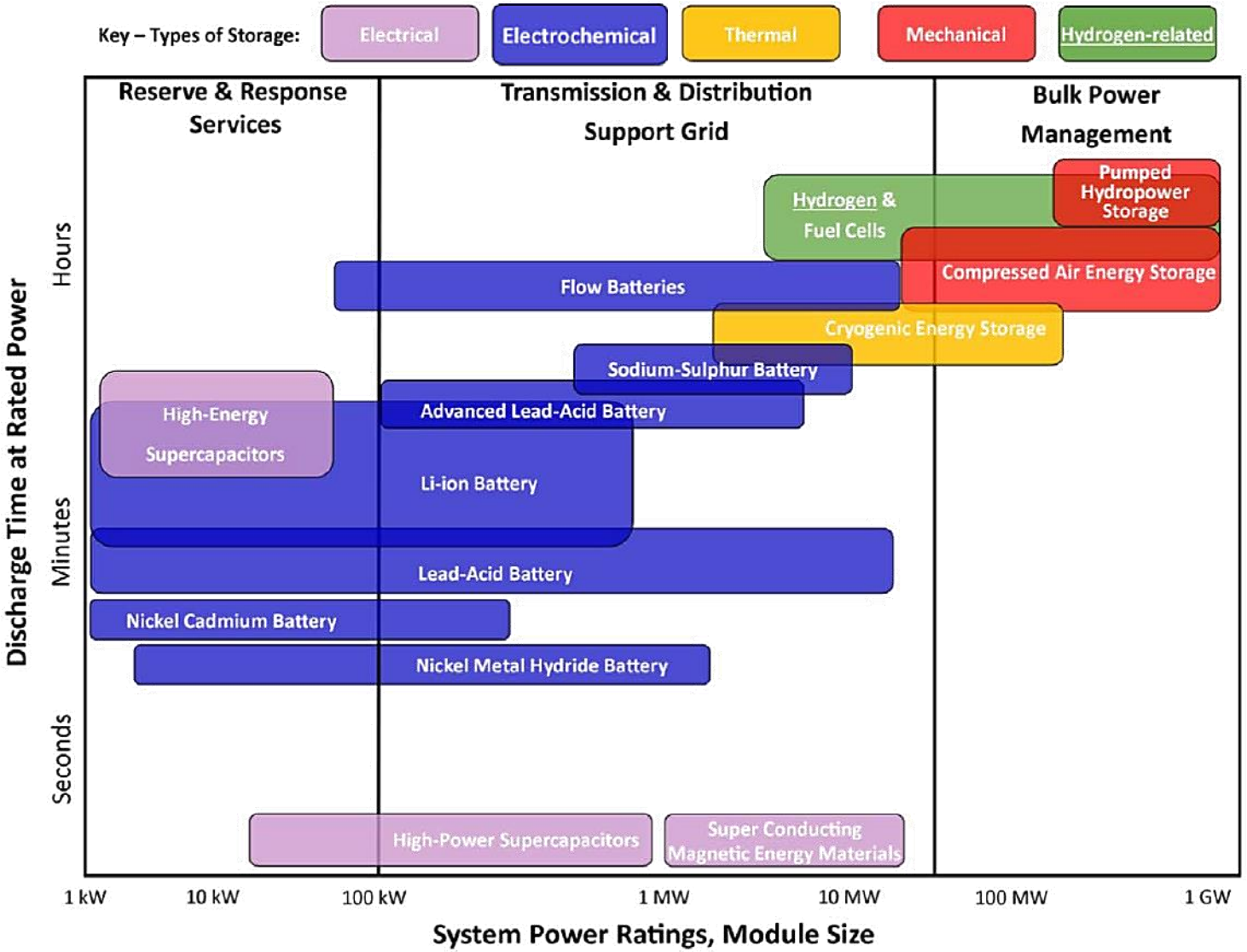
- Space Systems

# Energy Storage Systems




## Primary Cells or Batteries

These cells or batteries are discharged once and discarded.

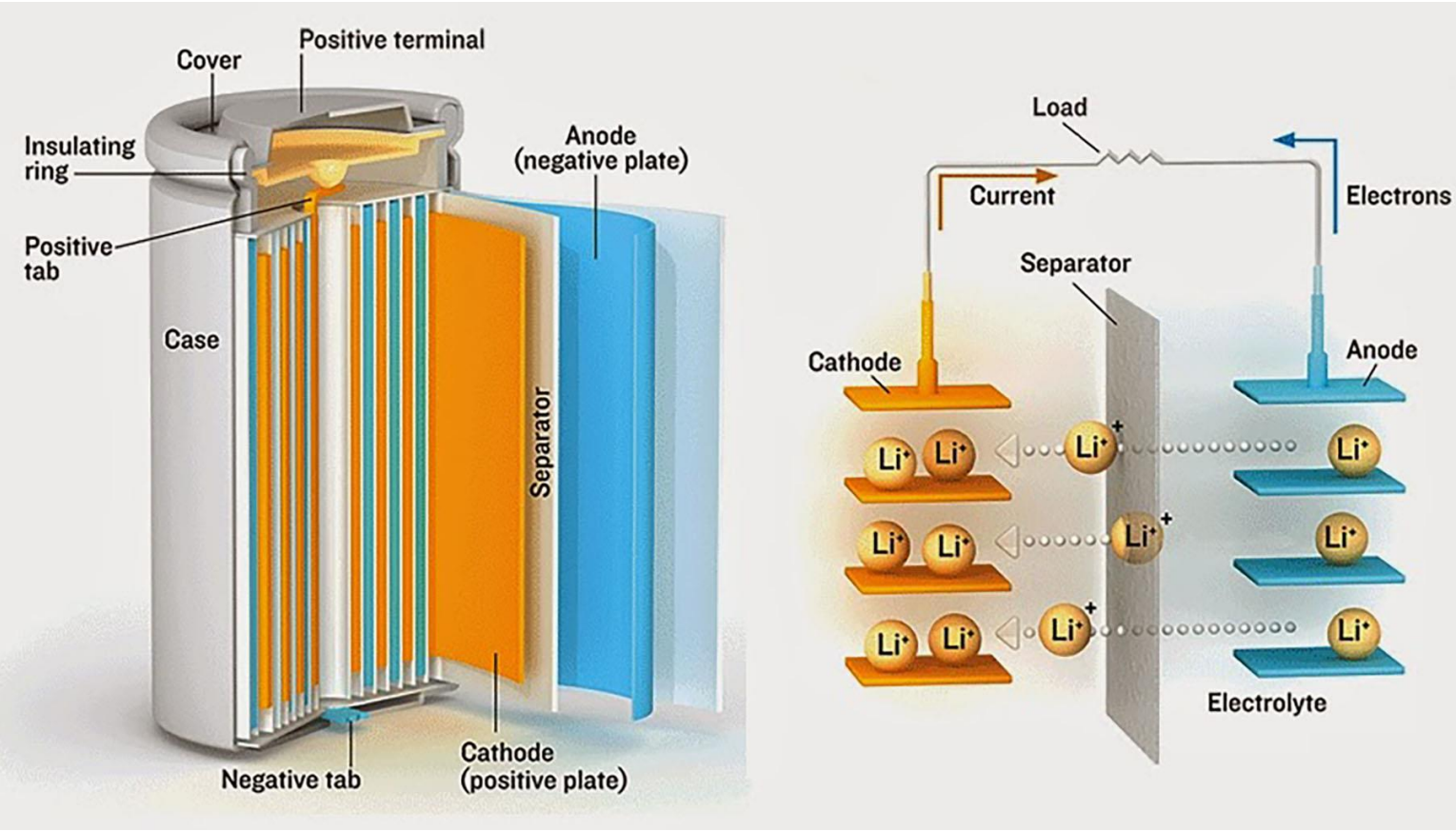
## Secondary or Rechargeable Cells or Batteries

These batteries can be recharged after discharge. They are also called storage batteries or accumulators.

## Reserve Batteries

In this type of primary battery, a key component is kept separate from the rest of the battery until activation. By doing this, chemical deterioration and self-discharge are essentially eliminated. Usually, the electrolyte is the component separated.

# Components of the Electrochemical Cell




**Cathode:** The positive electrode of the cell (for discharge).

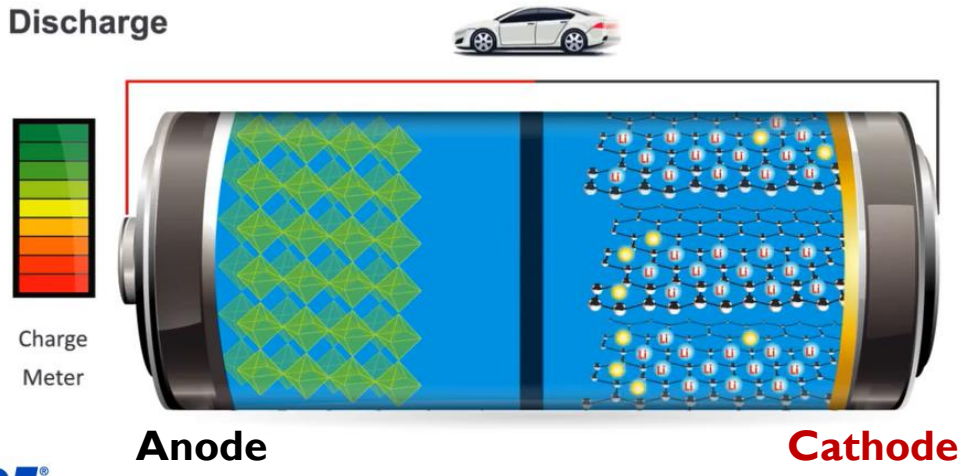
**Anode:** The negative electrode of the cell (for discharge).

**Electrolyte:** The medium that provides the ion transport mechanism between the positive and negative electrodes in a cell. (This can be aqueous or non-aqueous)

**Separator:** A microporous material that keeps the cathode and anode from touching each other.

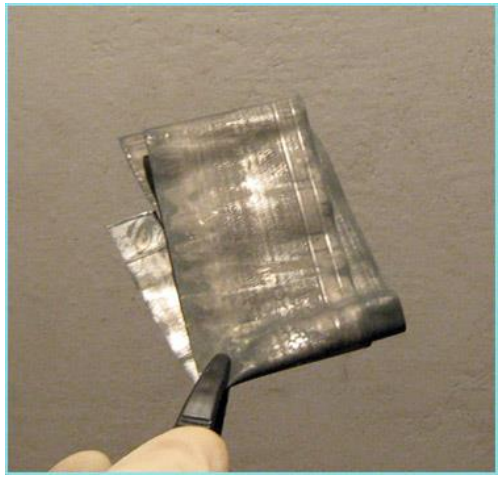
# Rechargeable Lithium-ion Battery

- High energy and power density
- High voltage per cell
- Long cycle and storage life
- High charge and discharge efficiency
- Reasonable cost per Wh
- Market – many manufacturers and high demand
- Different shapes and sizes
- Billions (1,000,000,000) of cells manufactured per day



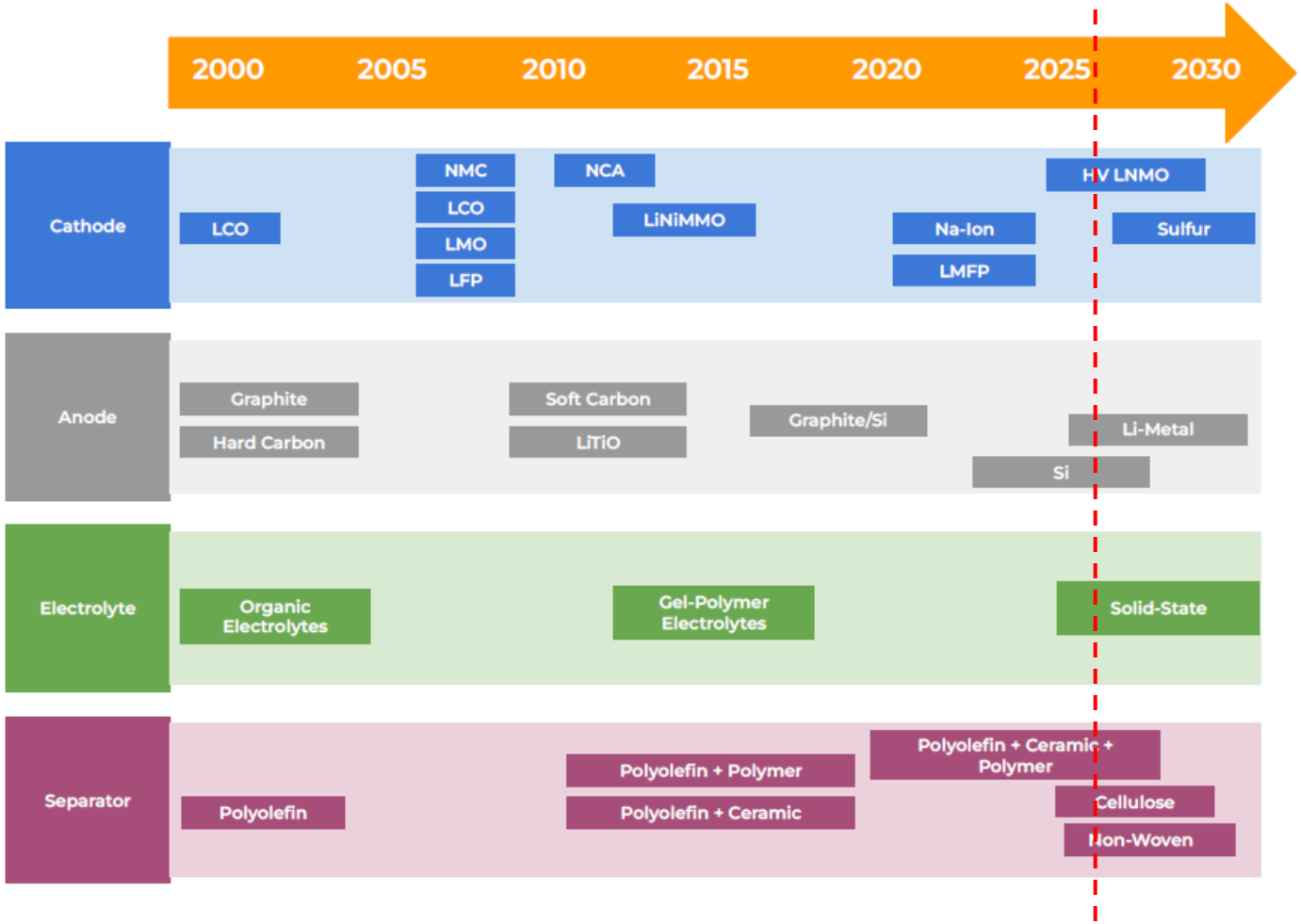

## Lithium Mine

## Lithium Sheet



## Reactivity

# Battery Cell Chemistry Development

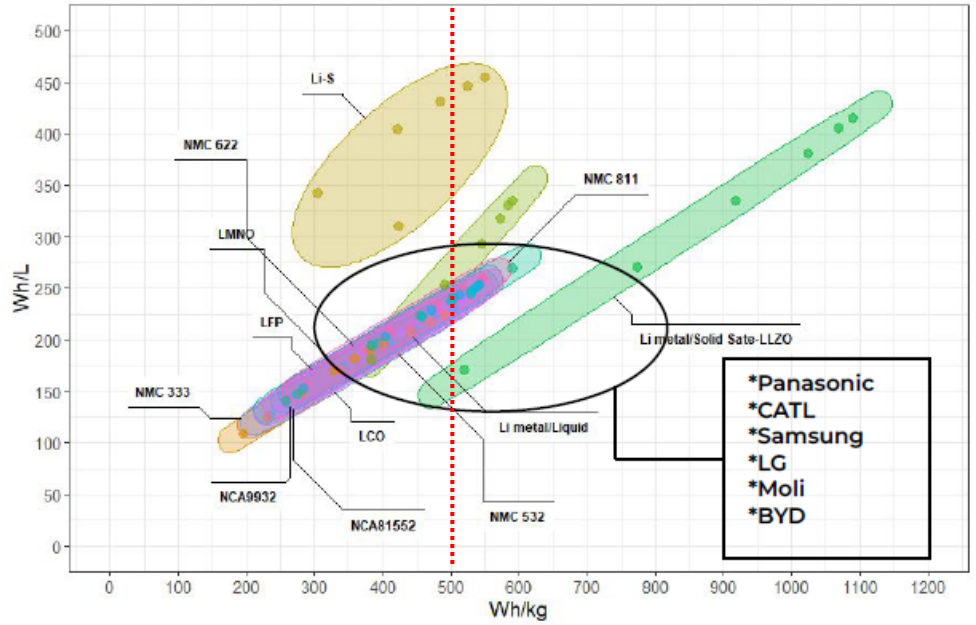



** 500 Wh/kg are the cells are the goal of government agencies in the US, EU, and Japan

***USA Battery 500**

***Japan Rising II (now Rising III)**

***Battery 2030 EU**



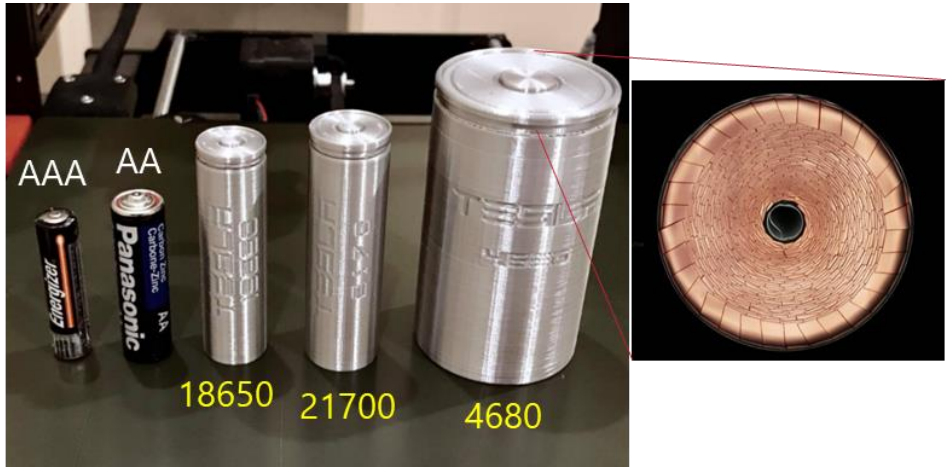

*Courtesy: Volta Foundation, 2023*

# Small Scale Batteries

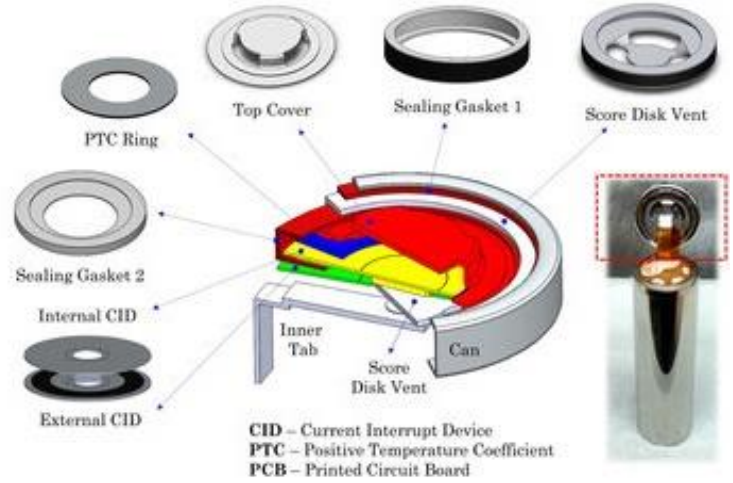
## Coin Cells


- **Size < 10 grams**
- In the worst-case scenario, the coin cell with leak the electrolyte through the gasket.
- No safety features included in the cell

## Cylindrical Cells



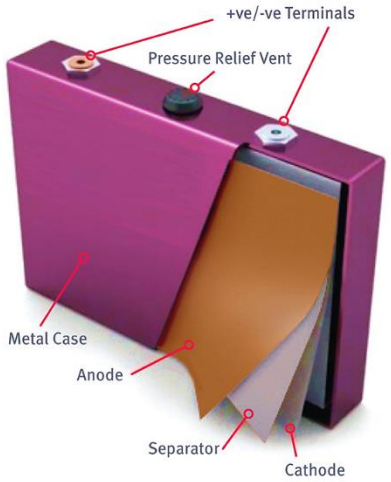





- **Size: 50 ~ 400 g**
- Cell may have internal protections (CID, PTC, PCB) against high temperature, current and pressure.
- The battery industry is mostly based on the 18650 cell architecture.
- Thermal runaway can lead to fire, smoke and ejecta. Propagation in large battery packs is common despite the cell protections
- Cells have a dedicated vents to releases gases and pressure generated within the cell.

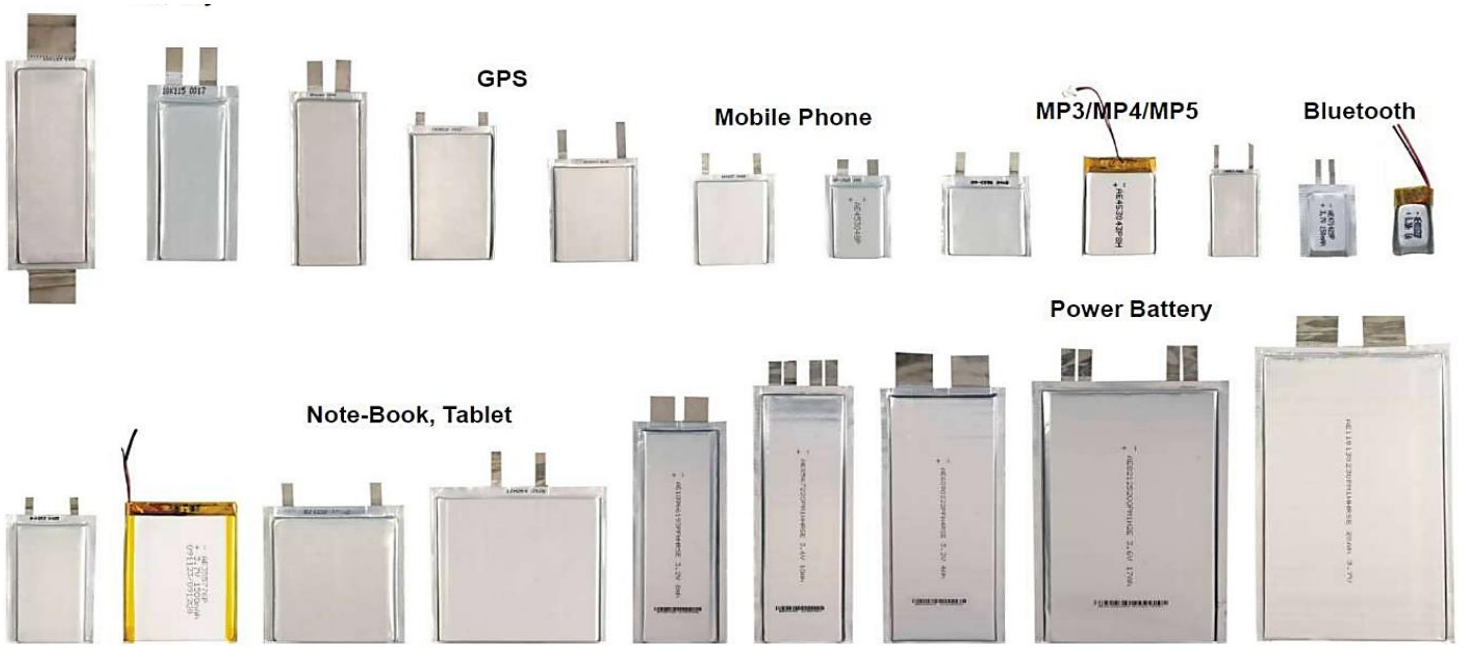
# Large Scale Batteries

## Prismatic Cells




- **Size: 400 ~ 6000 grams**
- Dedicated vent holes for pressure relief
- Large size = More energy stored that can be released if the cells is not operated properly
- Hard case protect the cells from mechanical deformation and rupture

## Pouch Cells




- **Size: 400 ~ 4000 grams**
- Non-standardized size, tab orientation/location. Tab area is susceptible to venting
- No dedicated vent path location
- The soft casing makes the cells susceptible to mechanical deformation increasing the likelihood of thermal runaway in case of failure
- Large size = More energy stored that can be released if the cells is not operated properly

# Manufacturing – Coin Cells

Mixing of Cu and Sn in stoichiometric proportions

Pressing of pellets 13 mm diameter, 1 mm thick (7 tons)

Sintering under argon atmosphere (400 °C, 12 h)

Grinding and sieving to 400-500 mesh powders

Weigh and mix dry powder

Mix powder with solvent and binder

Prepare binder solution

Cast slurry onto current collector

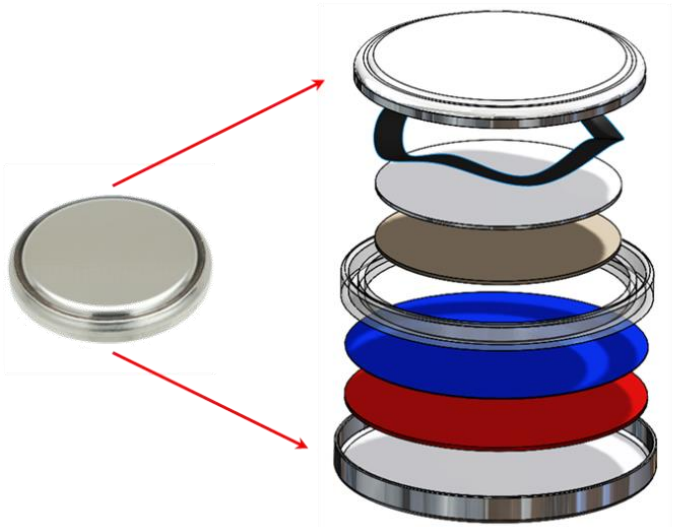
Prepare copper foil

Dry electrode sheet in oven

Punch electrodes

Construct coin cells

Perform tests and collect data



Cap (Negative)

Wave spring

0.5 mm spacer

Li metal disk

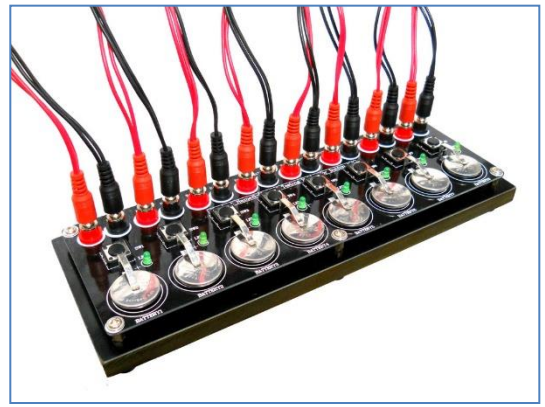
Gasket

Separator

$Cu_6Sn_5$ electrode

Case (Positive)


## Applications



*Daniel Juarez-Robles et al., ACS App. Mater. Interfaces, 2019, 11, 563-577*

# Manufacturing – Electrode Processing

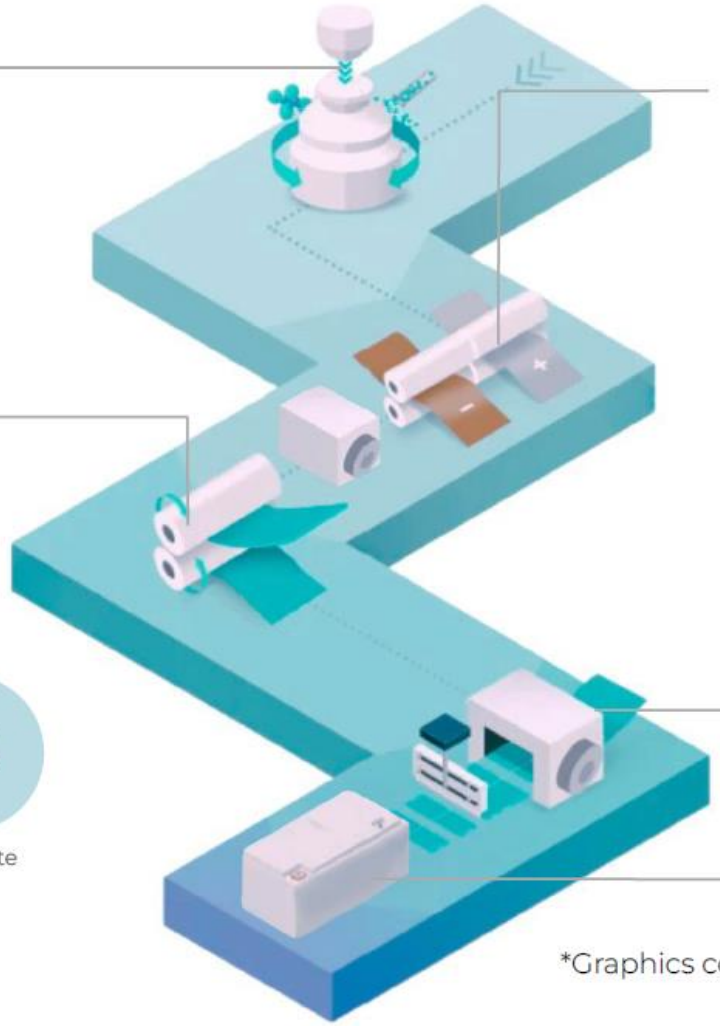
**Challenges**
slurry quality (uneven dispersion)

## Mixing
Slurries are made by mixing active material, binder, and solvent
**The different combinations between those three highly affect coating & drying**

**Challenges**
electrode waste; physical damage to material

## Calendaring
Electrodes are densified to a target value

Here it's important to determine **electrode quality** and density



## Coating & Drying
Electrode slurries are coated onto the current collector 54% cost of electrode production
**All other process steps depend on the quality of this step.**

**Challenges**
processing time; utilization loss; difficult to measure quality & get quality metrics

## Slitting & Notching
Electrodes are cut into singulated segments

Uncoated areas are **cut out** leaving the parts where tabs will be grounded

**Challenges**
edge quality (burr defects often occur - dangerous), difficult to inspect at speed; tool wear; **lowest OEE of any process because it's difficult to automate**

## Vacuum Drying
Removes leftover solvent

**Challenges**
processing time; footprint; takes 12-24 hours

**39%** of total manufacturing cost

**50-80 m/min** pouch film speed

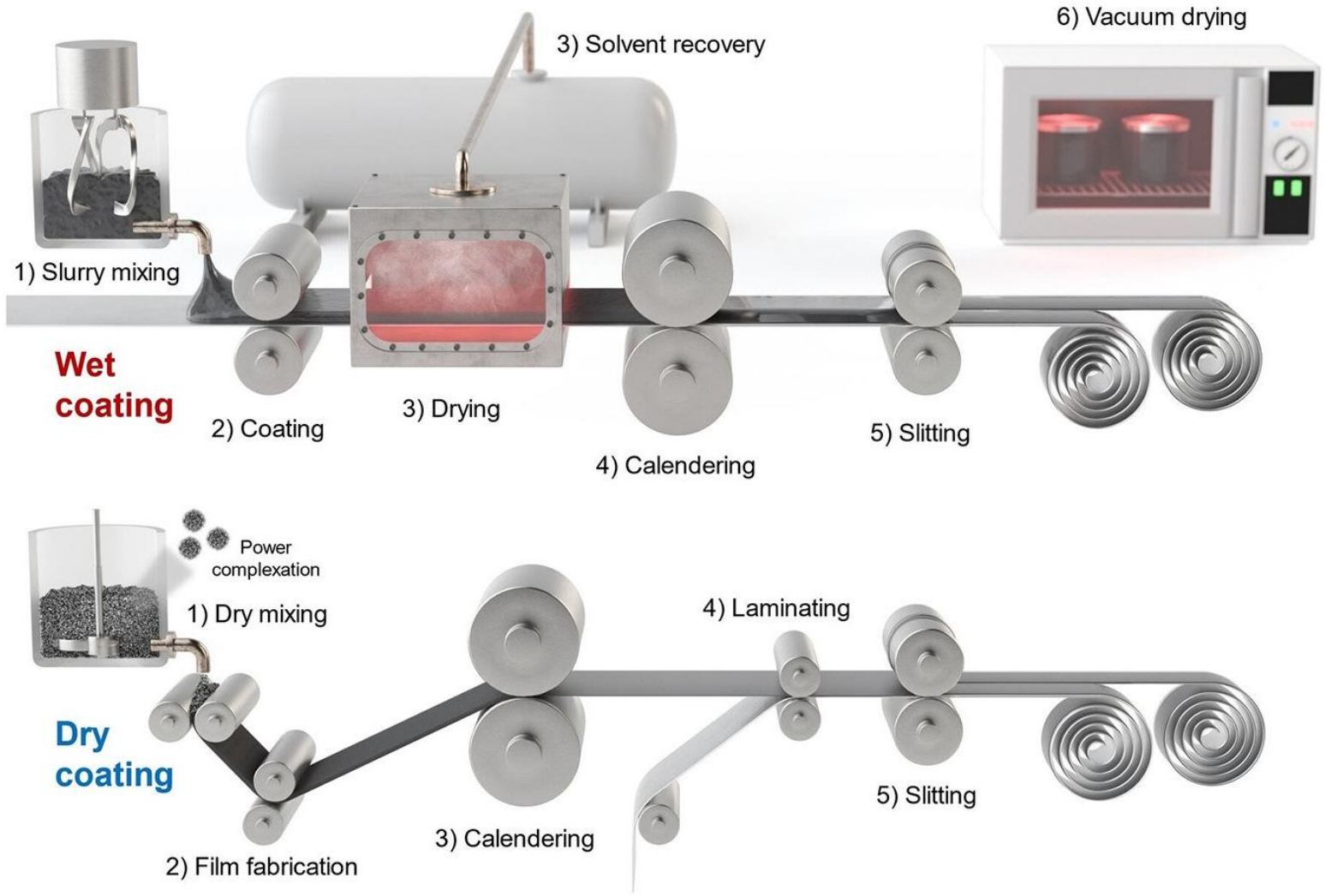
**20-30 m/min** cylindrical film speed

**5%** scrap rate

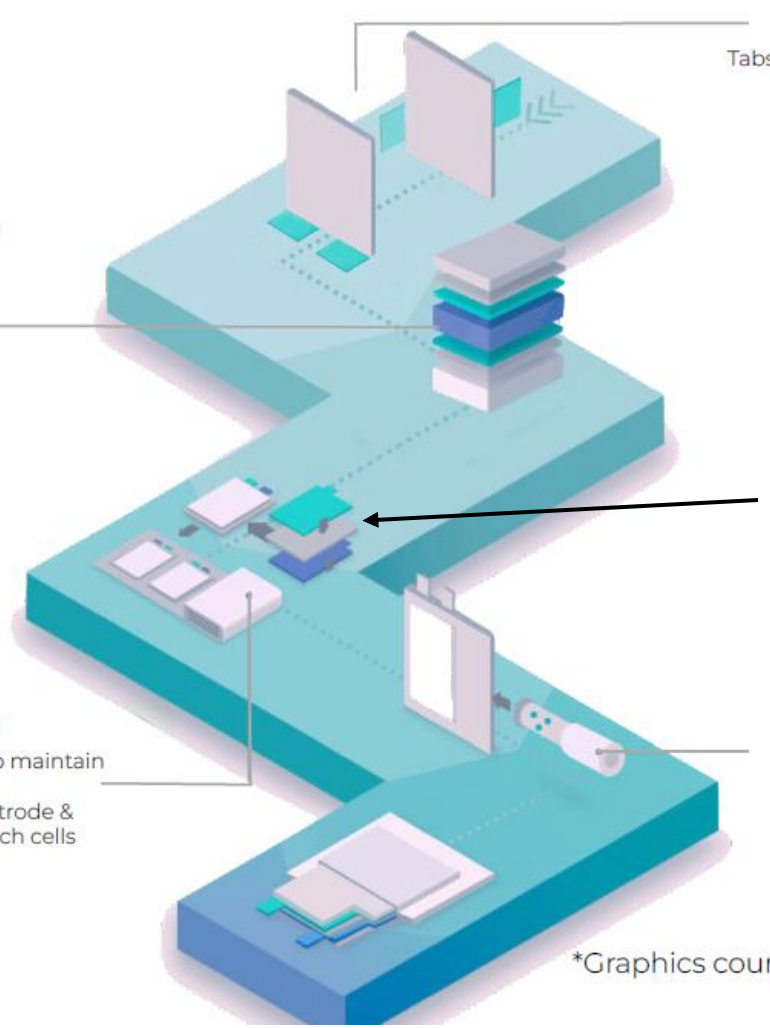
*Graphics courtesy of LG Energy Solution. Reproduced with permission.

*Courtesy: Volta Foundation, 2023*

# Manufacturing – Electrode Processing




# Manufacturing – Pouch Cell



**Tab Welding**
Tabs are ultrasonically welded to the jelly rolli

**Challenges**
foil damage; coating adhesion

**Challenges**
corner cracking

**Pouch Forming**
Making a case by pressing a film

20%
of total manufacturing cost

2-20 parts/min
speed

5%
scrap rate

**Challenges**
positioning accuracy of anode & cathode sheets (alignment); speed (affects positioning)

**Lamination & Stacking/Winding**
**Lamination:** laminating layers to maintain positional integrity
**Stacking:** stacking layers of electrode & separator. Note that **wound** pouch cells also exist.

**Electrolyte Injection**
Filling the electrode pocket with electrolyte through metered dispensing

**Challenges**
dosing and distribution accuracy of the electrolyte in the cell; No electrolyte residues in the sealing seam; seal integrity

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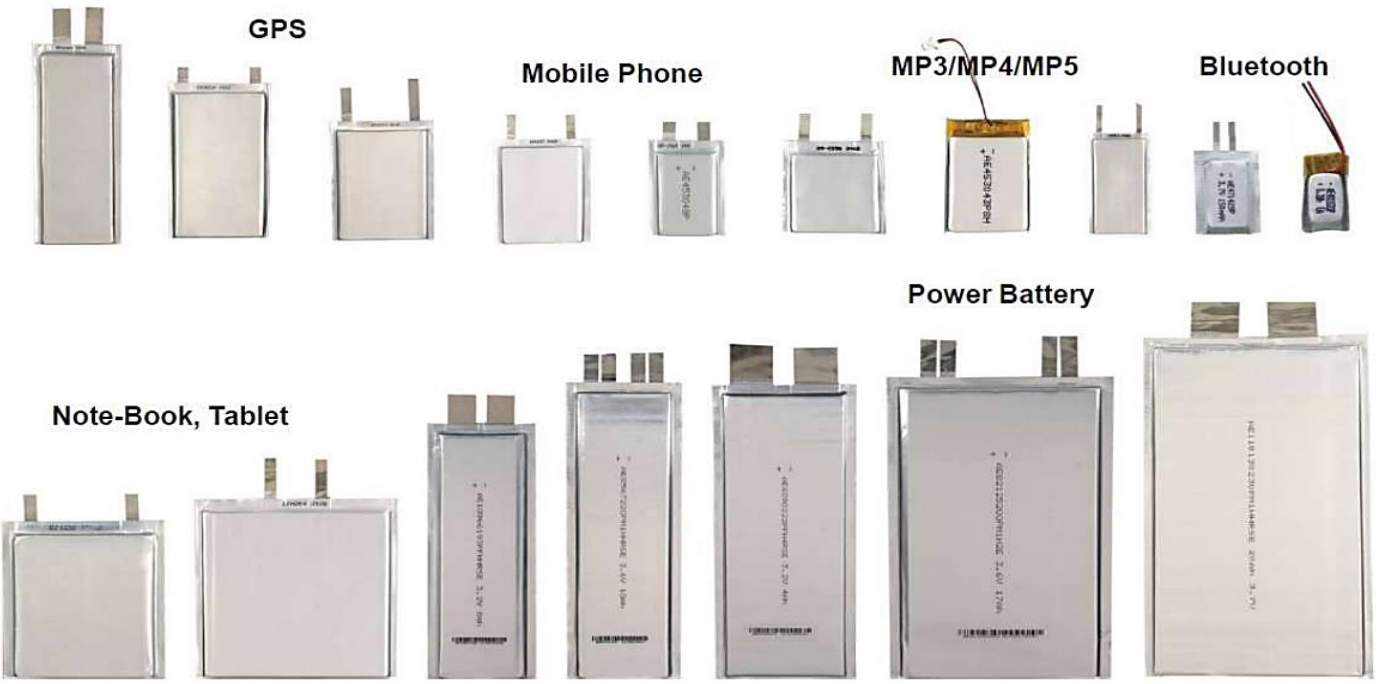
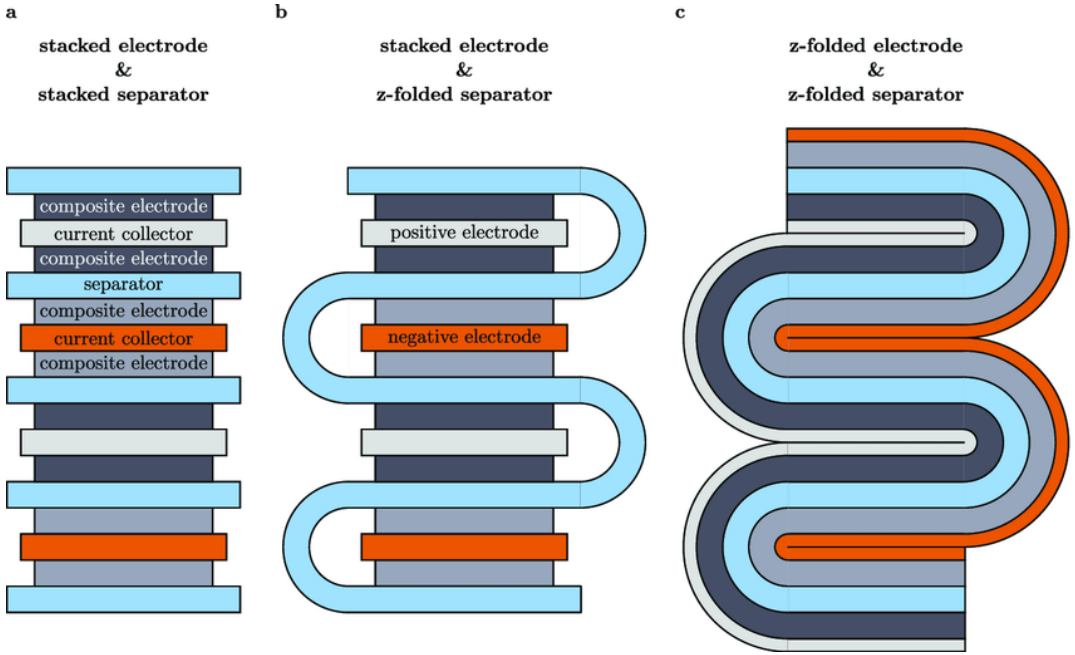
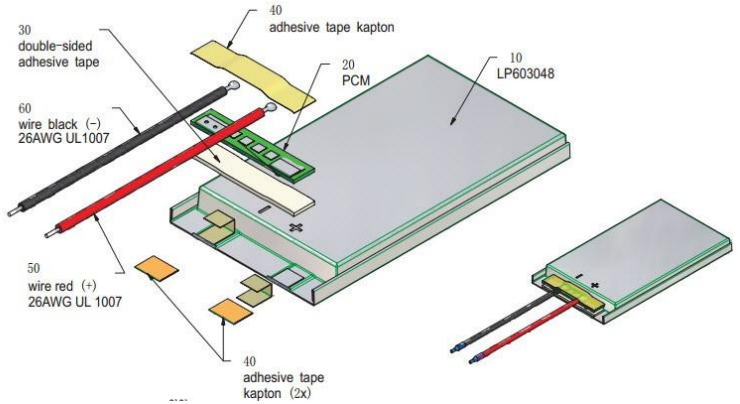
# Manufacturing – Pouch Cell

## Size Adaptability to Application

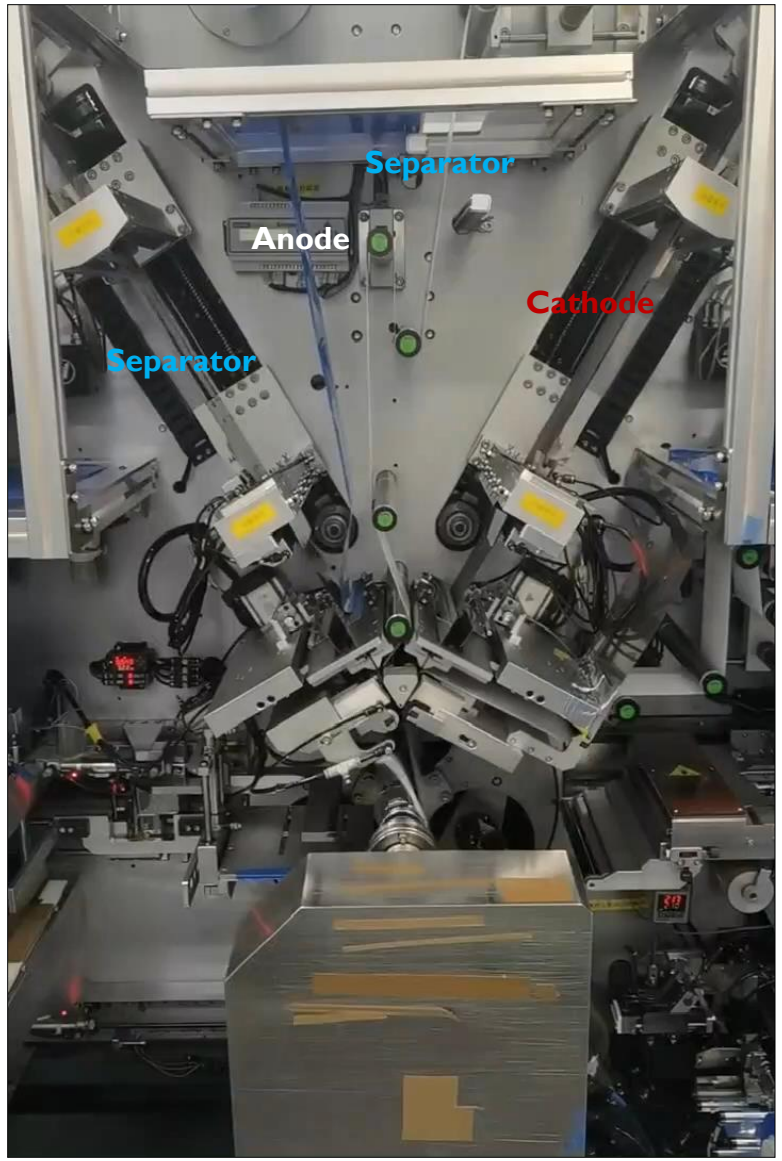


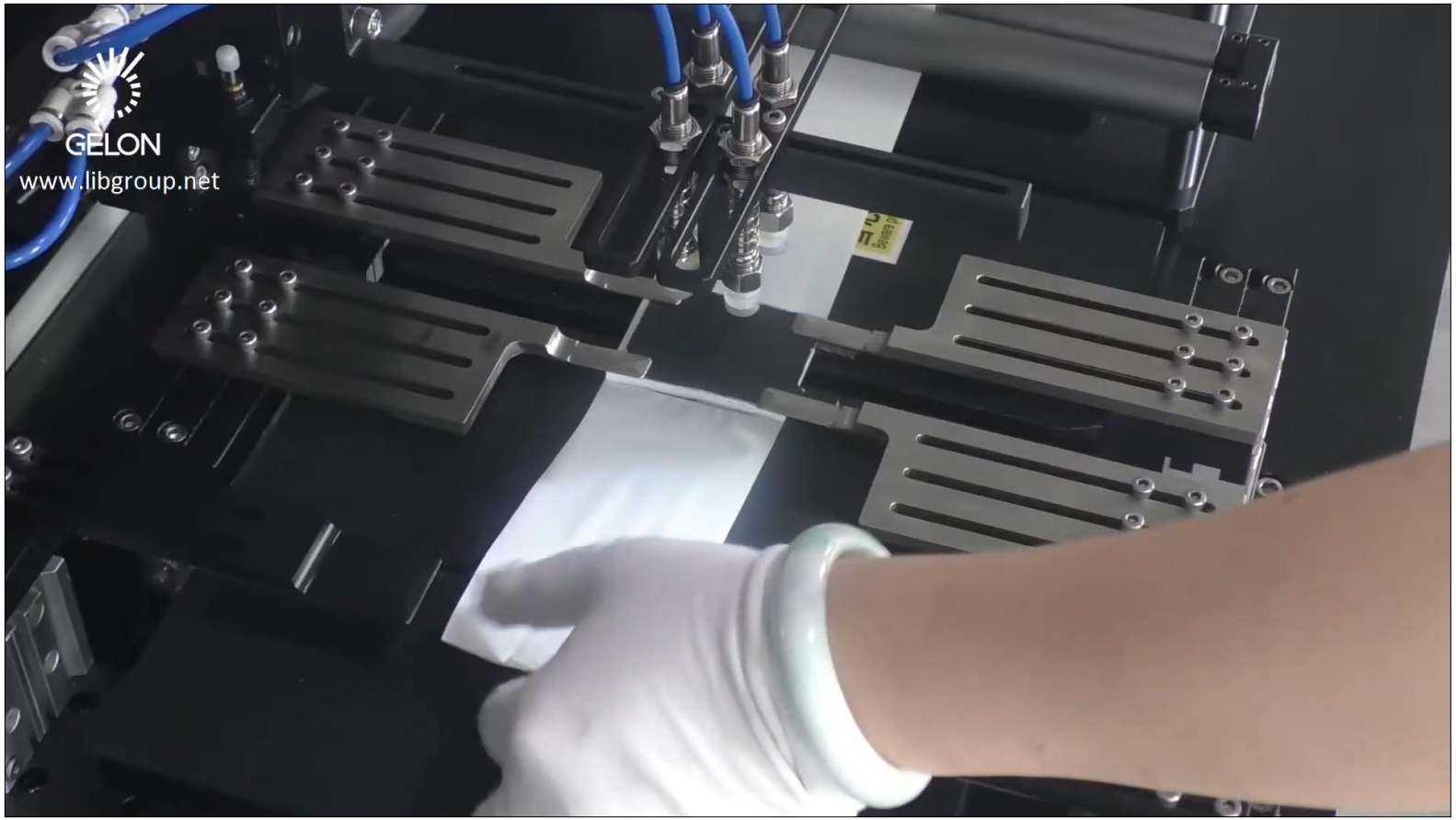

## Pouch Cell Internal Structure



# Manufacturing – Pouch Cell



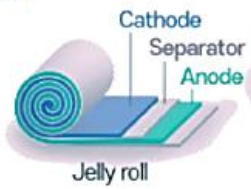



# Manufacturing – Cylindrical Cell

**Challenges**
anode, cathode, separator alignment; tabing, taping, cutting accuracy; tab welding quality (can introduce safety issues)

## Winding & Tab Welding

Winding the cathode, anode, and two separator rolls. Welding the aluminum and copper tabs onto the cathode and anode respectively.
**SPEED: 30 parts/min**



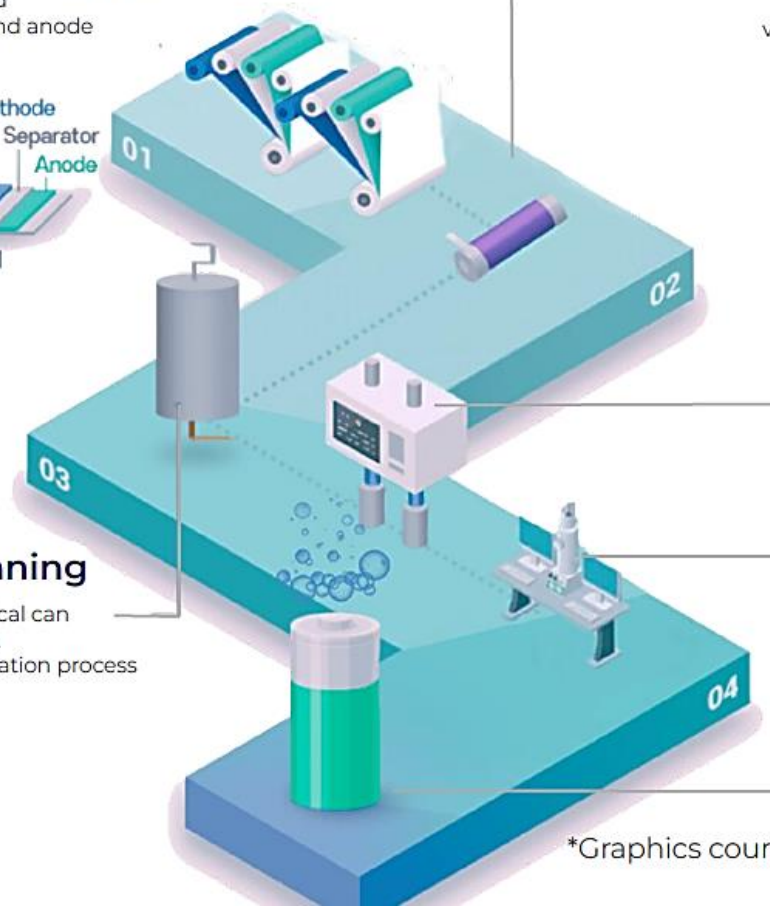

**20%** of total manufacturing cost

**5%** scrap rate

**Challenges**
metal contamination

## Tab Shaping & Canning

The jelly roll is put in the cylindrical can and then fixed through welding.
High-speed mechanical deformation process
**SPEED: 300-600 parts/min**




## Electrolyte Injection

Electrolyte is injected into the vacuumed can. The can is pressurized to accelerate electrolyte absorption and then sealed

**Challenges**
electrolyte absorption due to density; pooling of electrolyte

## Physical Inspection

Through CT and/or X-Ray, the battery cell is analyzed to detect potential defects.

**Challenges**
speed of analysis doesn't allow real-time analysis

## Degassing/ Pre-Charge

Optional process to remove gas

**Challenges**
exhaust gas treatment
Avoiding residual gas during sealing and folding steps

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*Courtesy: Volta Foundation, 2023*

# Manufacturing – Cylindrical Cell


*Courtesy: LandSnail*

# Manufacturing – Prismatic Cell

**Challenges**
anode, cathode, separator alignment

## Z-Stacking
Winding the cathode, anode, and two separator rolls. Welding the aluminum and copper tabs onto the cathode and anode respectively.
**SPEED: 30 parts/min**

**Challenges**
throughput

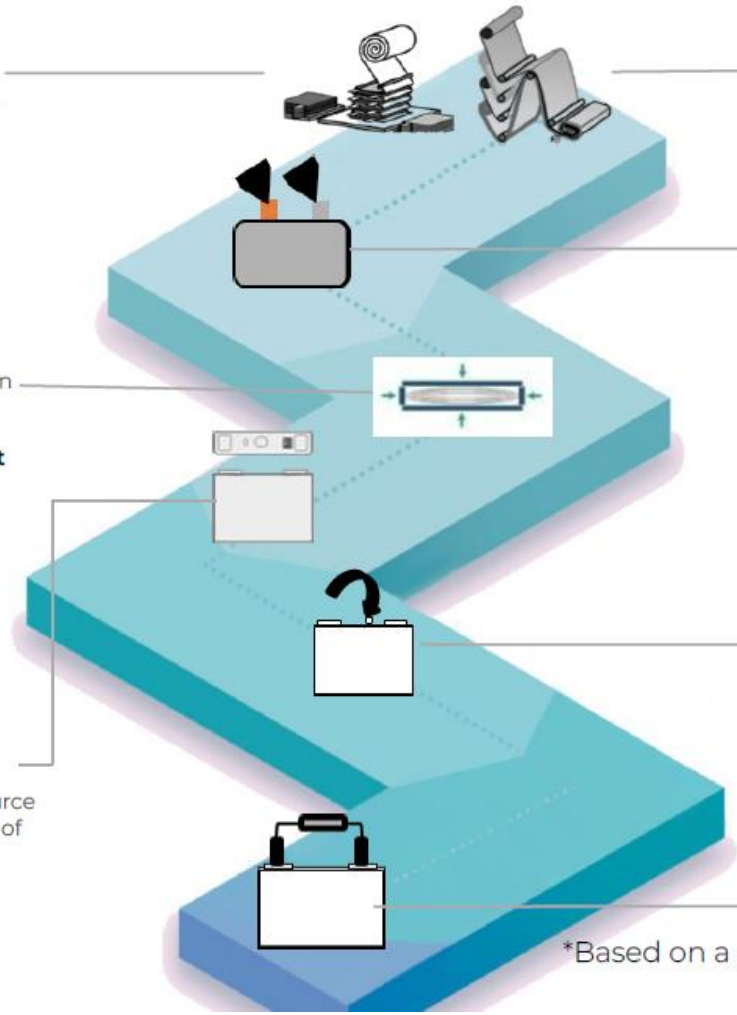
## Hot Press
The hot press machine works on the principle of heat and pressure application to achieve a strong and reliable bond between battery components.
**SPEED (DWELL TIME): >10 seconds/unit**

**20%** of total manufacturing cost

**5%** scrap rate

**Challenges**
cap to can alignment, missed laser welding spot

## Cap To Can Welding
The can to cap spot welding by laser source and followed by complete laser welding of the cap to can.



## Wound Prismatic
Roll the slitted cathode, anode, and separator together by controlling speed, tension, etc.
**SPEED: 30 parts/min**

**Challenges**
Uneven stress, burr issues, and powder loss

## Pre Welding & Trimming
The cathode and anode tab are aligned and U/S welded
**SPEED: 18-20 parts/min**

**Challenges**
anode, and cathode tab alignment

## Electrolyte Injection
Electrolyte is injected into the vacuumed can. The can is pressurized to accelerate electrolyte absorption and then sealed

**Challenges**
electrolyte absorption due to density; pooling of electrolyte

## Pre Charge & Formation
After the filling pre charge is performed and cell is kept for RT aging and followed by formation & grading process

**Challenges**
throughput and quality

*Based on a graphics by LG Energy Solution, modified with permission.

*Courtesy: Volta Foundation, 2023*

# Manufacturing – Prismatic Cell

# Areas de Oportunidad

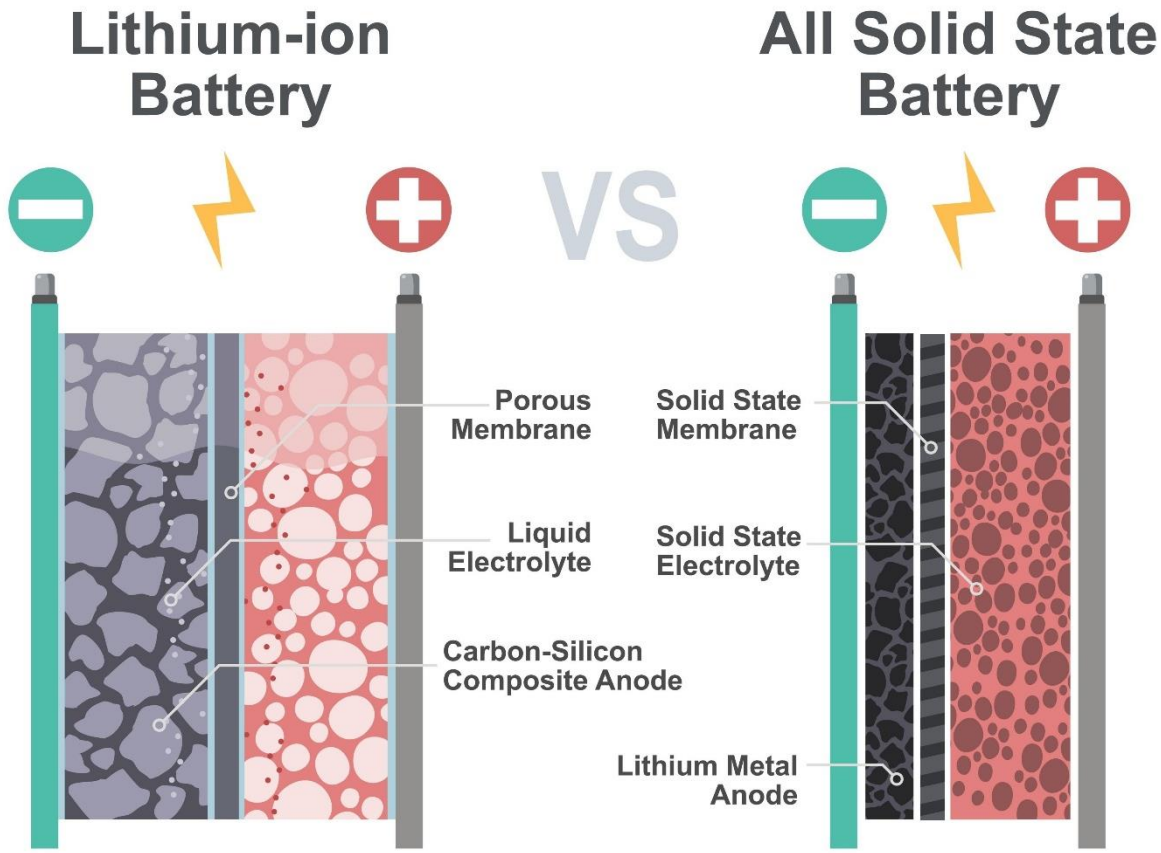
**Baterías de Estado Sólido (Solid-State):**

• Reemplazar el electrolito líquido inflamable con un material sólido (cerámico, polímero o vidrio).

• Resolver problemas de interfaces entre el electrodo y el electrolito sólido, y escalar la manufactura para reducir costos. Esto promete mayor seguridad y densidad energética.

**Baterías de Sodio-ion (Na-ion):**

- El sodio es más pesado y menos denso energéticamente que el litio.
- Al ser el sodio abundante y barato, es ideal para almacenamiento estacionario (red eléctrica) donde el peso no es crítico.



# Areas de Oportunidad

**Sistemas de Gestión de Baterías (BMS) y Software**

El hardware es inútil sin un "cerebro" eficiente.

Aquí es donde convergen la ingeniería eléctrica, electrónica y de software.

**Algoritmos de Estimación (SoC y SoH):**

Mejorar la precisión del State of Charge (cuánta energía queda) y State of Health (cuánto vida útil le queda a la batería) utilizando Filtros de Kalman y modelos electroquímicos avanzados.

**Inteligencia Artificial y Gemelos Digitales:**

Uso de Machine Learning en la nube para predecir fallas, optimizar cargas y extender la vida útil analizando terabytes de datos de flotas de vehículos.

**Gestión Térmica Activa:**

Diseño de sistemas de refrigeración (líquida o inmersiva) para permitir la carga ultrarrápida sin degradar las celdas ni provocar fugas térmicas (thermal runaway).

**Diseño de la Arquitectura para Nuevas Baterías**

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