BATTERY INNOVATION

From test tube to industrial production

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AUSTRIAN INSTITUTE OF TECHNOLOGY

over
1.300
employees

bmvit

8 Centers

Austria‘s largest
RTO

System
Competence

Applied Research

Infrastructure Systems

Federation of
Austrian Industries

2 Subsidiary
Enterprises

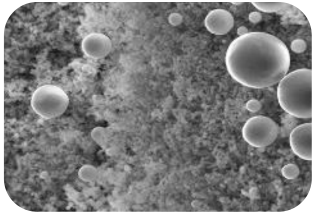
Next Generation
Solutions

143
m EUR total revenue

Tomorrow Today

CENTER FOR LOW-EMISSION TRANSPORT

Research Fields



Advanced battery materials

Battery processing technology and testing

Vehicle efficiency

Power electronics

Casting processes for high performance materials

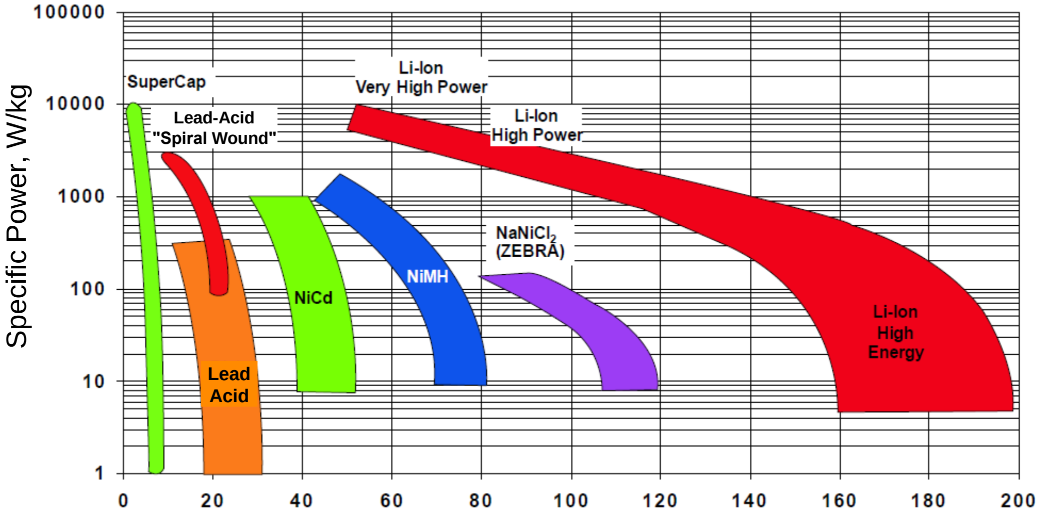
Advanced forming processes and components

LITHIUM ION - MOTIVATION

- Energy storage – Why do we need better systems?

→ $150bn Market up to 2025

WHY LITHIUM-ION TECHNOLOGIES?



Source: Saft SA

Advantages

- High energy density
- Low self-discharge rate[1]
- High cycling stability
- No „memory effect“[2]

Disadvantages

- Operating temperature: max. 60°C
- Sensitivity towards overcharge or deep discharge

SoA > 250 Wh/kg ⇒ exceeding expectations!

- LIBs dominate the markets for portable devices: cell/smart phones, laptops, tablet PCs, digital cameras, etc.
- Growing markets: EVs, power tools, energy storage systems for renewable energies, etc.

[1] Especially NiMH suffer from high self-discharge: typically 50% higher than NiCd

[2] Memory effect – most pronounced for NiCd

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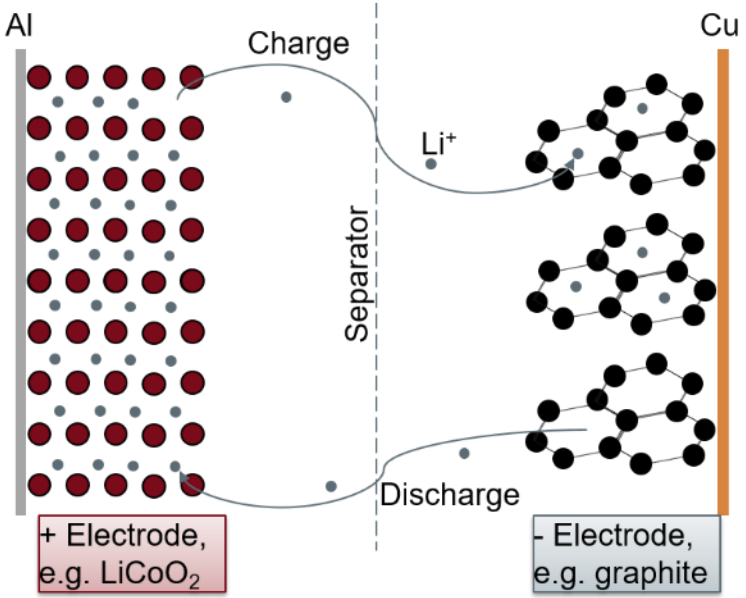
LITHIUM ION BATTERIES - CHEMISTRY

- Graphite anode (-)
  - $Li^+ + e^- + 6C \leftrightarrow LiC_6$

- Lithium Cobalt Oxide Cathode (+) (example)
  - $LiCoO_2 \leftrightarrow Li_{0.5}CoO_2 + 0.5\ Li^+ + 0.5\ e^-$



- Charge: Li^+ move from cathode to anode
- Discharge: Li^+ move from anode to cathode

LITHIUM ION TECHNOLOGY DEVELOPMENT: DRIVING FACTORS

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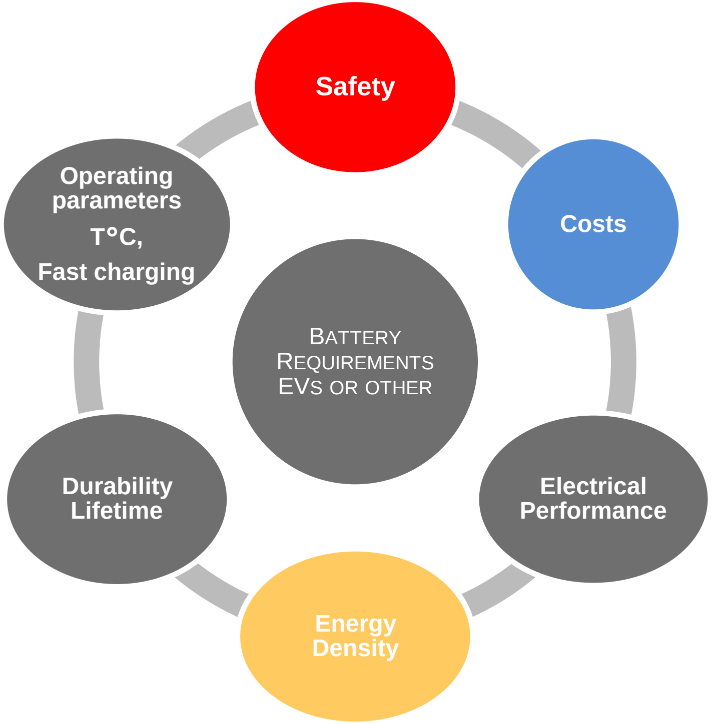
- Large variety of cell technologies available on the market: NMC, NCA, LFP, spinel, LTO, etc.
- Cells are produced for different applications: high power/energy
- Depending on the geometry/type of casing - different cells available: soft-case cells → pouch; hard-case cells → cylindrical and prismatic
- Cell chemistry – most influencing factor regarding safety, energy density, performance and lifetime
- Other factors: electrode/cell design and manufacturing, system integration, Battery Management System



FUTURE TRENDS

General Trends

- Replacing/**reducing the amount of critical raw materials –** e.g. Co, graphite $\Rightarrow$ Ni, Mn-rich cathode materials; Si as anode
- Applying **environmentally friendly processes** for materials synthesis, electrode and cell manufacturing
- Replacing Li with **multivalent ions** (e.g. Mg, Al, Ca, Zn, Ni-ion) – for achieving better/higher energy storage in comparison to univalent Li- or Na-ion batteries
- Modelling and **simulating ageing** mechanisms for better estimating SoX

Main Aims

- Higher energy density for achieving a better driving range
- Lower costs

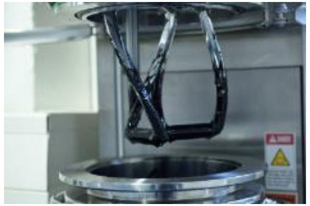
POST-LITHIUM ION CHEMISTRIES

- Current technologies and Advanced Li-Ion
  - **Ni rich NMC**, high power LFP, LTO
  - High energy cell components (thin current collectors & separators, tailored electrode design)
- Tomorrow‘s technologies
  - **Na-ion** – worse than Li-Ion, but interesting (abundance, safety, cost)
  - Thin film **All-Solid-State** – available in small format, huge interest (safety, power density)
  - High voltage cathodes and electrolytes for Li-Ion
- Generation 2025+
  - Bulk All-Solid-State – for large scale, challenge of scale up
  - **Mg-Ion** – higher energy density than Li-Ion
  - **Metal-air** – promising, but huge challenges in reversibility

CONVENTIONAL CELL ASSEMBLY

General description of pouch cell production steps (incomplete)

Scale up parameters identified



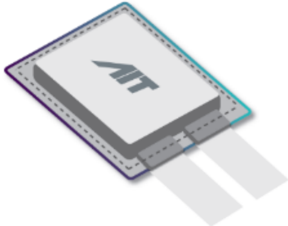
Slurry preparation

Electrode coating

Coated electrodes

calendering

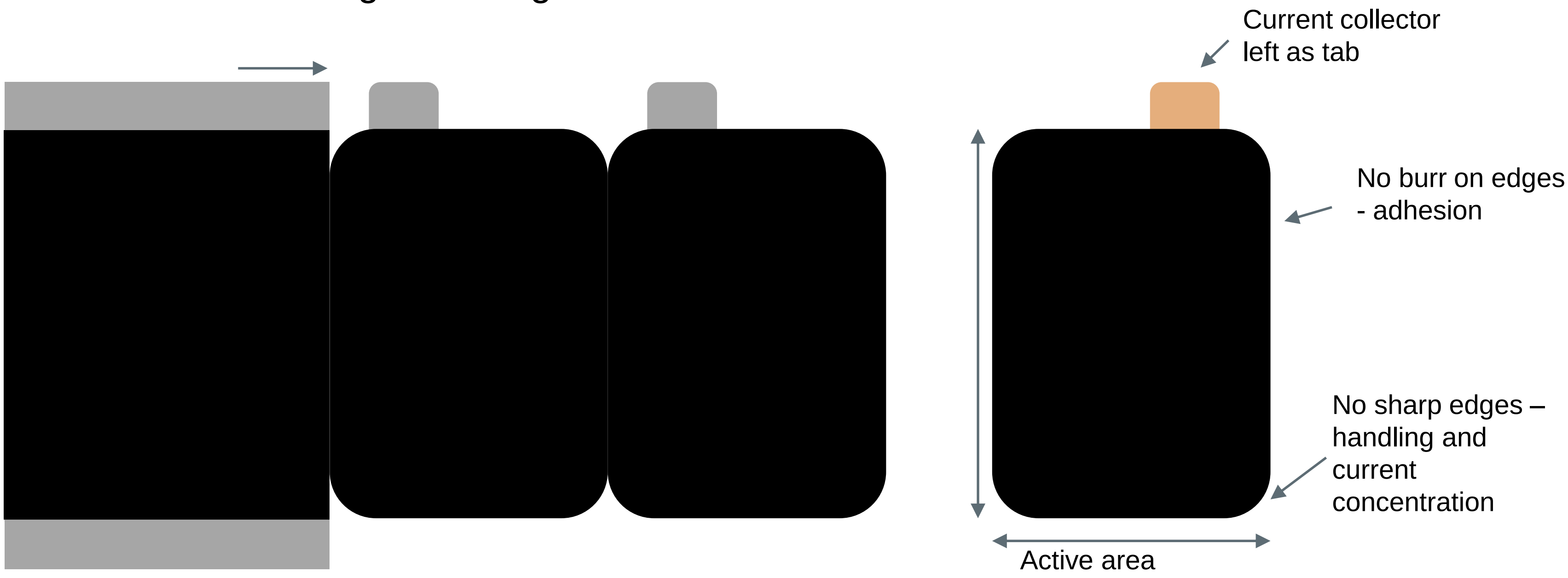
Cell assembly



Pouch cell

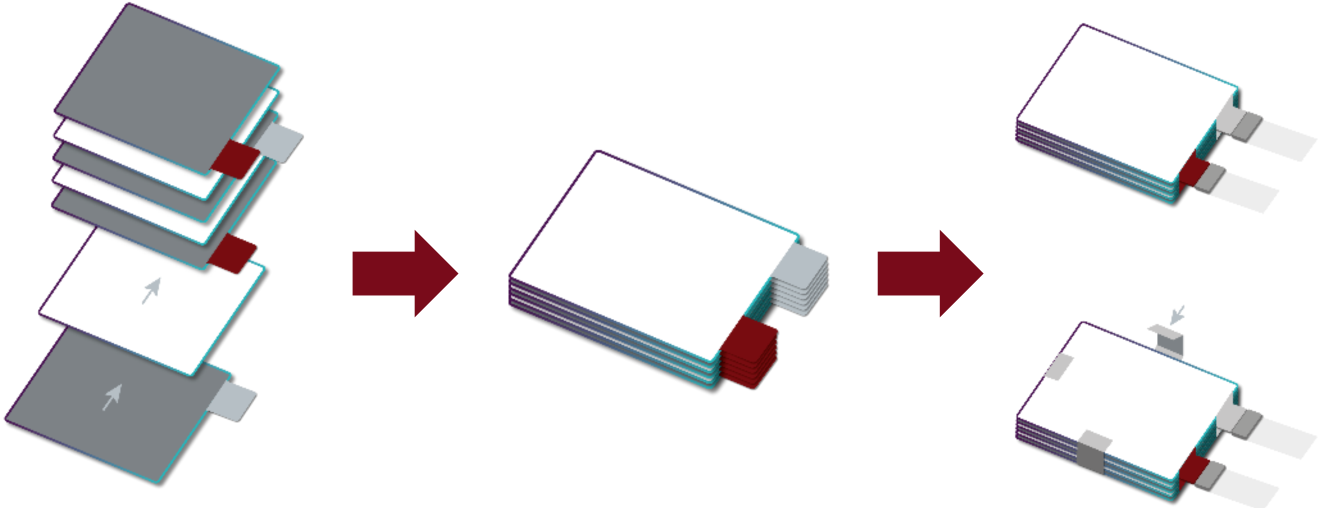
HOW A POUCH CELL IS MADE – CUTTING

- Electrode notching or cutting



HOW A POUCH CELL IS MADE – STACKING

- Stacking (single stacking, z-fold, winding – advantages and disadvantages)
  - Amount of electrodes determines end capacity
    - E.g. 2 mAh/cm^2 on a 5 x 10 cm active area:
    - 2 mAh/cm^2 * 50 cm^2 = 100mAh per side = 200 mAh per electrode (double sided)
    - 5 Ah pouch cell requires 25 electrode pairs (e.g. 25 cathodes, 26 anodes)



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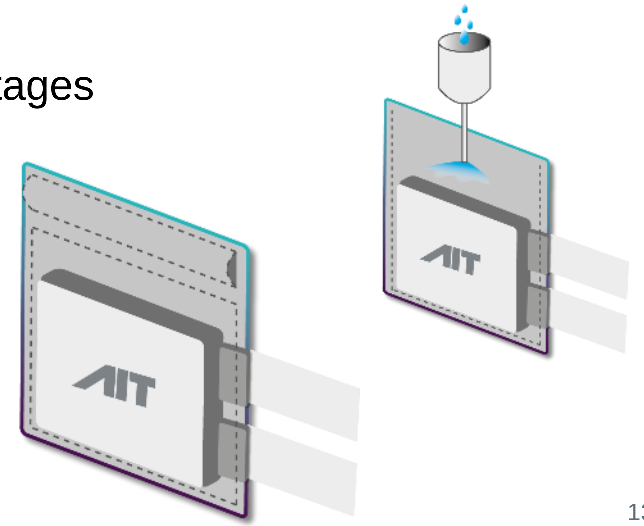
HOW A POUCH CELL IS MADE – FILLING

- Electrolyte filling should happen under vacuum/reduced pressure
- Amount: important measure for proper operation and critical for industry
  - starting values: 4 ml/Ah for NMC; 7ml/Ah for LFP
  - Just enough, not too much (cost, gas) – not too few (resistance, performance loss)

- Filling tends to be *sequential* – total amount in 3-4 stages
  - *E.g.* 5Ah NMC cell = 20 ml electrolyte
  - Pull full vacuum on empty cell (remove trapped air)
  - ½ amount (10 ml) at 600 mbar (abs.)
  - ¼ amount (5 ml) at 300 mbar (abs.)
  - ¼ amount (5 ml) at 150 mbar (abs.)
  - Soaking for 30s – 60s at 150 mbar (abs.)
  - Sealing at 100 mbar (abs.)

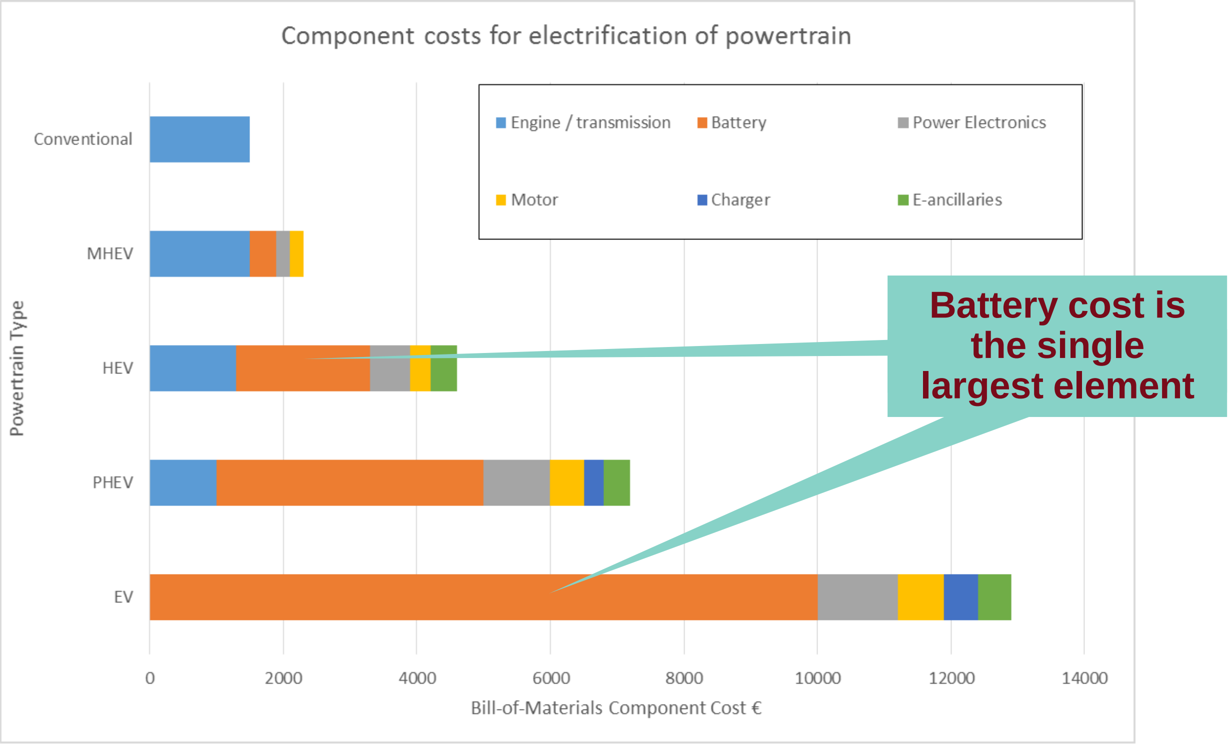


PRIMARY FUNCTIONS OF THE BATTERY SYSTEM

Conventional	Engine starting (3kW, 2-5Wh) Ancillary loads (400W average, 4kW peak, ~1kWh)
Mild Hybrid	Absorb regenerated braking energy (per event) 3kW, ~50Wh for micro hybrid 13kW, ~100Wh for mild hybrid 40kW, ~ 1000Wh for HEV, PHEV, FC
Full Hybrid	Support Acceleration (power and energy as above)
Electric Vehicle	Provide primary energy and power 10kWh – 80kWh 50-300kW

CHALLENGE FOR COMMERCIALISATION

COST



CHALLENGES DIFFER BY POWERTRAIN

High C Rates (>20C)

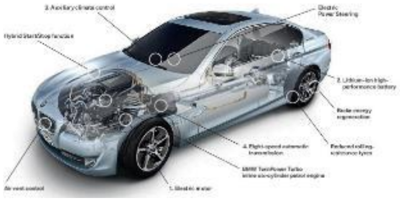
For mild and micro hybrids and high performance cars

Key technical challenges are **thermal** and **impedence, Cost/kW**


Source: McLaren

Cell Level

- Chemistry and electrode structure suited to high C
- Internal resistance of cell traded against capacity
- Thermal conductivity to cell walls/ends important
- Accurate cell level SoC understanding is critical


Source: BMW

Pack level

- Liquid cooling or forced air cooling required
- BMS algorithms and sensors must respond to rapid transients – active balancing sometimes required


Source: Continental

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CHALLENGES DIFFER BY POWERTRAIN

Low C Rates (<5C)

For Electric Vehicles

Key technical challenges: **energy density & Cost /kWh**

Although C rates rising as performance / range increases

Cell Level

- Capacity more important than rate of reaction
- Chemistry and electrode structure designed for durability at high depth of discharge
- Slower transients allow for simpler cell design and monitoring

Pack level

- Air cooling generally sufficient (unless sealed)
- Simpler BMS due to slower transients.
- **Packaging volume and shape** constraints

AUTOMOTIVE – ROBUSTNESS

- Temperatures: Hot (>50° C) and cold (<-40° C) environments
- Water on the road, shock absorption
- Safety – crash impact, fire



AUTOMOTIVE – HIGH VOLUMES

- A typical production car makes 100,000 – 500,000 units/yr
- At 200 cells per pack, this is 3 cells per second or .3s/cell
- At 7000 cells per pack, this is 100 cells per second or .01s/cell

Photograph by Michael Conroy/AP Images

AUTOMOTIVE – HIGH QUALITY

- The best laptop cells have circa 1 in 200,000 failure /yr
- Laptops have typically 6-12 cells and 3 year life so premature battery failure affects <0.01%/yr
- Automotive batteries have 200 to 7000 cells/car and 8-10 year life, so higher quality standards are required.

AIT BATTERY TECHNOLOGIES: RESEARCH AREAS

Our aim: To cover the whole development chain

Materials
Anodes, Cathodes

Electrode and Cell Fabrication

Performance and Safety Tests
→ Up to Module Level

Batterie SoX-Diagnostics
Ageing-Modelling

Post-mortem Analyses

Lithium Ion
- Cathodes: HE-NMC, HV LVP
- Anodes: Sn-alloys

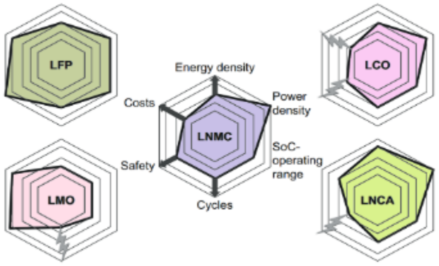
Post-Lithium Ion
- Mg-Ion
- Metal/Air

RPL, Dry room
- Electrode fabrication
- Cell fabrication: pouch cells, up to max. 10 Ah

Accredited tests
Electrical, environment, and safety tests

Analytical methods for real-time diagnostics
- *In situ* XRD-cell
- Multiplex integration in GC/MS
- Vibration-based tests

Comprehensive Characterisation
- Physical, chemical and electrochemical methods
- *In situ* and *operando* measurements



NMC among other cathode materials for electric vehicles

ECAIMAN

Electrolyte, Cathode and Anode Improvements for Market-near Next-generation Lithium Ion Batteries

Project Objectives

The objective of eCAIMAN is to bring European expertise together for developing a automotive battery cell that meets the following requirements:

- Energy density: 270 Wh/kg
- Costs: 200€/kWh
- The cells can be produced in Europe

Consortium

RTOs and academic

AIT Austrian Institute of Technology TOMORROW TODAY (Coordinator)

cea

CERTH

RI. SE

OEMs

CRF CENTRO RICERCHE FIAT

PIAGGIO GROUP

VOLVO

Industrial/pilot

IMERYS

ARKEMA

LITHOPS

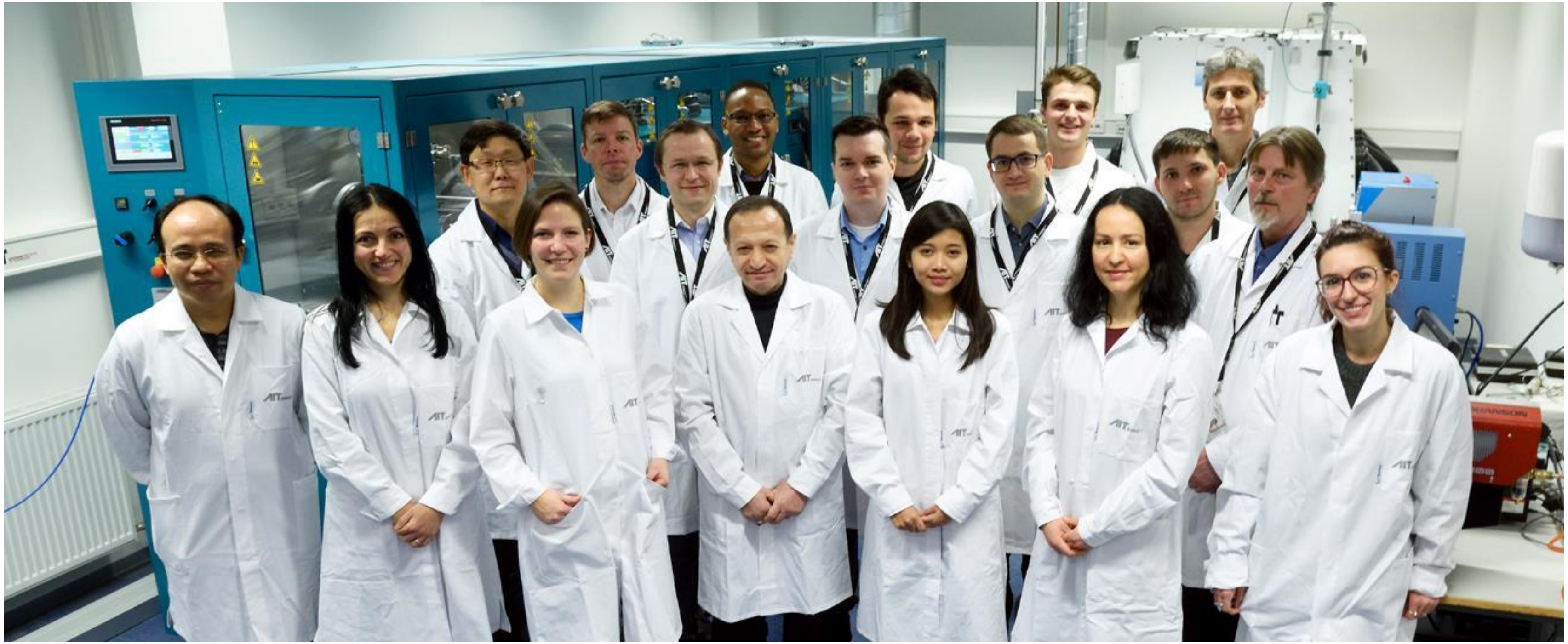
Dissemination, LCA

eu|te|ma TECHNOLOGY MANAGEMENT

thinkstep

This project is co-funded by the European Union‘s Horizon 2020 program under grant agreement no. 653331

THE AIT BATTERY TECHNOLOGIES TEAM



THANK YOU!

Dr. Marcus Jahn

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