NEXTCELL

BATT4EU Success Stories

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FEV

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TOWARDS THE NEXT GENERATION OF HIGH PERFORMANCE LI-ION BATTERY CELLS

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NEXTCELL Partners

Project Overview Organisation

FEV, SIE, AVESTA

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AGENDA

- **CONSORTIUM OVERVIEW ,MOTIVATION & OBJECTIVES**
- PROJECT STRUCTURE
- NEXTCELL SUCCESS STORY

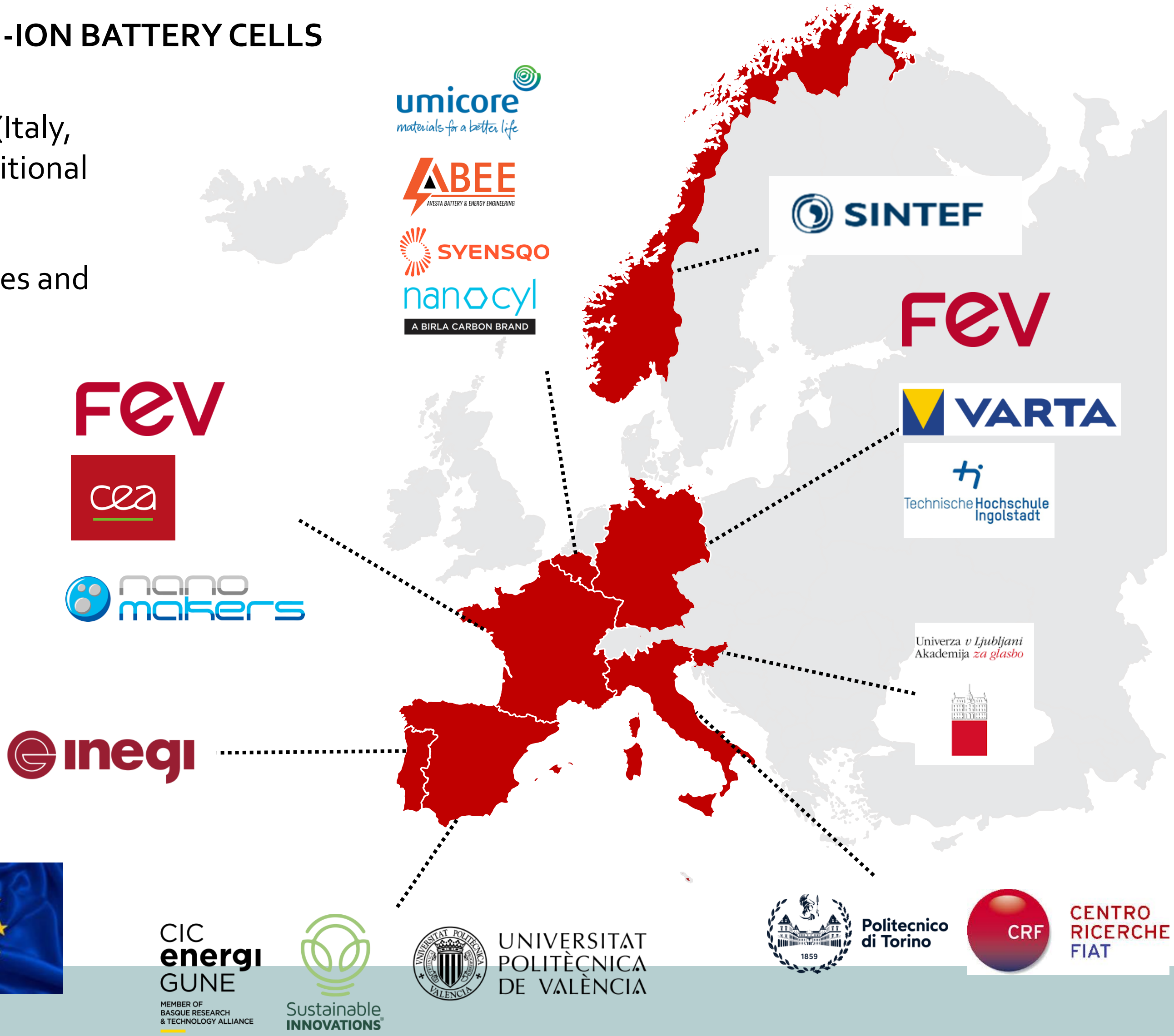
Consortium Overview

TOWARDS THE NEXT GENERATION OF HIGH PERFORMANCE LI-ION BATTERY CELLS

NEXTCELL consortium consists of 17 partners from 7 Member States (Italy, Spain, France, Belgium, Germany, Slovenia and Portugal), and an additional country (Norway).

Each one, of these partners has a distinctive role in the project activities and ensure that the project results is exploited in an efficient manner.

- Timeline:
  - Start date: 1 January 2023
- Budget:
  - Overall : € 7,995,015.47
  - EU contribution : € 7,995,015.47
- Project Coordination:
  - FEV France & FEV Europe GmbH
- Funding Details:
  - Call: HORIZON-CL5-2021-D2-01
  - Grant agreement ID: 101069910



Motivation & Objectives

TOWARDS THE NEXT GENERATION OF HIGH PERFORMANCE LI-ION BATTERY CELLS

- Research & Innovation challenges lie in the development of advanced materials enabling higher energy / power density thanks to higher capacity and operating at higher voltage.
- Focus is on adapting the cathode materials, the anode materials, the electrolytes and their interplay.

NEXTCELL's overarching goal is :

- to provide a new Li-Ion cell generation for both **high capacity** and **high voltage applications.**
- developing and validating a ground-breaking **gellified cell concept**
- integrating several **innovations at the material level** for each of the main cell components

Motivation & Objectives

TOWARDS THE NEXT GENERATION OF HIGH PERFORMANCE LI-ION BATTERY CELLS

• PROJECT GOALS

- **High energy density**.

Excellent performance in high capacity and high voltage applications,

- **Physical and mathematical models.**

Key methodology to optimize and accelerate the research and development process of new energy storage technologies.

- **Sustainable**.

Optimization of manufacturing processes, reducing capital and operating costs of future gigafactories, by avoiding the evaporation of solvents and the electrolyte filling step,

- **Cheaper**.

Reduction of around **50% in energy consumption**.

- **Safer**.

Intrinsically safe cells, avoiding the presence of low-boiling point components in the electrodes and the separator.

AGENDA

- CONSORTIUM OVERVIEW ,MOTIVATION & OBJECTIVES
- **PROJECT STRUCTURE**
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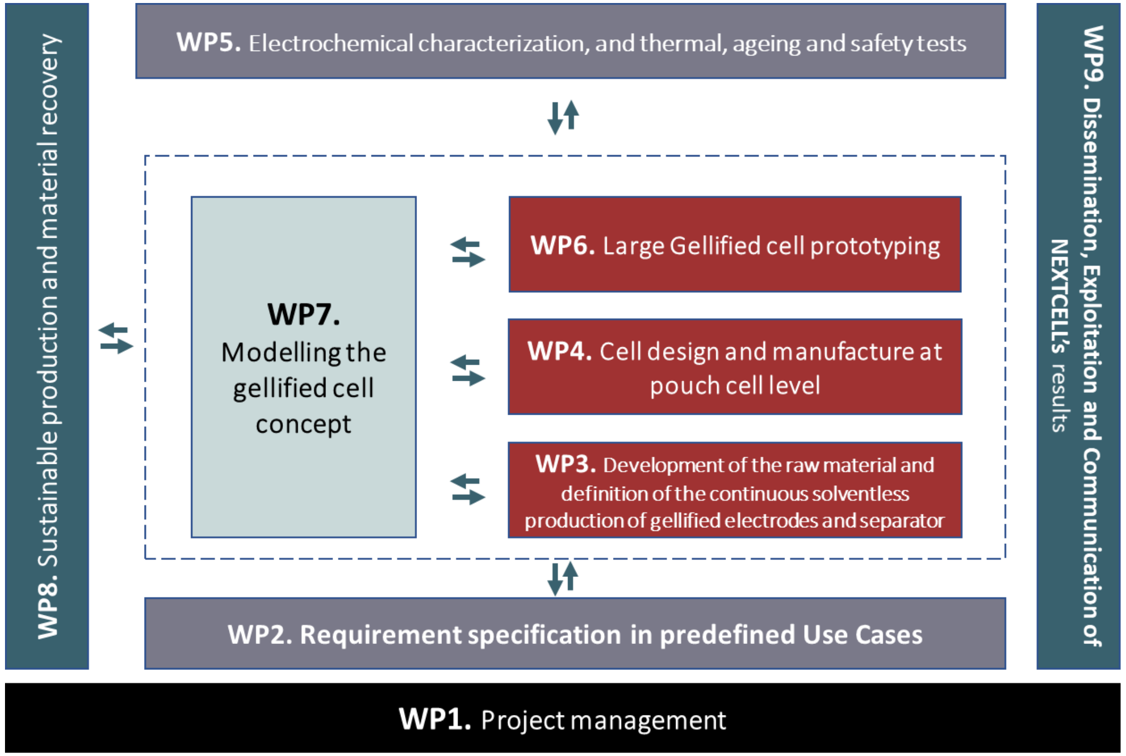
Project Structure

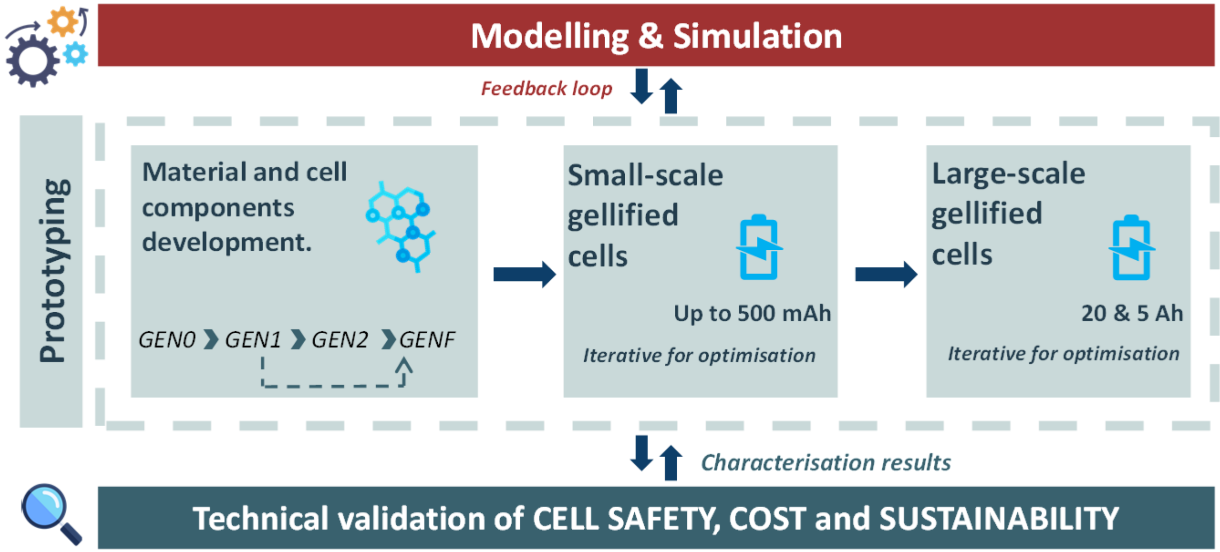
- TOWARDS THE NEXT GENERATION OF HIGH PERFORMANCE LI-ION BATTERY CELLS

• PROJECT STRUCTURE



• OVERALL CONCEPT & METHODOLOGY

The project workplan revolves around:



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- CONSORTIUM OVERVIEW ,MOTIVATION & OBJECTIVES
- PROJECT STRUCTURE
- **NEXTCELL SUCCESS STORY**

Development of the raw material and definition of the continuous solvent-less production of gellified electrodes and separator

The general objective is the development of material **fulfilling the KPI issued from the WP2** and processable through the cheaper and more sustainable solvent-less process (extrusion of paste instead of solvent casting).

The specific objective are :

i. **development of raw materials**: **anode** and **cathode** active material, high voltage **gel polymer electrolyte, CNTs**

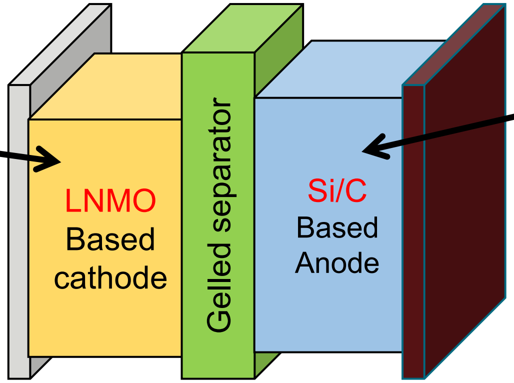
ii. **definition of the recipe** for the raw materials integration in the gellified electrodes separator, assembling of small scale batteries to evaluate the performances of the raw materials in comparison with standards (coin cell and/or single layer pouch cell)

iii. **initial definition of the continuous solventless process** for the fabrication of the gellified separator and electrodes.

Development of the raw material and definition of the continuous solvent-less production of gellified electrodes and separator

Raw materials

Active material: LNMO from Umicore
Conductive carbon: C65 to be replaced by CNT from Nanocyl
Binder from Syensqo
Electrolyte designed jointly by CEA and Syensqo



Active material: Si/C from Nanomakers
Conductive carbon: C65 to be replaced by CNT from Nanocyl
Binder from Syensqo
Electrolyte designed jointly by CEA and Syensqo

Binder specifically designed by Syensqo for gelled electrodes (electrolyte trapping) and to be compatible with solventless process (extrusion)
Electrolyte is designed to be compatible with Si-C / LMNO based system

Production of gelled electrodes and separator

The choice of **liquid electrolyte (part of the gel) is crucial** for the production of electrodes and the chemistry of the gelled separator will depend on the electrolyte

➔ First focus the **identification of electrolyte** and the **electrode process** and then separator chemistry

Experimental process for the production of electrodes

- Dry material mixing
- Extrusion : preparation of the electrode paste
- Lamination/Colamination : preparation of the electrode

Si/C Anode Development

Si/C Material Evolution

Multiple generations of silicon-carbon materials were tested, improving morphology and reducing surface area for better performance.

Optimized Anode Formulation

Si/C Gen2.3 combines high capacity near 1000 mAh/g with enhanced stability using graphite and conductive additives. Binder ratio favors electrolyte trapping and electrode cohesion.

Process Compatibility

Solventless binder system enables defect-free extrusion, lamination, and co-lamination of the anode material.

Stable Electrochemical Performance

Electrochemical tests confirmed stable cycling, supporting further scale-up for practical applications.

Extruded rods

Laminated strips

Nanomakers proposed different grades of SiC, and after several iterations between CEA and Nanomakers, the compatible SiC grade was selected.

LNMO Cathode Development

High-Voltage LNMO Material

LNMO offers increased energy density and reduces dependence on critical raw materials for cathode development.

Solventless Manufacturing Process

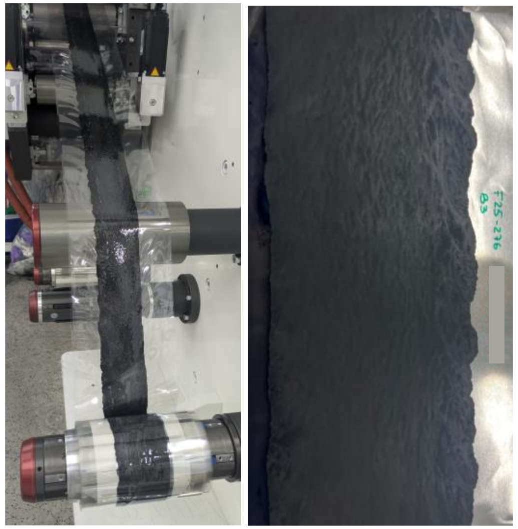
Implementing LNMO in a solventless manufacturing route requires precise powder mixing to prevent microstructural defects.

Optimized Material Formulations

Controlled ratios of carbon black and nanotubes enhance electronic conductivity and mechanical strength of LNMO electrodes, while binder ratio favors electrolyte trapping and electrode cohesion

Improved Electrode Performance

Optimized LNMO electrodes show homogeneous and smooth appearance, no electrolyte leakage and stable cycling behavior.



The use of CNTs reduces the required amount of conductive additive compared to conventional electrodes. CNTs are incorporated into the electrodes without negatively affecting the solventless process.

Solventless Manufacturing Process

Continuous Solventless Process

WP3 developed a continuous solventless process replacing solvent-based electrode coating, enhancing sustainability.

Energy and Environmental Benefits

Removing solvents reduces energy use, avoids recovery steps, and cuts environmental impacts significantly.

Materials and Process Interdependency

Materials, formulations, and processing parameters are strongly interdependent, requiring careful optimization.

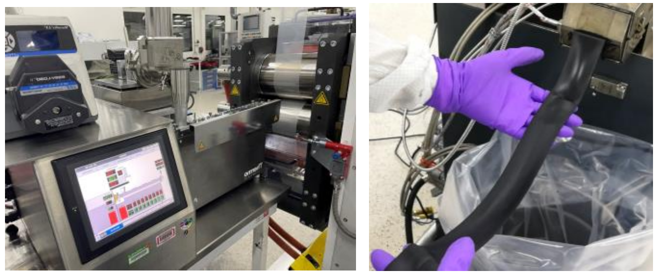
Technical Feasibility and Scalability

Experimental results confirm the feasibility and reproducibility of solventless electrode fabrication at scale.

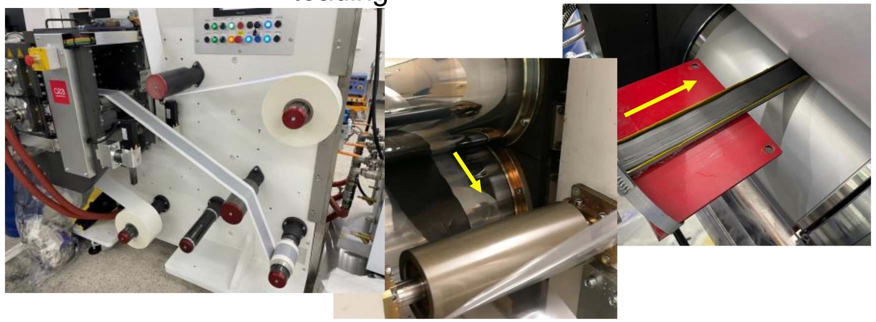
Manufacturing process for single-side gelled electrode

Powder mixing: to prepare the powder mix according to the electrode formulation

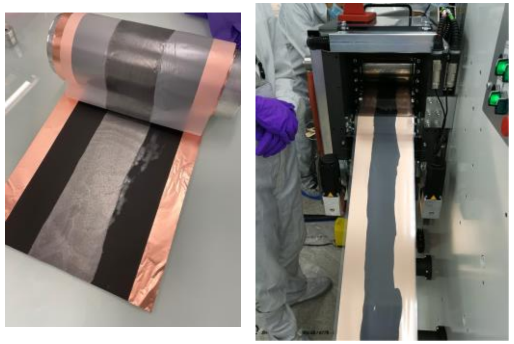
Extrusion: to mix the powder mix with the electrolyte and shape the paste in form of thick strip or rod



In-line lamination: to thinner the thick strip or rod, close to the target loading



Co-lamination: R2R deposit on the current collector



Gelled Separator Development

Polymeric Gelled Separator

Development of a PVDF-based gel membrane which traps liquid electrolyte while ensuring stability and conductivity.

Electrolyte Formulation Screening

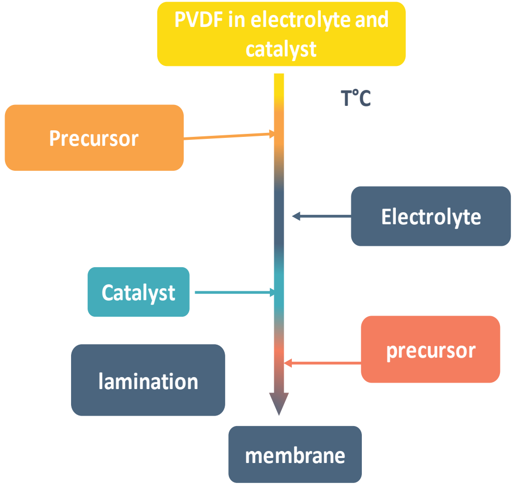
Gen1d formulation identified as optimal electrolyte candidate; Geno plus FEC serves as backup.

Conductivity vs Mechanical Trade-off

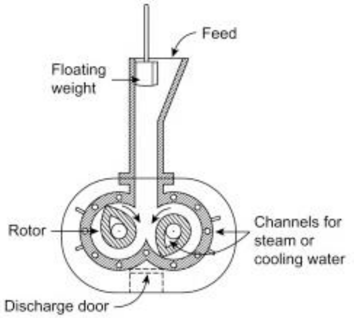
Higher ionic conductivity conflicts with increased crosslinking degree required for mechanical robustness.

Solventless Fabrication Route

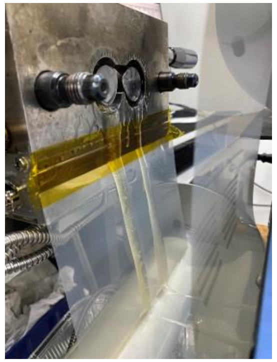
Established a functional solventless sol–gel crosslinking method for coherent gelled separator fabrication.



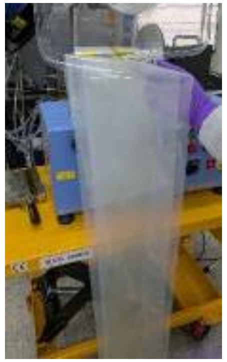
Polymeric paste preparation: to add and mix Mem-PF, the electrolyte, the different precursors and catalysts by the top, through the feeder.

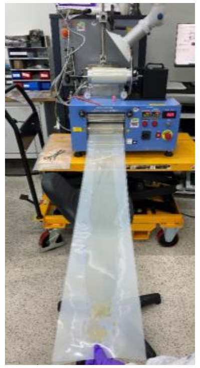


Collect of the polymeric mixture: after opening the lateral wall of the mixing chamber (manually or automatically)



Lamination: to shape the membrane between two PET liners





Achievements & Innovation

Achievements

WP3 delivered key technological building blocks and validated critical battery materials for NEXTCELL development.

Process Innovation

Demonstrated feasibility of fully solventless electrode and gelled separator processes at laboratory scale.

Transition to Upscaling

WP4 focuses on upscaling production, integrating components into pouch cells, and refining process stability.

Cell design and manufacture at pouch cell level

Overview:

- **Main objective:**

WP4's general objective is to **validate the full cell components at pouch cell level**. The specific objectives are:

  - Scale-up and optimize electrode/separator formulations, compositions, and interfaces.
  - Lab-cell design of small pouch cell monolayer (60 mAh) and cell assembly process definition
  - Assembly process development for the stacked 500 mAh pouch cells
  - Knowledge transfer for manufacturing large format prototype cells at WP6

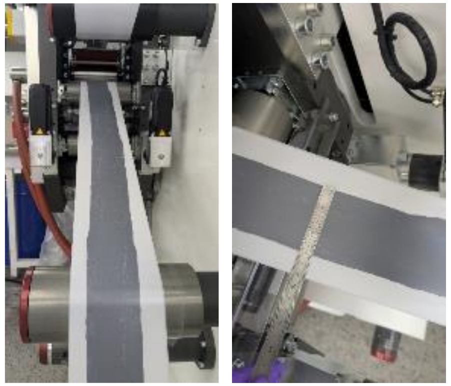
- **Participants:** CICe, CEA, Syensqo, ABEE , SINTEF, INEGI

Upscaling the electrode processing

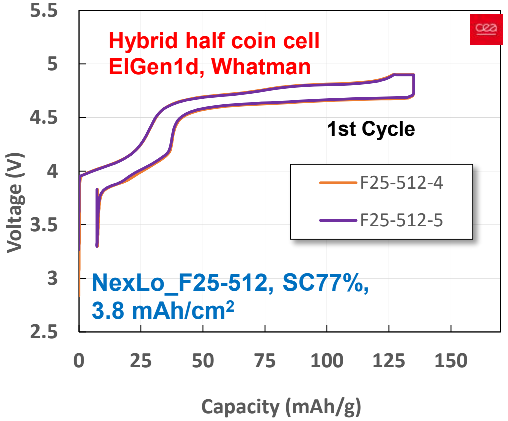
❖ Production of long length of gelled single-side positive and negative electrodes

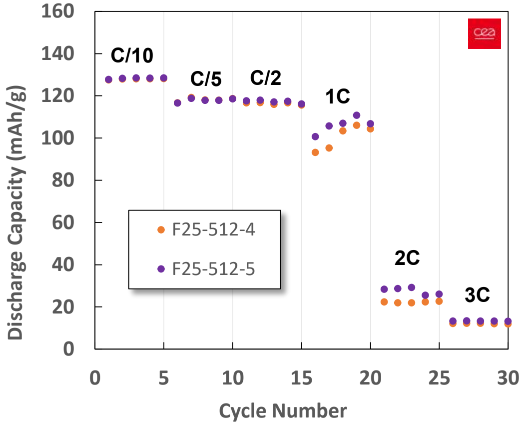
- Use of a multi-layer calendering equipment for the co-lamination step
- Different technological solutions studied in order to consolidate the process, guiding by the electrode specifications: screw profile and speed, temperature extrusion, specific die, grade of liners (quality, thickness), tension and winding speeds for the liners and the current collector...

In-line lamination:



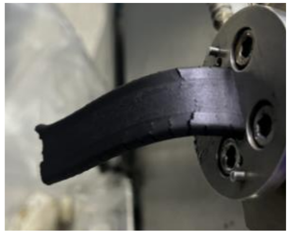
R2R co-lamination (multicomplexor)

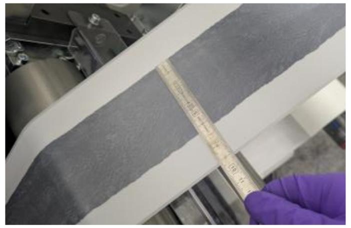




co-lamination

- Production of long electrodes (meters length)
- Si-C and LNMO formulations optimized
- Targets: stable process, adhesion, uniformity
- Performance comparable to conventional electrodes





Double colamination for double-side electrodes demonstrated promising results.
Flexible, no electrolyte leakage and no cracks

Membrane Scale-Up

Development of the process and the formulation to prepare long length of **gelled membrane:**

- Use of continuous R2R process involving **reactive extrusion step** coupled with **in-line lamination**
- Produced in stable mode, the membrane must be highly crosslinked with the electrolyte trapped in its polymeric network with high ionic conductivity (a few mS/cm at 25°C)

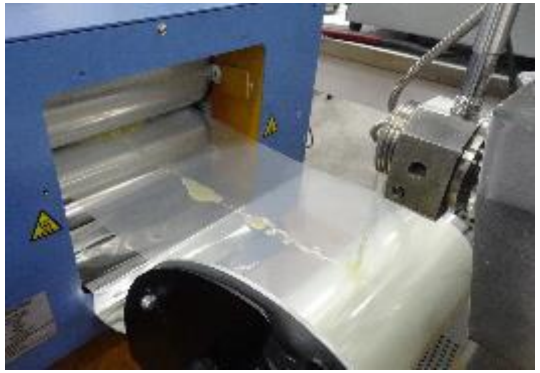
➔ To evaluate first the **feasibility to prepare gelled membrane by reactive extrusion**

❖ Preparation of the feasibility trial

- To identify the extrusion conditions like the screw profile, speed, temperature… and the different methods and equipment/tools to feed the various compounds (PVdF, electrolyte, precursors and catalysts…) throughout the extruder barrel in order and calibrate them.
- To design the various feed inlets specifically to prevent any backflow during the compound flowing

Feeding of the compounds

Collect of the polymeric paste



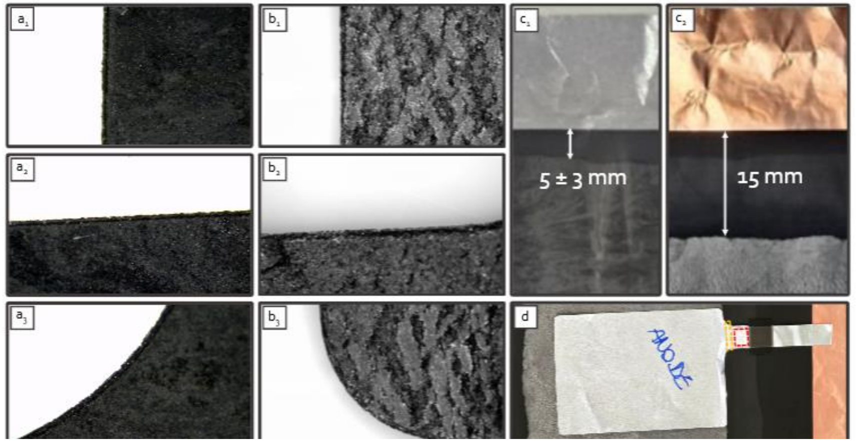
Lamination between two liners

Several meters of membrane on PET liner

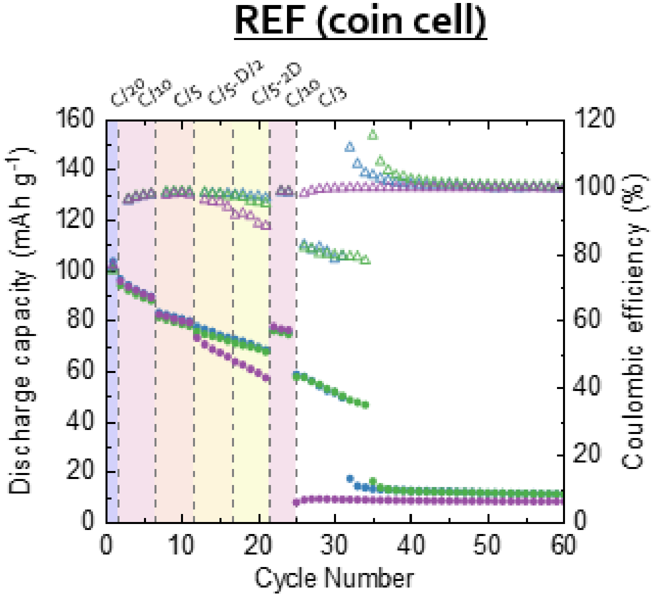
Pouch Cell Design

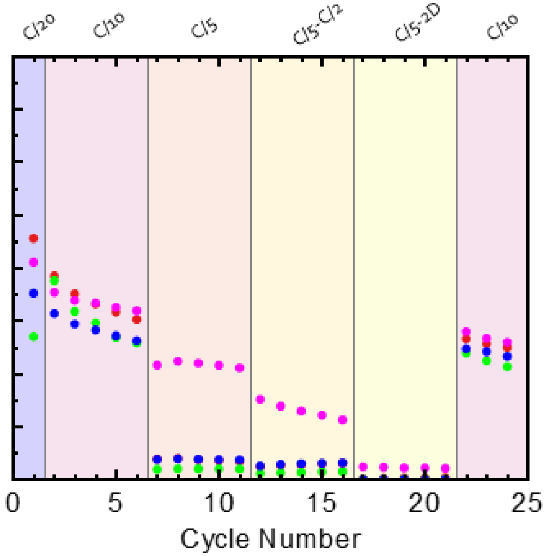
- Small monolayer (~60 mAh) and stacked (~500mAh)
- Optimization of electrode/electrolyte design
- Interface compatibility is critical
- Closer to industrial battery architecture

Edge integrity in mechanically punched electrodes



C-rate performance of the jellified monolayer





60 mAh jellified cell monolayer

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Achievements & Innovation

WP4 bridges materials to real cells

Successful scale-up of key components

Challenges: Increase performance to match conventional systems. Through repeated process and assembly trials, we are able to produce more reliable cells

Next: optimization and industrial validation

NEXTCELL

Electrochemical characterization and thermal, ageing and safety tests

- **It was demonstrated that the electrodes can be stored (after shipping) for more than one year in inert environment without loosing their electrochemical performance**
- **Stable electrochemical performance during cycling in the full cell configuration were demonstrated by using three electrode cell set ups with an additional Li reference electrode**
- **Specific electrochemical tests were provided to WP7 to develop and validate the models**
- **Parameters and test for validation the full cell performance:**

1. Characterization Test at 25 ºC and 45 ºC
- Capacity test
- GITT
- Constant discharge@3 C-rates and C/50
- EIS

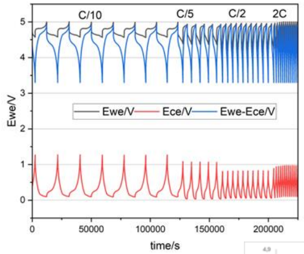
2.Performance Test at 25 ºC and 45 ºC
- Capacity test
- Constant discharge@ 3C rates and C/50

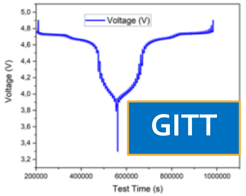
3. Performance Test at 25 ºC and 45 ºC
- Capacity test
- Constant discharge@ 3C -@C/50

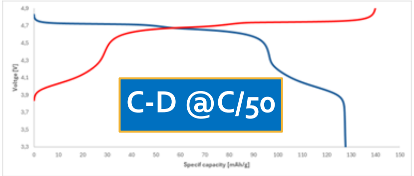
1. Abuse Tests
- Nail Penetration
- Crush Test
- External Short Circuit
- Overcharging
- Overdischarging

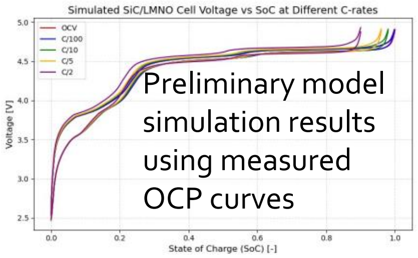
2. Cycling (Aging) Test
- At 20°C and 40°C

Abuse Tests
- Overheating
- Overcharging









Politecnico di Torino

FEV

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Technische Hochschule Ingolstadt

Sustainable production and material recovery

- **Main objectives**
  - Develop **sustainability studies for the evaluation of the developed battery** technology;
  - **Mature & Adapt** the **Digital Data Platform (DDP)** (now called **SUNDIAL**) for the economic and environmental data;
  - Conduct **LCA studies** & **cost assessments** of the developed cells prototypes and modules;
  - **Develop recycling processes** of the prototype for **recovery of the CRM materials**.
- **Participants: INEGI, ABEE & FEV**

Results by Task

Digital Data Platform ✓ CLOSED

- SUNDIAL platform deployed and validated
- Training workshop conducted with all partners
- User manual delivered → economic & environmental data integration ready

Green Environmental Assessment LCA baseline: cell production dominates impacts; anode & cathode are main contributors

- Component LCA completed: SiC anode, LMNO cathode, PVDF binder, CNT carbon
- Recycling LCA: new process yields ~76.7% recovery of Li, Mn, Ni
- Potential avoided GWP: 9.12 kg CO_2 eq. | Ecotoxicity avoided: 808 kg 1,4-DCB
- D8.1: Baseline green cell modeling and MS8: Preliminary environmental performance assessment have both been completed and delivered.

Cost Modelling

Baseline cell cost model completed (NMC622/Graphite, Belgium, series production)

- SUNDIAL integration of cost input parameters planned
- Adaptation to gellified NextCell cell underway

Recycling Process Design ✓ CLOSED

- 3-step process defined: Solvation → Froth Flotation → Downstream CRM recovery
- Novel process required due to gellified cell structure (PVDF dissolution)
- D8.4 deliverable: recycling process flow design complete

Experimental Recycling & CRM Recovery

DMSO dissolution tested: Li, Al, Ni detected across all samples

- Leaching trials: HCl, H_2SO_4, Lactic Acid tested on LMNO cathode material
- Anode annealing at 750°C/5h under Ar: 10.8% mass loss, impurities removed
- Next: solvent extraction for Li, Mn, Ni selective recovery

inegi FEV ABEE AVESTA BATTERY & ENERGY ENGINEERING

Achievements, KPIs & Future Challenges

Key Achievements

✓ **SUNDIAL platform operational, workshop & manual delivered**
✓ **LCA baseline established** – SimaPro + Ecoinvent 3.9, ReCiPe 2016
✓ **Novel recycling process designed** – 3-step flow for gellified cells
✓ **Cost model baseline complete** – NMC622/Graphite cell, Belgium conditions

Quantitative KPIs

- **~76.7% CRM recovery rate** (Li: 76.9%, Mn: 76.7%, Ni: 76.5%)
- **9.12 kg CO_2 eq. avoided** per kg of recycled material
- **808 kg 1,4-DCB ecotoxicity avoided** through recycling
- **10.8% anode mass loss** after thermal treatment (750°C, 5h Ar)

Future Challenges

→ Collect data from final cells and compute to obtain results and evaluate improvements
→ Adapt LCA & cost models to the final NextCell gellified cell design
→ Validate solvent extraction for selective Li, Mn & Ni recovery at lab scale
→ Address contamination from the solid electrolyte affecting mass balance
→ Integrate results into SUNDIAL and conduct a full WP8 environmental and cost assessment

FEV uses the established cost modeling approach to determine the impact of the gellified cell materials and production steps on the cell costs.

INPUTS

Input needed from consortium partners

Material cost rates

- Cathode and anode material
  - Active material, additives
- Electrolyte, separator
- Metals and plastics
  - Enclosure, terminals, gaskets, electrode foils

Cell Design

- Type (pouch, prismatic, cylindrical)
- Capacity, voltage
- Dimensions
- Cell composition
  - Cathode, anode, separator, electrolyte ...

Production scenario

- Production time model
- Annual production volume
- Labor, energy & occupancy costs
- Depreciation times
- Mark up rates

FEV will define production scenario based on agreed location

COST MODELING

Material

- Bottom-up calculation of virtual cell design
- Derivation of gross weights

- Electrode dimensions ?
- Coating mass ?
- Number of electrodes ?
- Enclosure area ?
- Gross weights ?
- ...

Manufacturing

- Setup of virtual manufacturing process chain
  - Exemplary

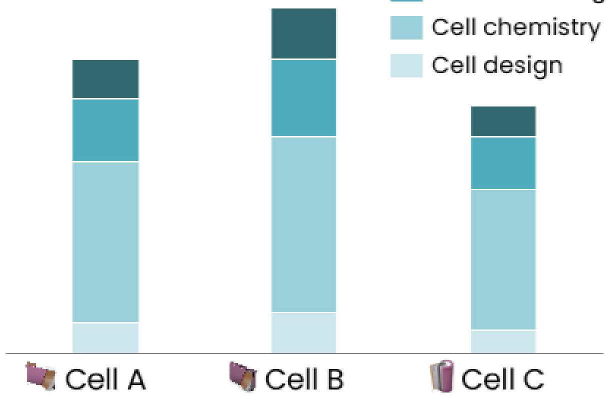
- Machine throughput?
- Number of workers?
- Machine invest?
- ...

Mark ups

RESULT

Cost breakdown

- Illustrative



THANK YOU FOR YOUR ATTENTION

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SiGNE
Anode Material Development

By
Rajeev Gautam

This project has received funding from the European Union's Horizon Europe transport programme under grant agreement No 101069738

WP1 Overview – Timeline, Tasks, Partners

Gantt Chart		Year 1/Q				Year 2/Q				Year 3/Q				Year 4/Q			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
WP1: Anode Material Development																	
1	Development of SiNW@Gr composite																
2	Slurry formulation of SiNW@Gr																
3	Characterize SiNW@Gr anodes																

WP1 Partners: **UL**,CID,TMEC,DLR, SIDRABE

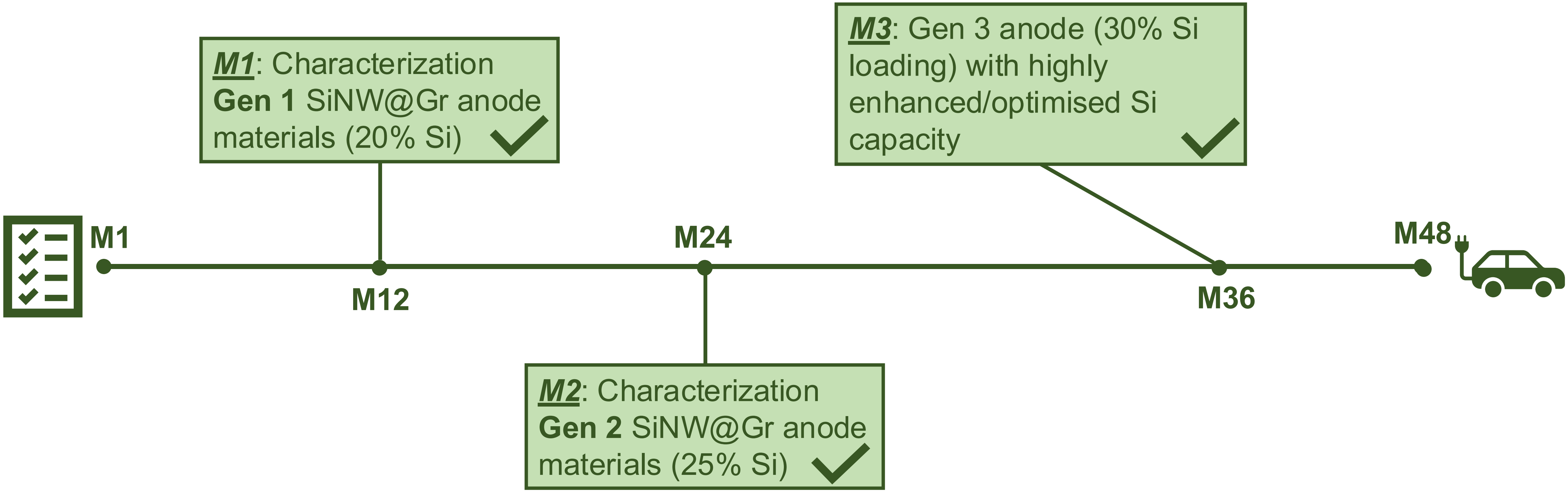
Task 1.1: UL, DLR, TMEC

Task 1.2: UL, CID

Task 1.3: UL, CID, SIDRABE

This project has received funding from the European Union's Horizon Europe transport programme under grant agreement No 101069738

Milestone Timeline



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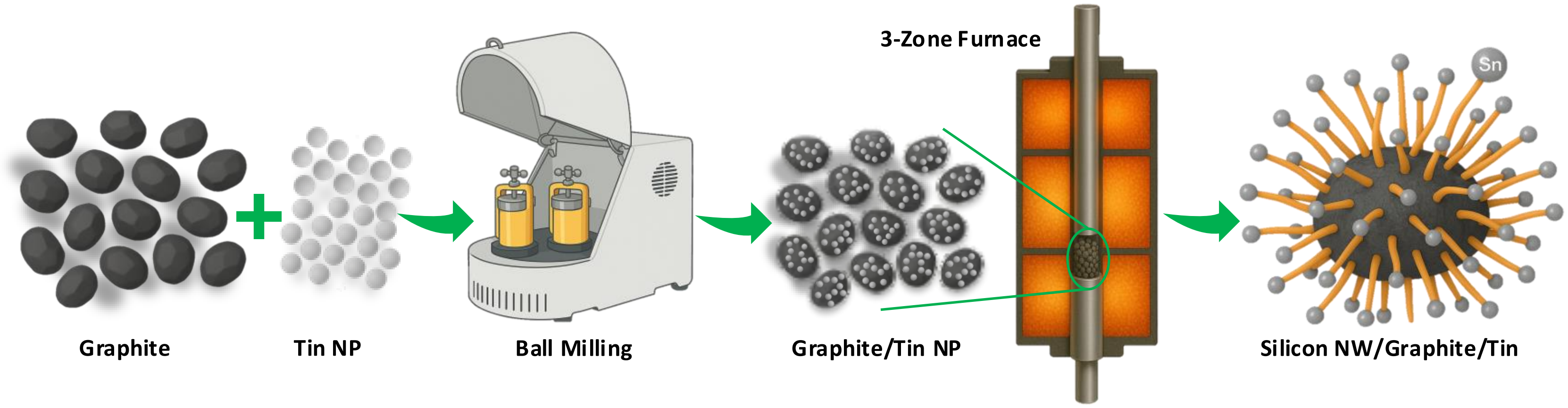
SiGNE Anode Development

Anode Concept Refresh: *Si Nanowires (NWs) grown directly from graphite using Sn as a seed.*

Synthetic aims:

- Control Sn dispersal for NW diameter and Si % control in the anode.
- Optimise reaction conditions for upscaling (precursor to Sn ratio, temperature, graphite amount).
- Move from glassware-based synthesis to batch reactor and finally continuous reactor



Anode Performance Targets:

- Move from 20 % to 30 % Si content in anode during progression from GEN 1 to GEN3.
- The final anode capacity target is stable cycling at 1000 mAh g^{-1}.

This project has received funding from the European Union's Horizon Europe transport programme under grant agreement No 101069738

SiGNE Anode Development

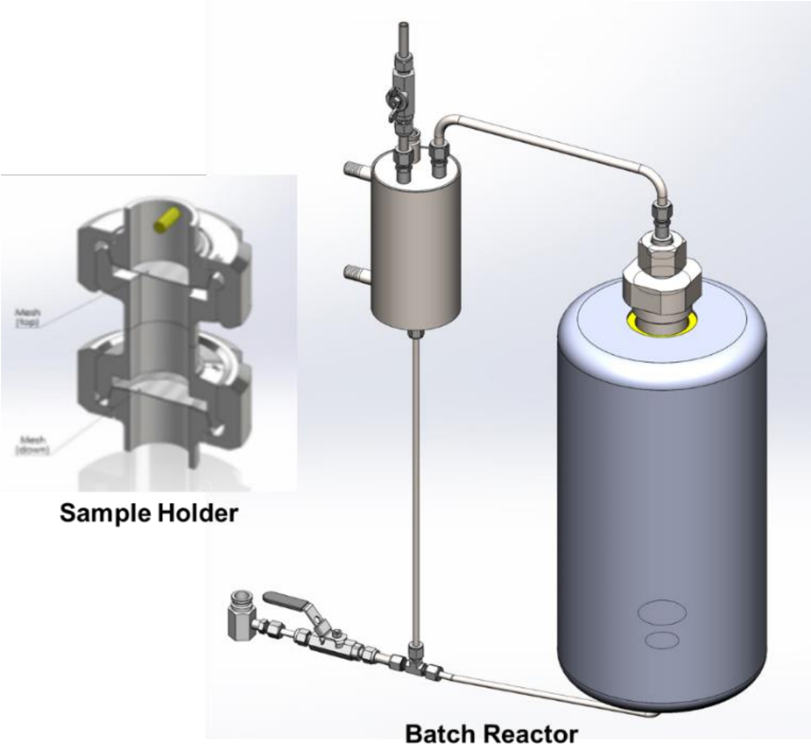
Lab Scale reactor

The synthesis of SiNWs involves a multi-step procedure:

1. Dispersing tin (Sn) seeds onto graphite flakes via ball milling.
2. Introducing phenylsilane as the silicon precursor.
3. Thermally decomposing phenylsilane to produce silane gas.
4. Growing SiNWs on the graphite substrate.
5. Collecting the resulting active material and performing subsequent washing steps.

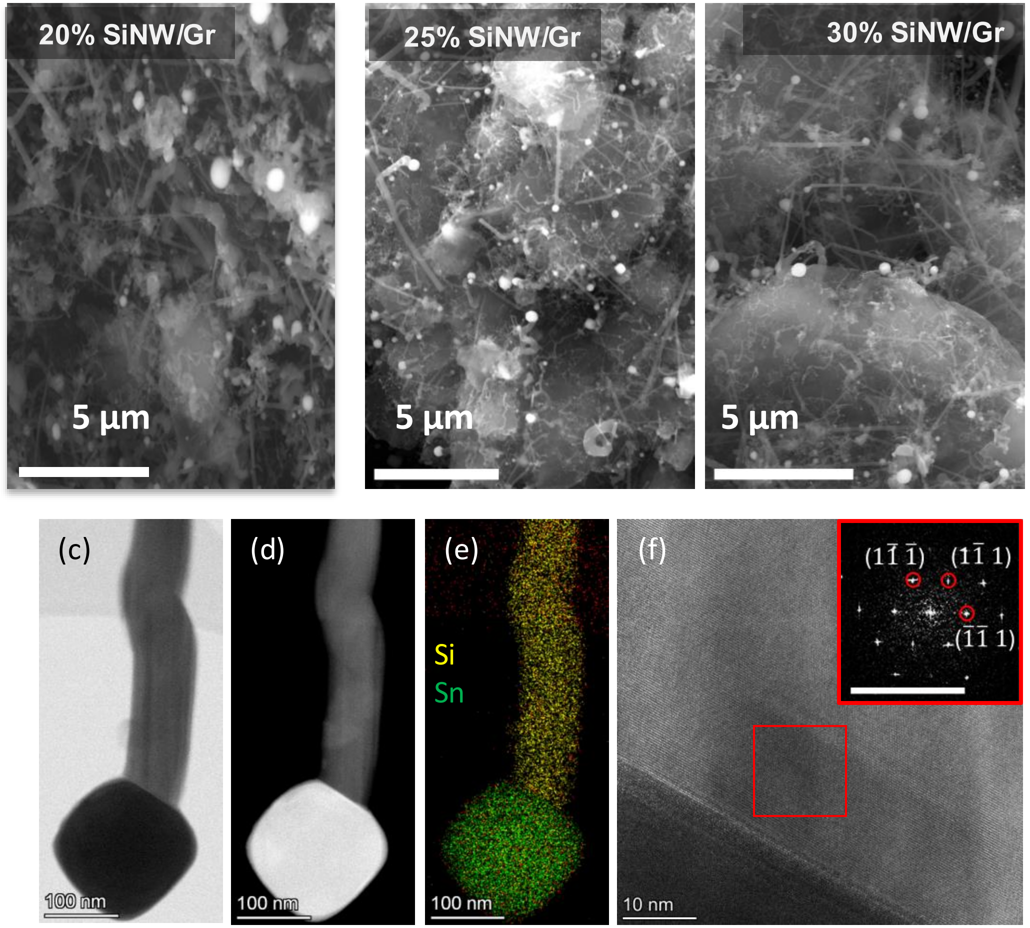
The chemical decomposition of phenylsilane into silane gas is represented by the following reaction:

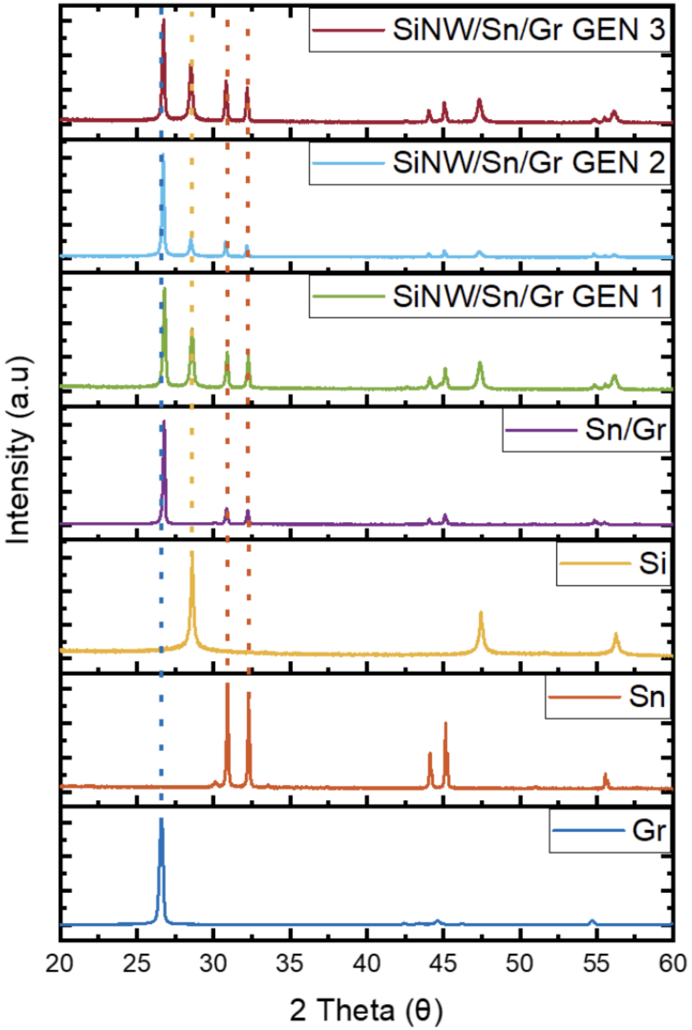
$$2\ PhSiH_3 \rightarrow SiH_4 + Ph_2SiH_2$$



This project has received funding from the European Union's Horizon Europe transport programme under grant agreement No 101069738

Characterization of SiNW@Gr
Lab-Scale Batch Reactor





Gen1: 20% SiNW/Gr
Gen 2: 25% SiNW/Gr
Gen 3: 30% SiNW/Gr

Successful, scalable synthesis of Si NWs on Gr Substrate:

- **XRD** confirming phase purity and no byproducts.
- **SEM** shows dispersed Sn-seeded Si NWs grown on Gr.
- **HRTEM/EDX** verify the crystalline nanowire structure.

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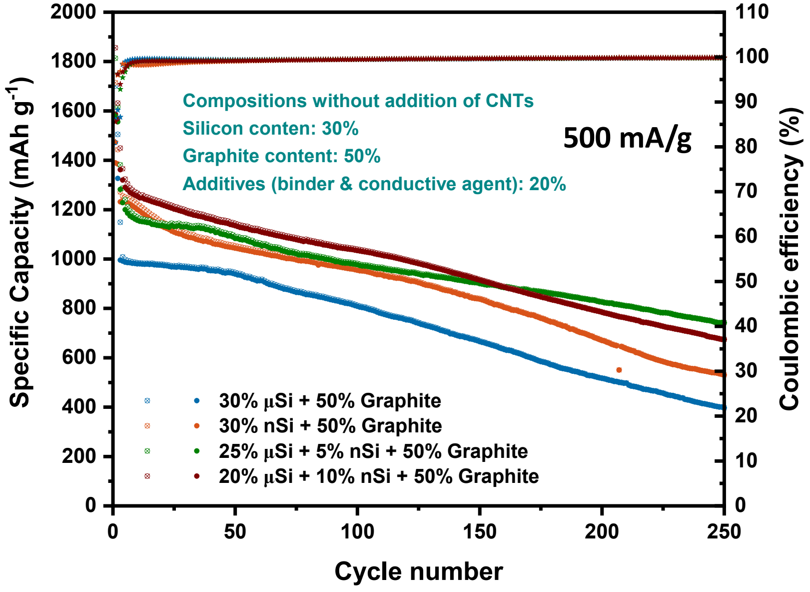
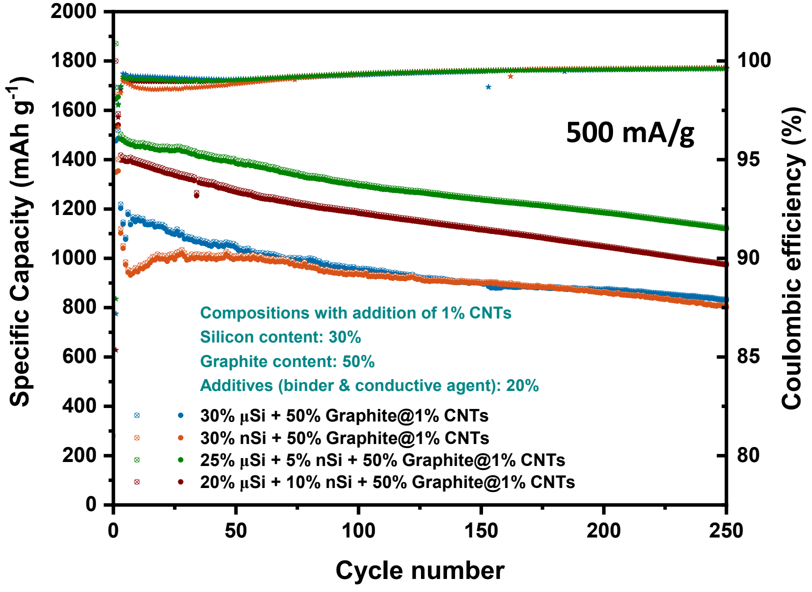
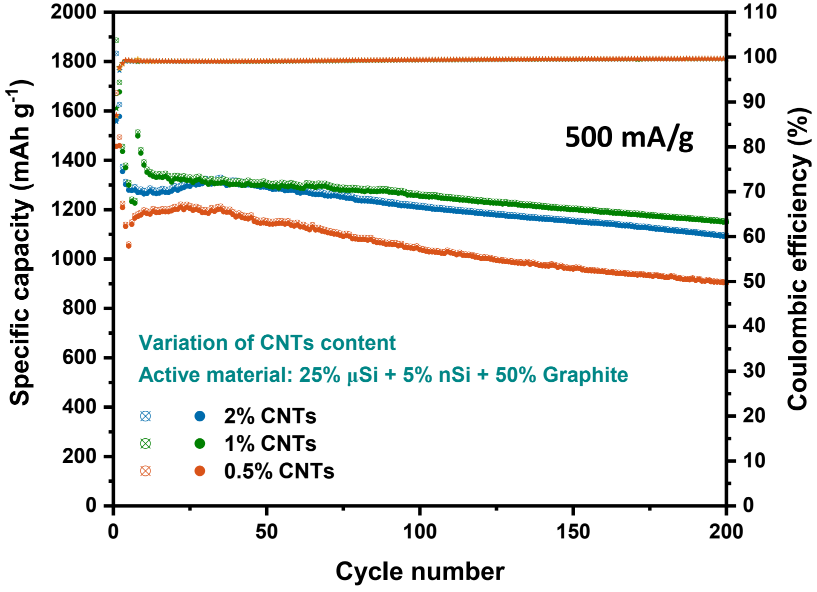
Slurry Formulation
CNTs Investigation – Micro and Nano Si mixtures







Sample	ICE(%)	Capacity retention (%) after 250 cycles
30% µSi	86.53	23.35
30% nSi	81.06	30.95
25% µSi/5% nSi	86.96	40.93
30% µSi@1% CNTs	87.18	49.22
30% nSi@1% CNTs	81	48.25
25% µSi/5% nSi@1% CNTs	87.94	60.08

- Bare 30% µSi with graphite could not provide stable cycling.
- **Addition of 5% nSi with 25% µSi outperformed** without addition of CNTs.
- Further **long-term stability with boost in capacity can be achieved after addition of 1% CNTs.**

Half Cell Counter Lithium foil
Electrolyte: 0.8 M LiPF6 + 0.2 M LiFSi (EC:EMC) + 10% FEC;
Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

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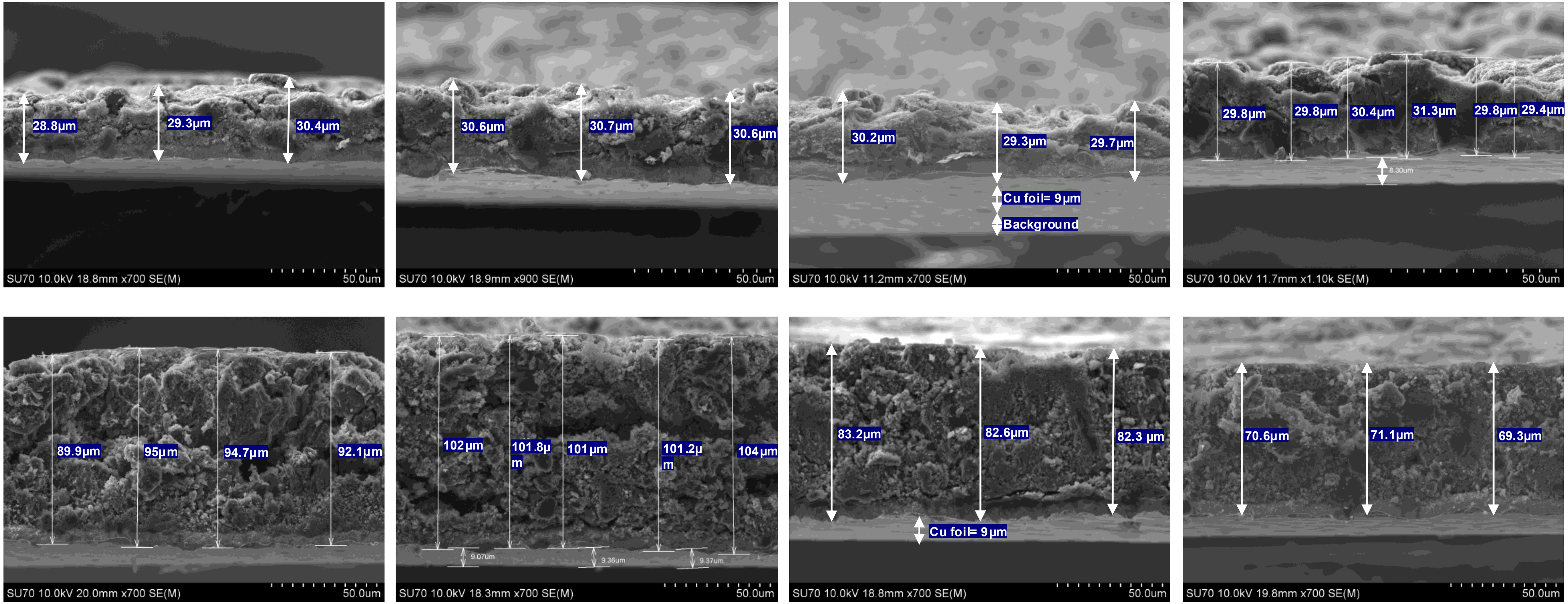
Slurry Formulation
CNTs Investigation – Micro and Nano Si mixtures

30% µSi | 25% µSi/5% nSi | 30% µSi@1% CNTs | 25% µSi + 5% nSi@1%CNTs

Pristine electrodes

Post 250 cycled electrodes



- **More swelling & delamination of electrode materials were seen for 30% silicon containing electrode. The same trend was also seen in 25% micro+ 5% nano silicon composites.**
- **Less swelling & delamination of electrode materials were seen after addition of 1% CNTs to the same composites**
- **Better electrode architecture on addition of CNTs were observed providing mechanical strength and flexibility to the electrodes.**

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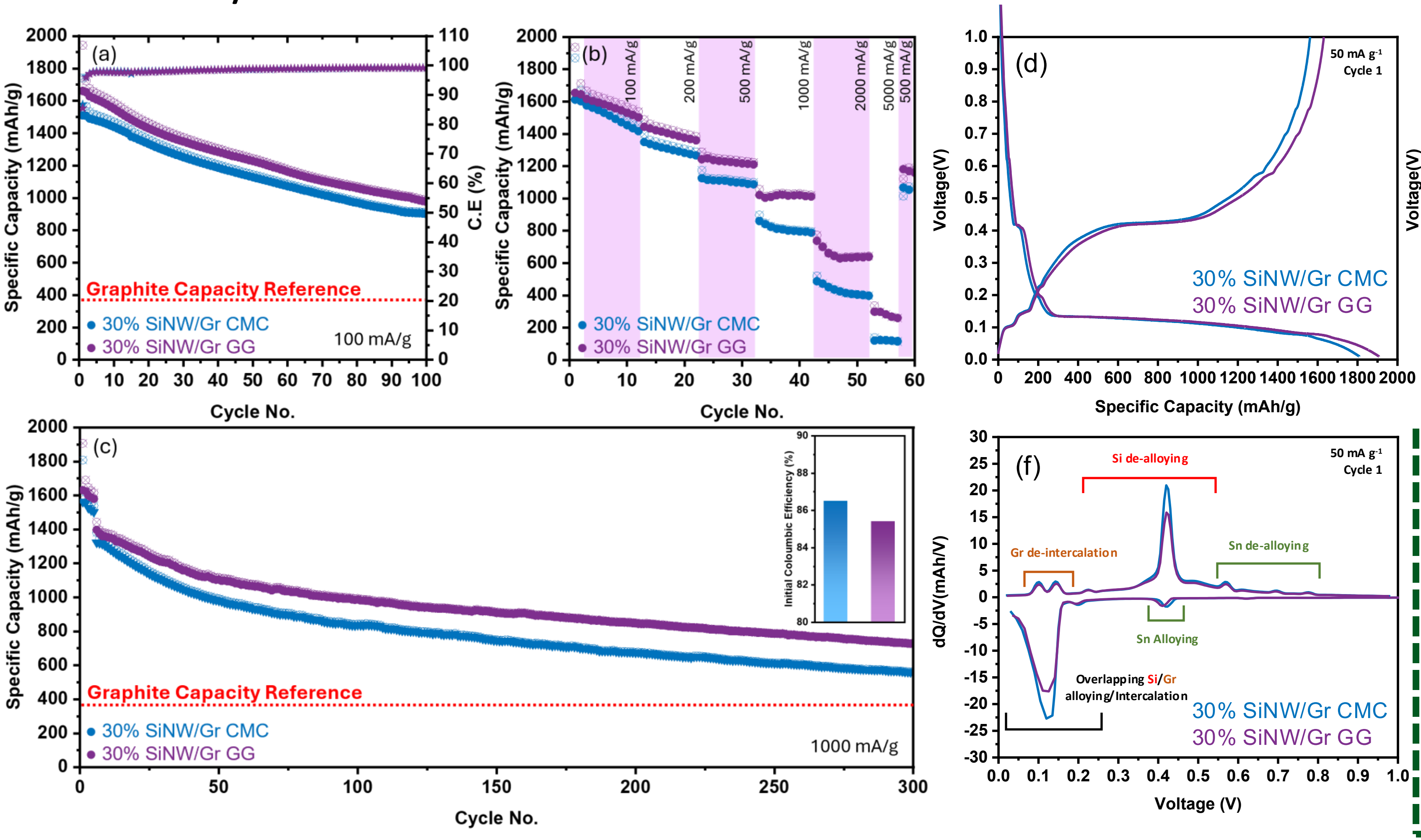
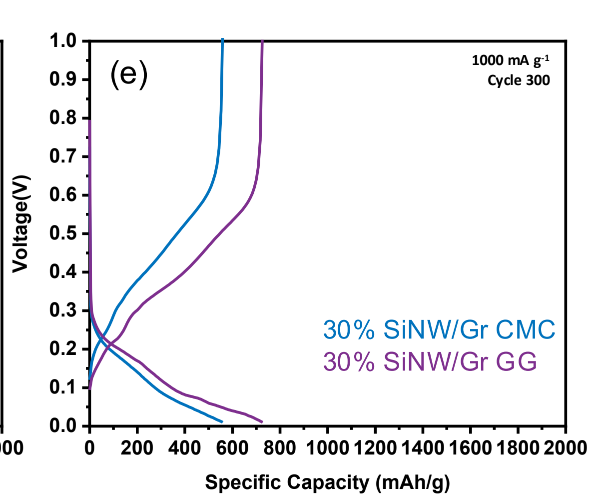
Characterization of SiNW@Gr Lab-Scale Batch Reactor

Binder 1: Carboxymethyl Cellulose (CMC)
Binder 2: Guar Gum (GG)

Gen 3: 30% SiNW/Gr





- High ICE for Si NW/Gr system.
- Electrochemical cycling at low and high current rate shows stable performance.
- RCT at higher current rates shows stable and higher specific capacity as compared with Graphite.
- GG helps in gaining more capacity and more stable performance

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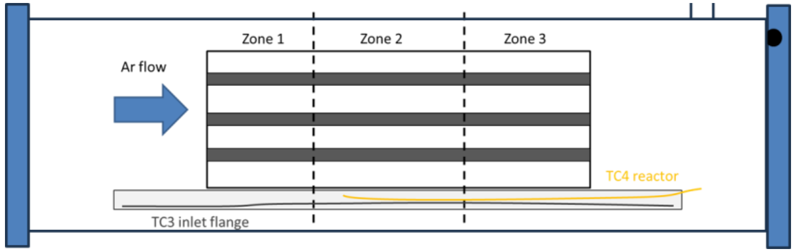
Half Cell Counter Lithium foil
Electrolyte: 0.8 M LiPF6 + 0.2 M LiFSi (EC:EMC) + 10% FEC; Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

Development of Si NW/Gr Composites
Larger Batches



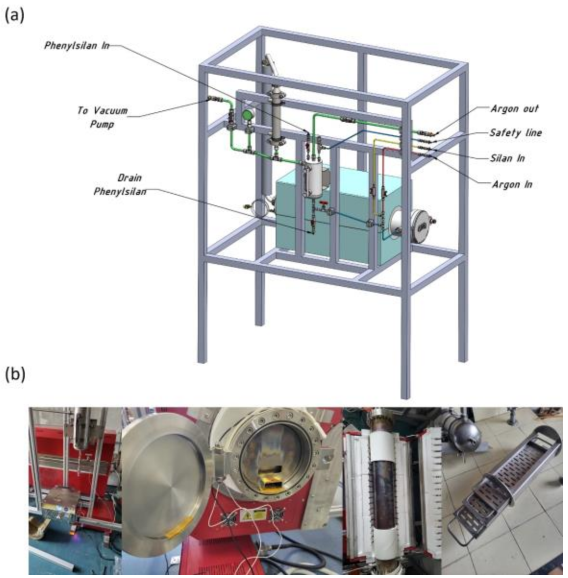
Each batch
Reaction has six samples

Zone 1
(3 samples)

Top (**T Z1**) | Middle (**M Z1**) | Bottom (**B Z1**)

Zone 23 (2 & 3 mix)
(3 samples)

Top (**T Z23**) | Middle (**M Z23**) | Bottom (**B Z23**)



		Total number of samples	Si content (wt.%)	Capacity (mAh/g) @ 500 mA/g	Amount available (gm)
Optimization of Reactor operations	Batch 1	6 @450°C	8-14	700-1250	120
	Batch 2	6 @450°C	2-6#	300-700	95
	Batch 3	6 @450°C	1-3#	330-400	94
	Batch 4	6 @450°C	0.5-1.5#	290-350	88
	Batch 5	6 @450°C	2-6#	370-376	102
	Batch 6	6 @450°C	2-9	366-410	101
	Batch 7	6 @450°C	2-10	371-410	81
	Batch 8	6 @450°C	5.9-9.4	328-395	109
	Batch 9	6 @450°C	14.2-16.20	450-452	29
	Batch 10	6 @450°C	17-24	600-700	100
	Batch 11	6 @450°C	16-21	600- 700	100
Temperature Optimization	Batch 12	6 @450°C	16-21	600- 700	100
	Batch 13	6 @490°C	9-30	400-1100	109
	Batch 14	6 @480°C	7-29	400-1000	111
	Batch 15	6 @470°C	8-26	300-900	102
	Batch 16	6 @460°C	7-28	600-1000	101
	Batch 17	6 @450°C	7-23	650-1050	100
					~1.5 Kg

#extremely low Si NWs

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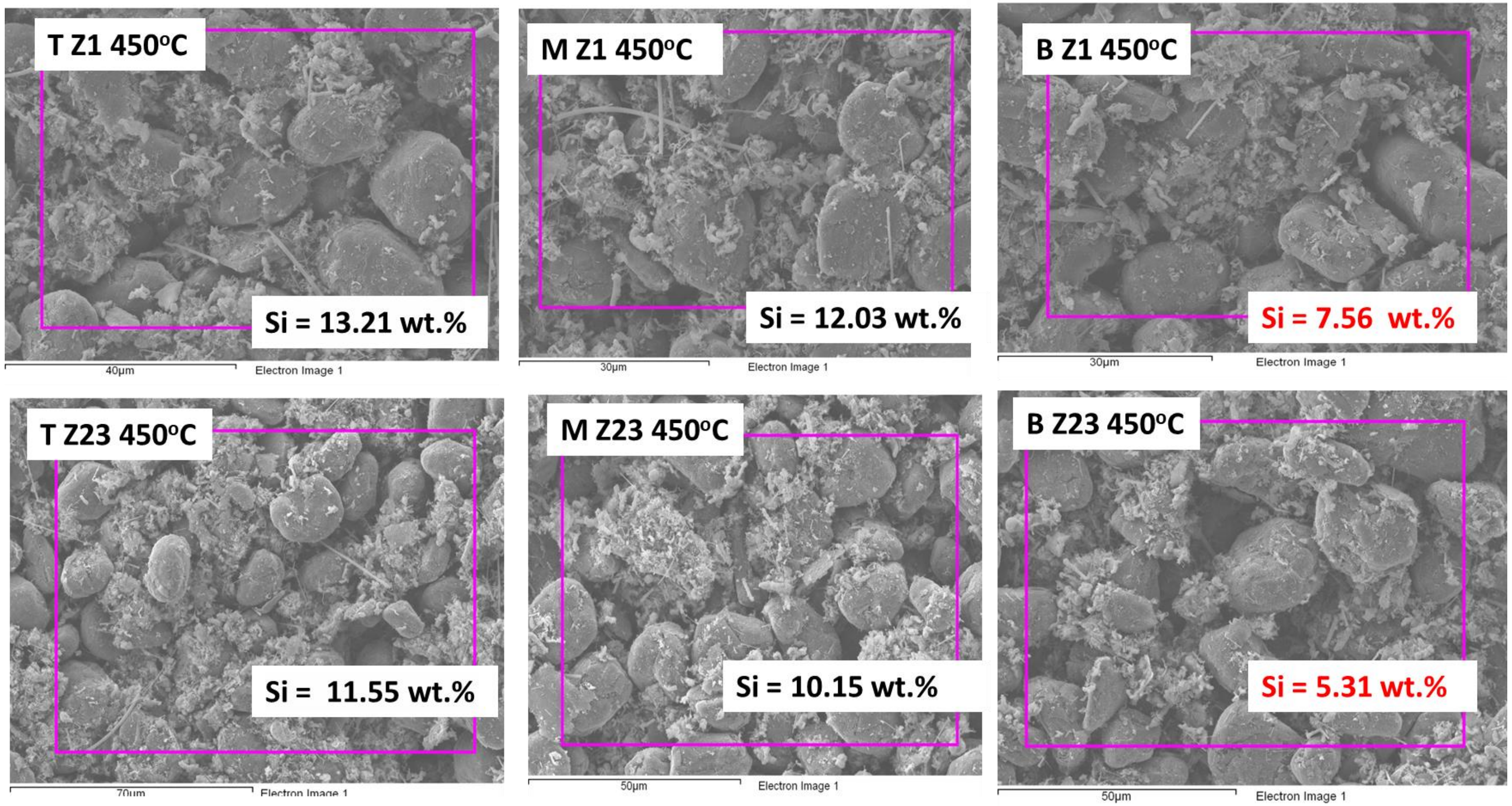
Development of Si NW/Gr Composites
Larger Batches: Product Analysis at 450^{o}C



Si NWs produced across the different reaction zones @ 450^{o}C. For all the samples from each zones of the batch reactor the average SiNWs content was around **5 - 13 wt.%.**

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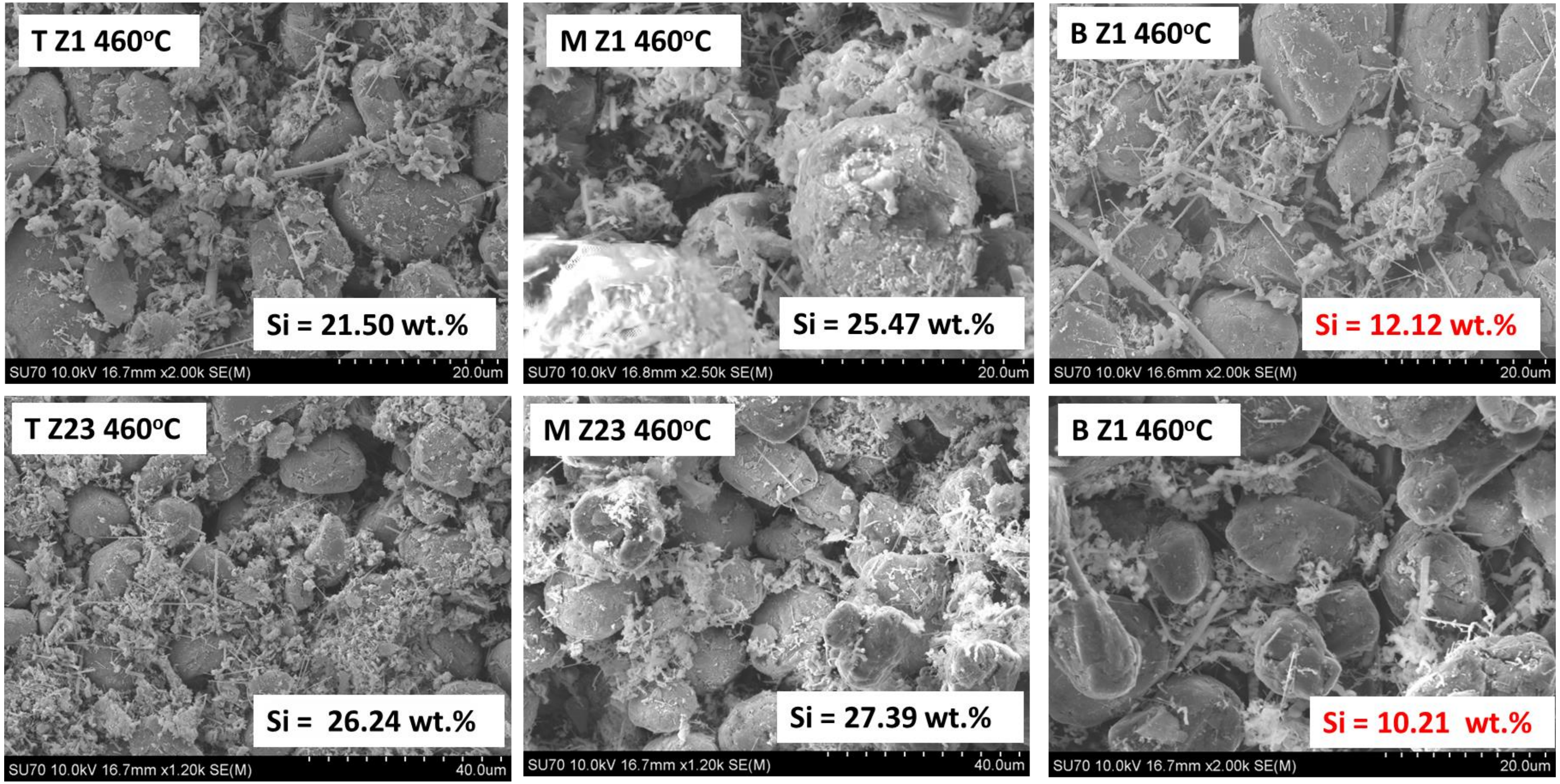
Development of Si NW/Gr Composites

Larger Batches: Product Analysis at 460^{o}C

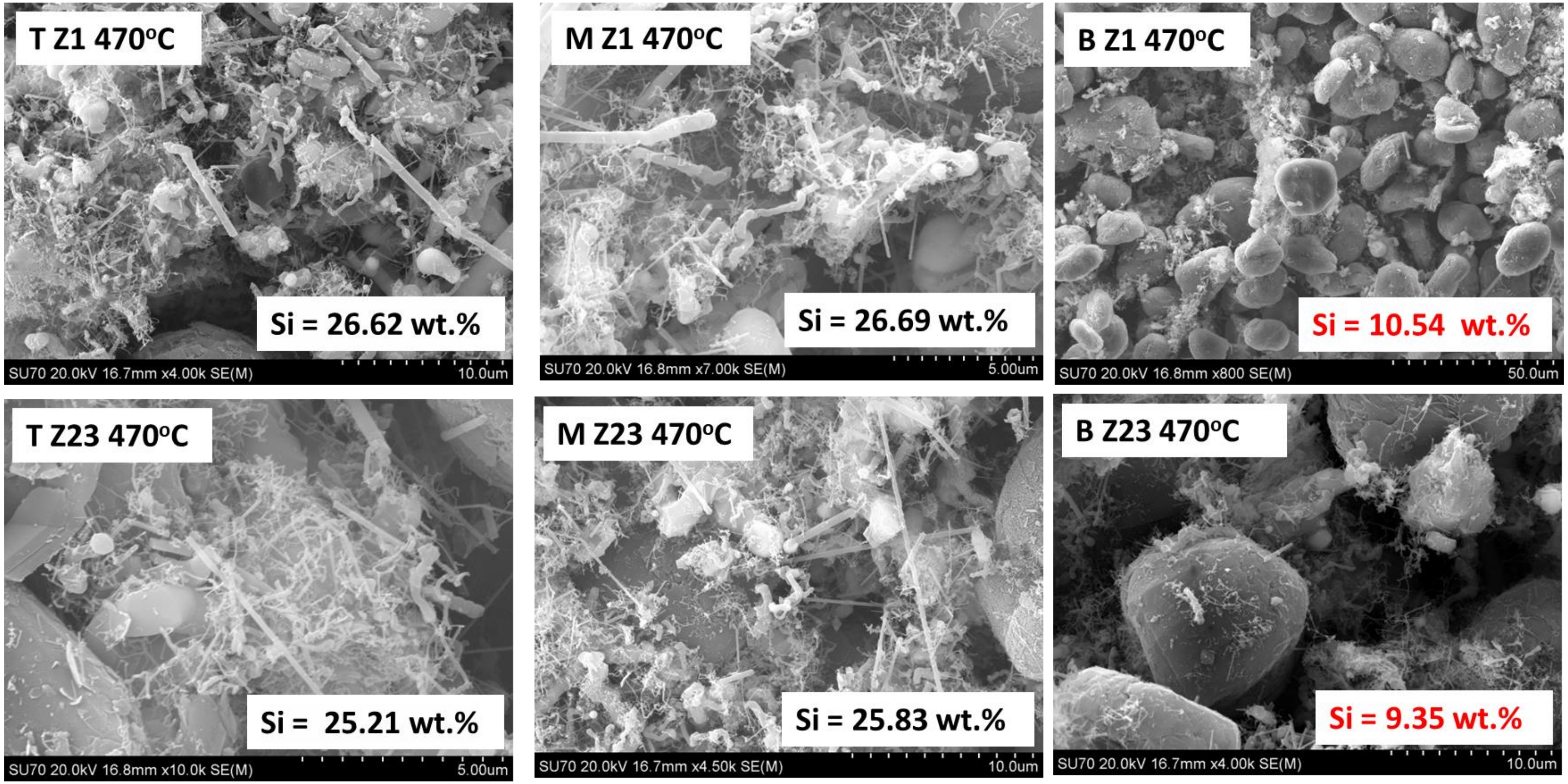


Si NWs produced across the different reaction zones @ 460^{o}C. For all the samples from each zones of the batch reactor the average SiNWs content was around **9 - 30 wt.%.**

This project has received funding from the European Union's Horizon Europe transport programme under grant agreement No 101069738

Development of Si NW/Gr Composites

Larger Batches: Product Analysis at 470°C



Si NWs produced across the different reaction zones @ 470°C. For all the samples from each zones of the batch reactor the average SiNWs content was around **9 - 30 wt.%.**

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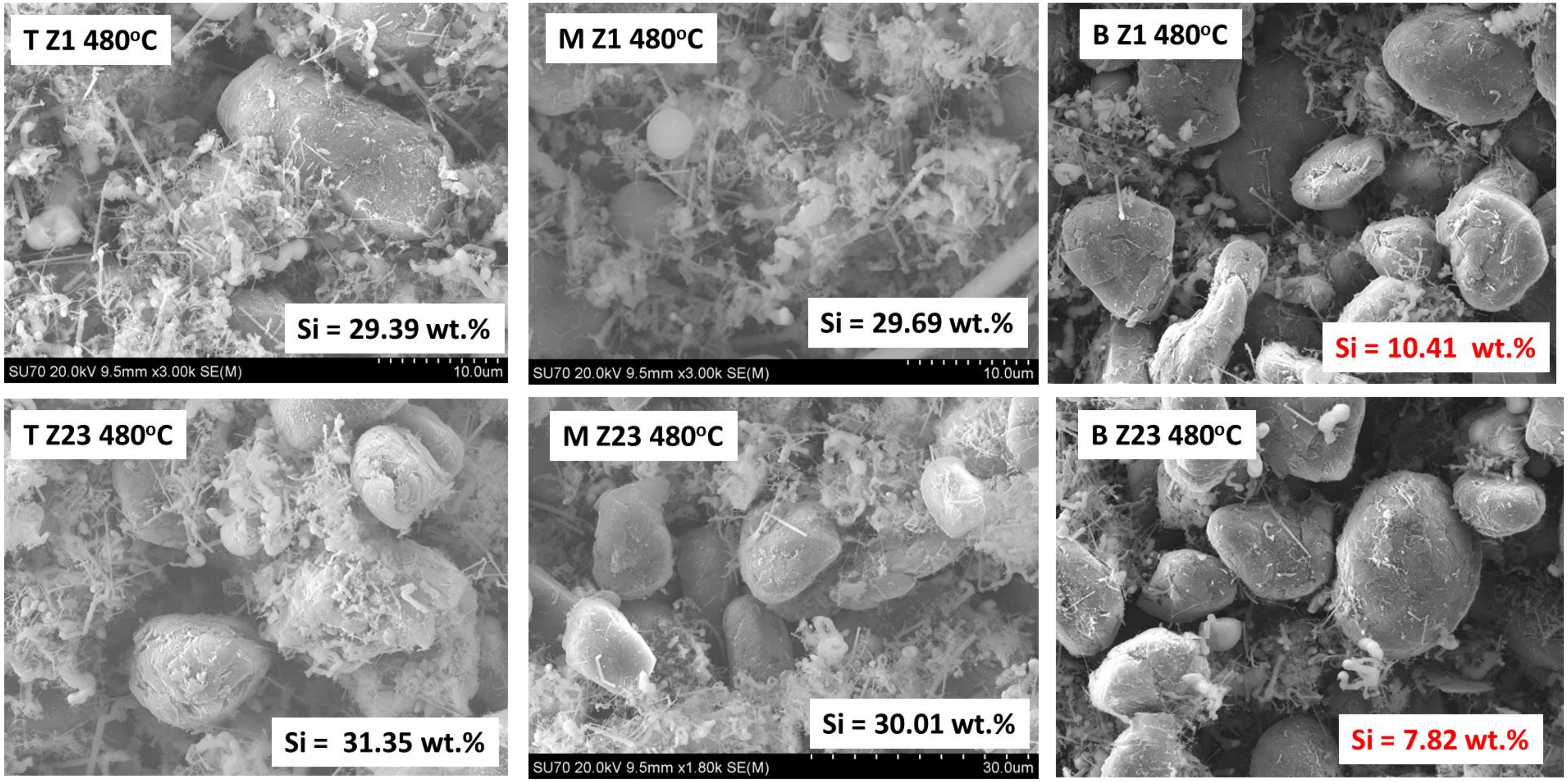
Development of Si NW/Gr Composites
Larger Batches: Product Analysis at 480^{o}C



Si NWs produced across the different reaction zones @ 480^{o}C. For all the samples from each zones of the batch reactor the average SiNWs content was around **8 - 30 wt.%.**

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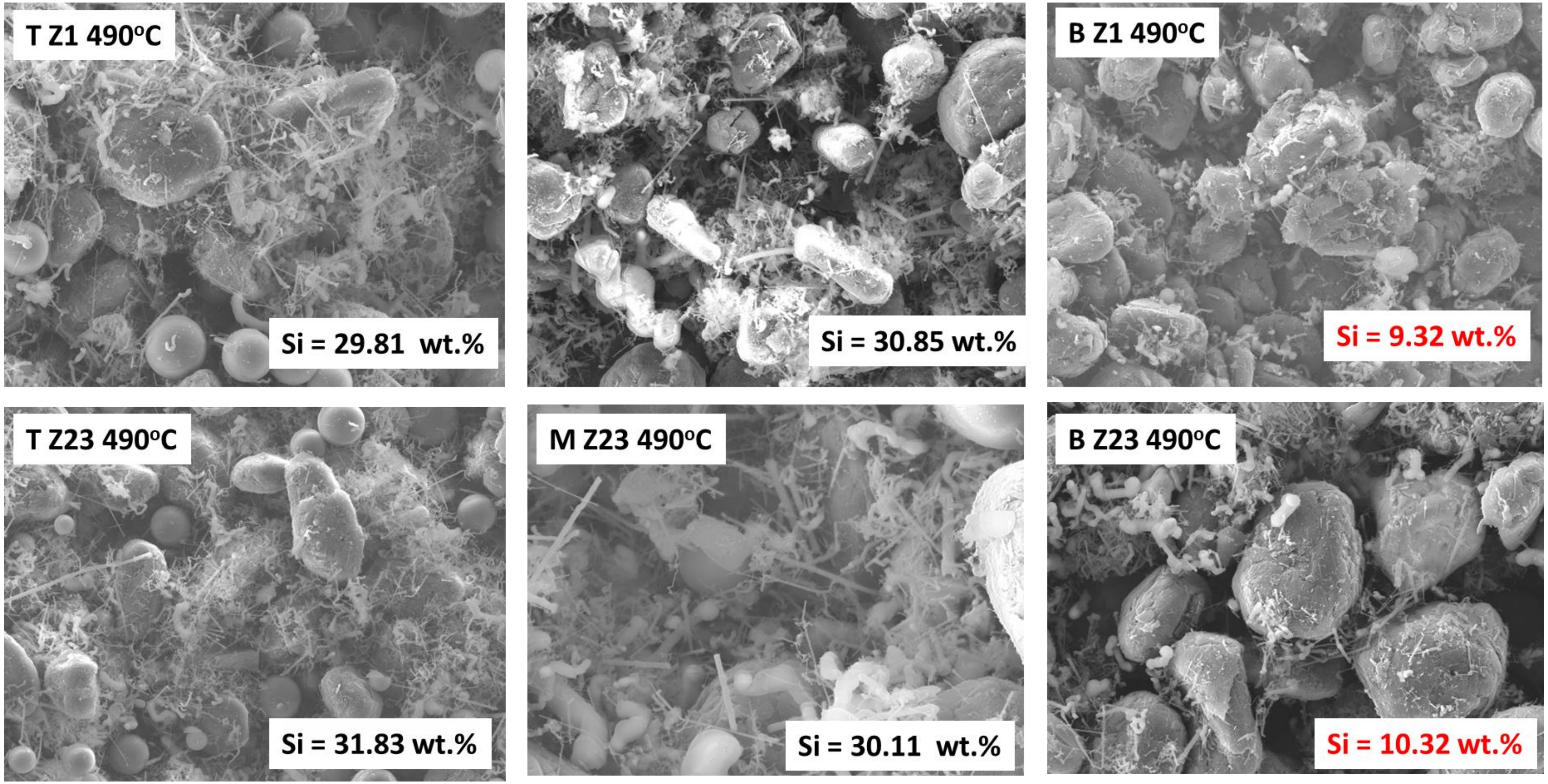
Development of Si NW/Gr Composites
Larger Batches: Product Analysis at 490^{o}C



Si NWs produced across the different reaction zones @ 490^{o}C. For all the samples from each zones of the batch reactor the average SiNWs content was around **9 - 30 wt.%.**

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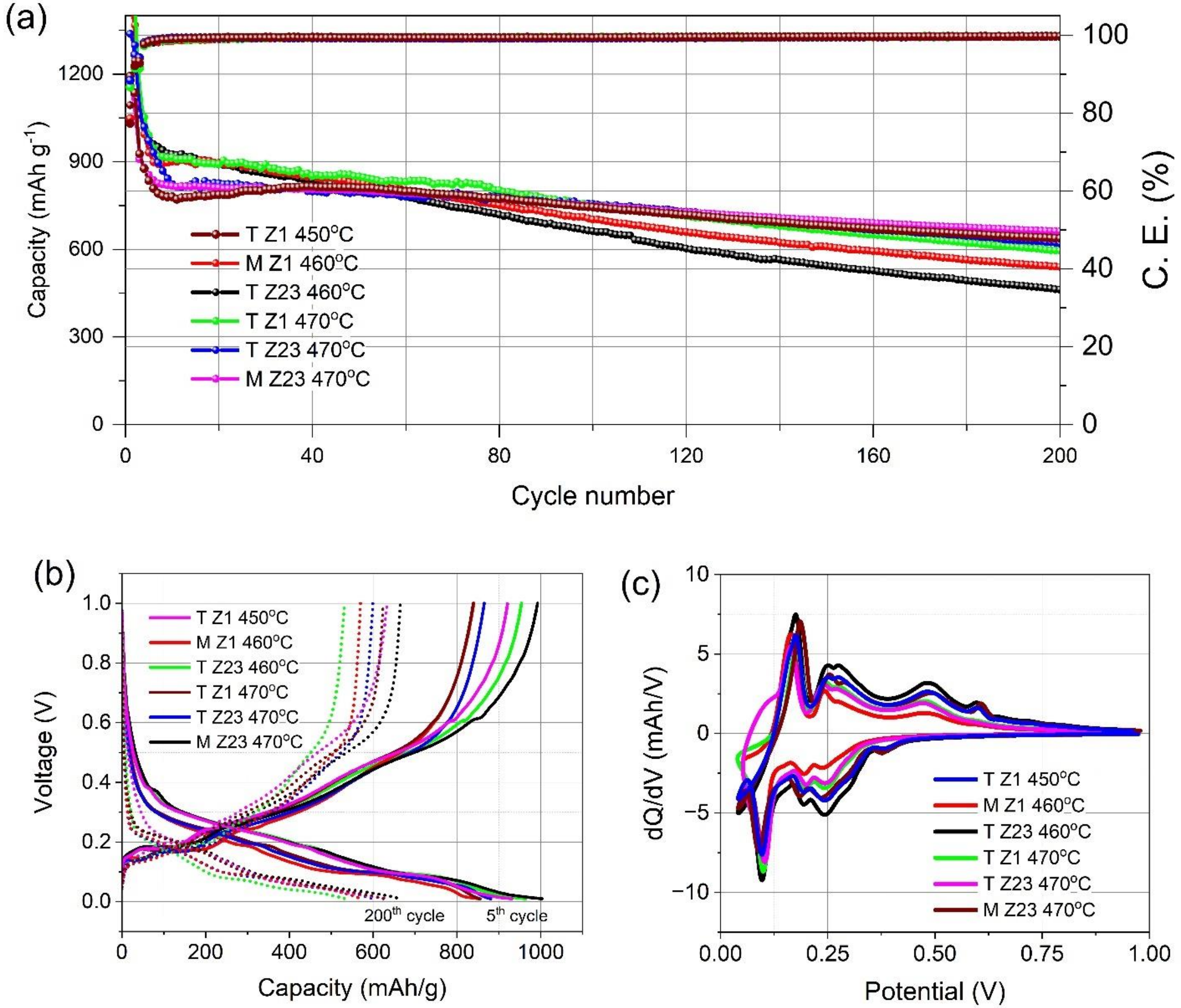
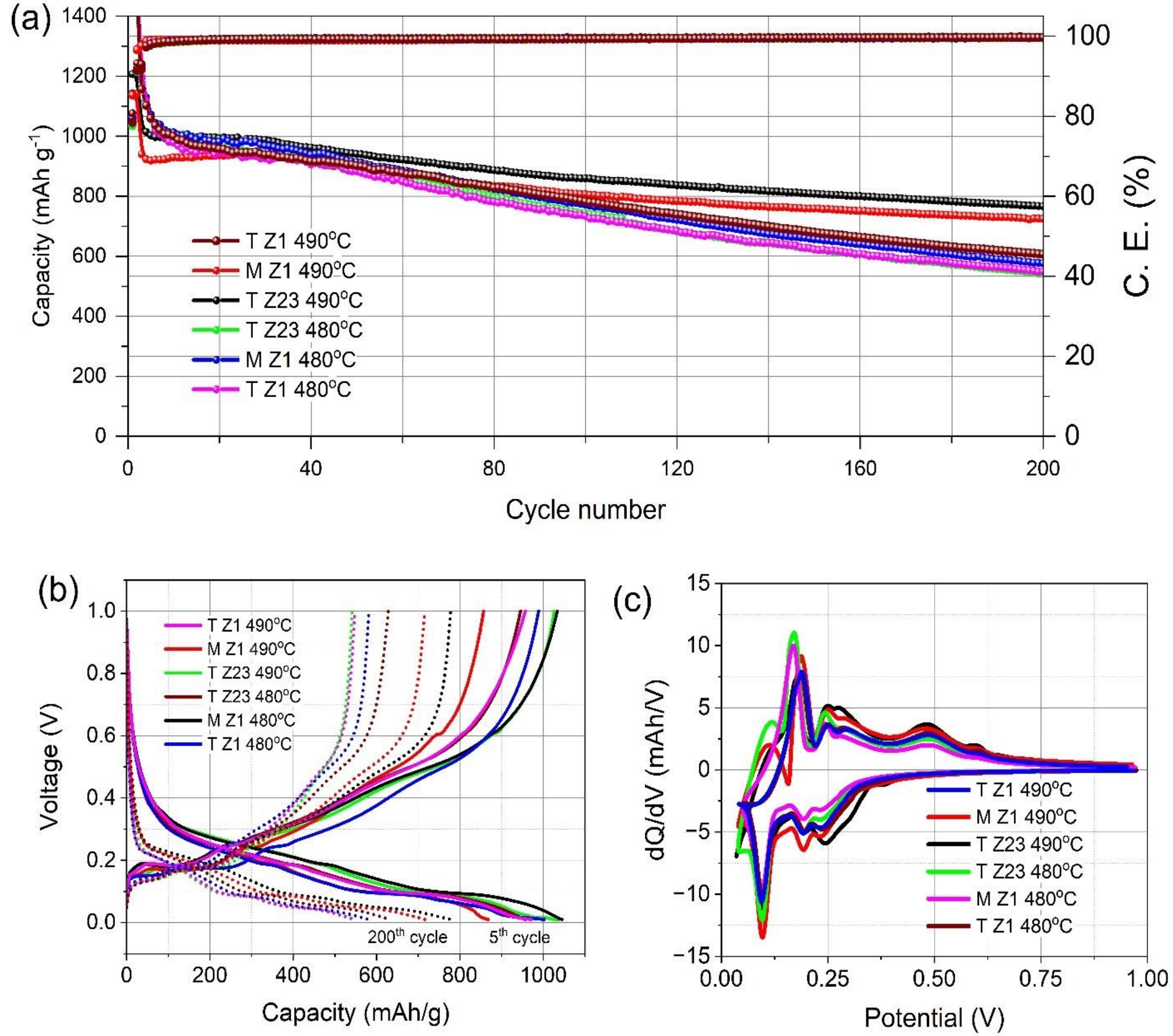
Task 1.3: Characterization of SiNW@Gr
Larger Batch: Electrochemical Results

Si content of 24.93 - 26.62 wt.%



Si content of 29.39 - 31.83 wt.%



Half Cell Counter Lithium foil
Electrolyte: 0.8 M $LiPF_6$ + 0.2 M LiFSi (EC:EMC) + 10% FEC; Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

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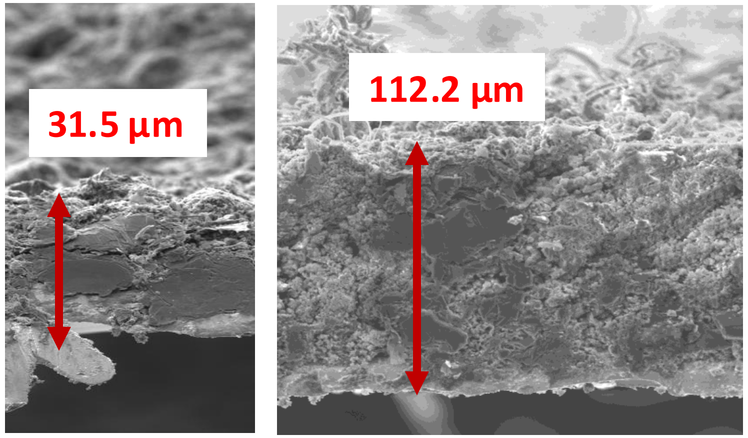
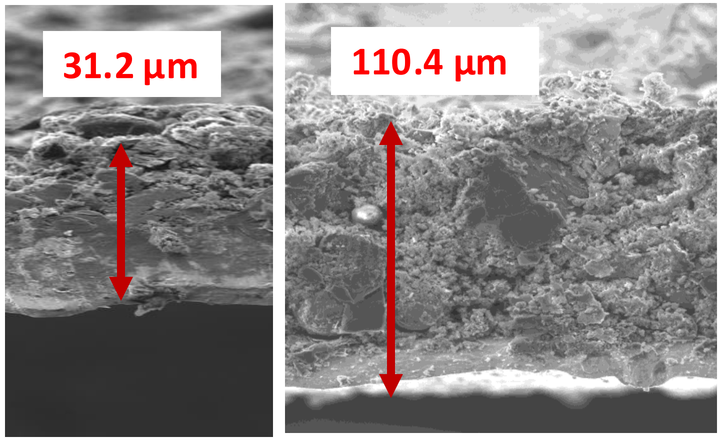
Task 1.3: Characterization of SiNW@Gr Larger Batch: Electrochemical Results

Post-mortem analysis after long-term cycling test for samples with Si content of 24.93 - 26.62 wt.%

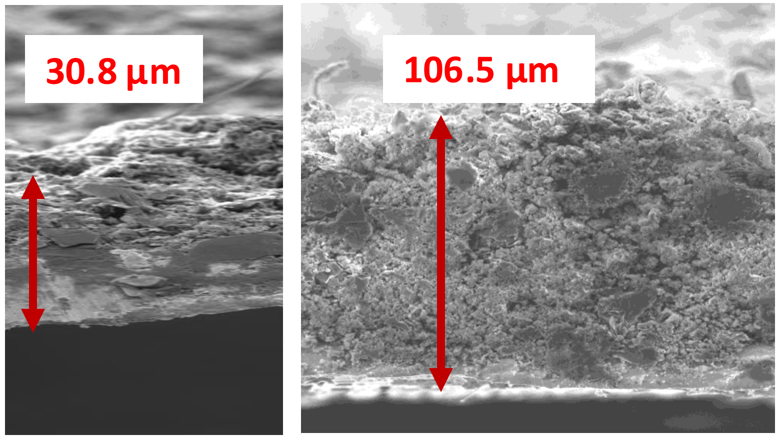
T Z1 450ºC



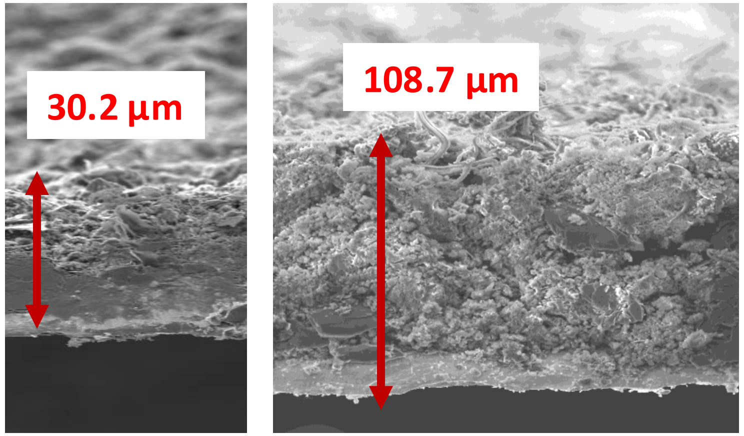
M Z1 460ºC



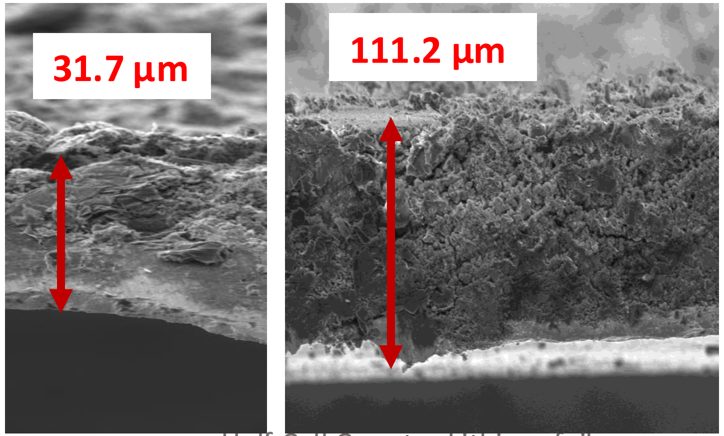
T Z23 460ºC



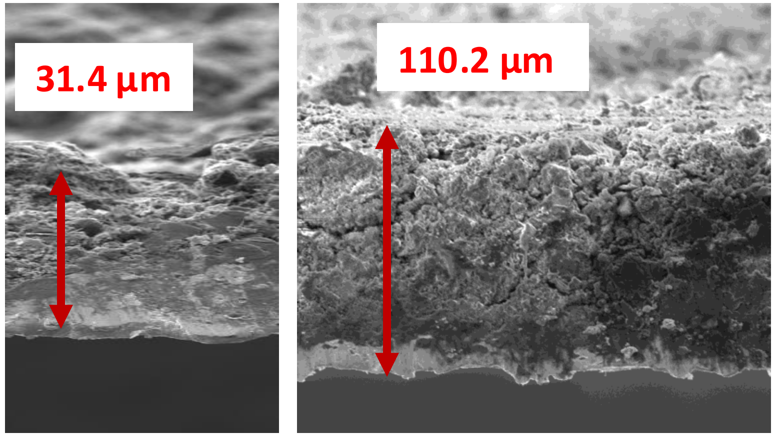
T Z1 470ºC



T Z23 470ºC



M Z23 470ºC



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Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

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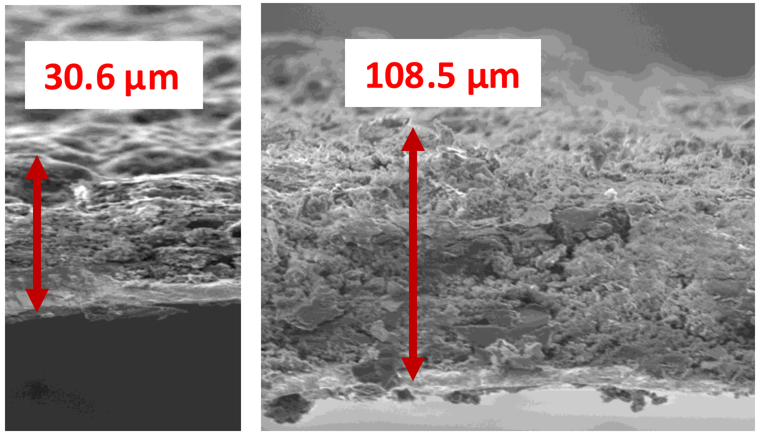
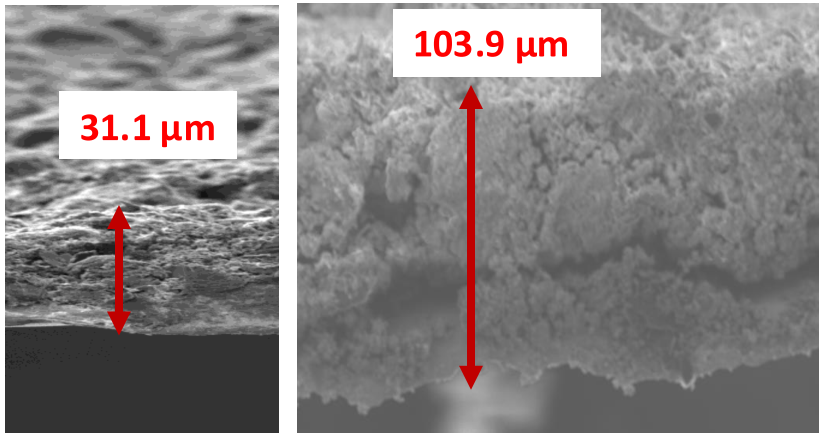
Task 1.3: Characterization of SiNW@Gr
Larger Batch: Electrochemical Results

Post-mortem analysis after long-term cycling test for samples with Si content of 29.39 - 31.83 wt.%

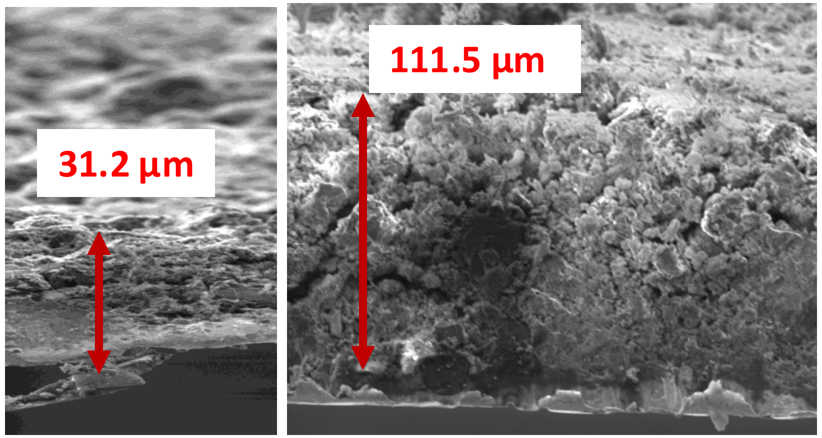
T Z1 480°C



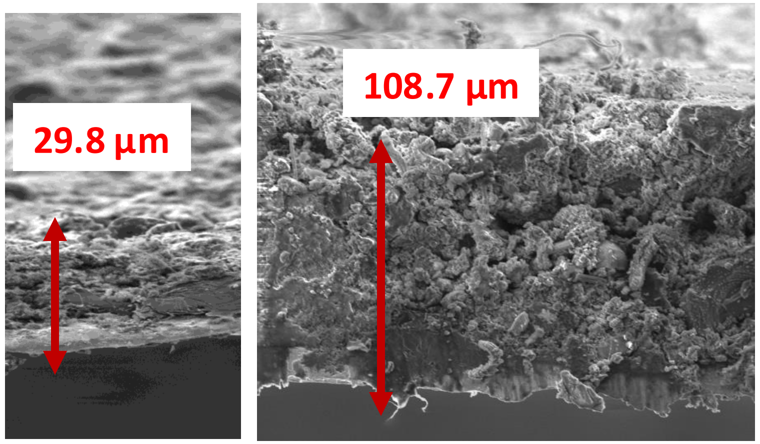
M Z1 480°C



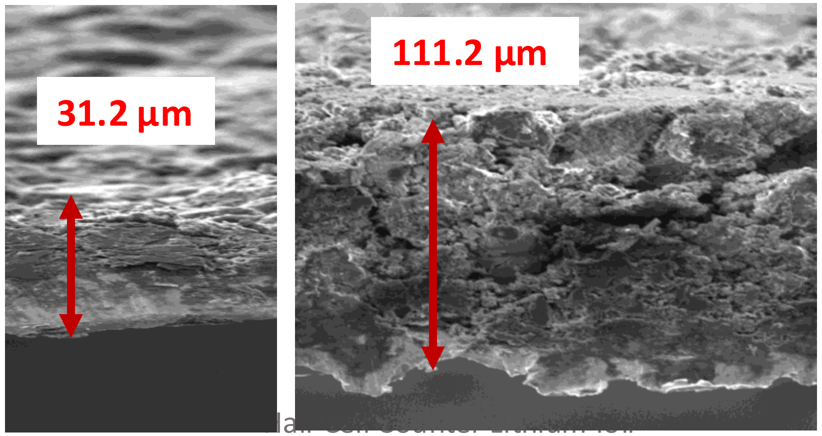
T Z23 480°C



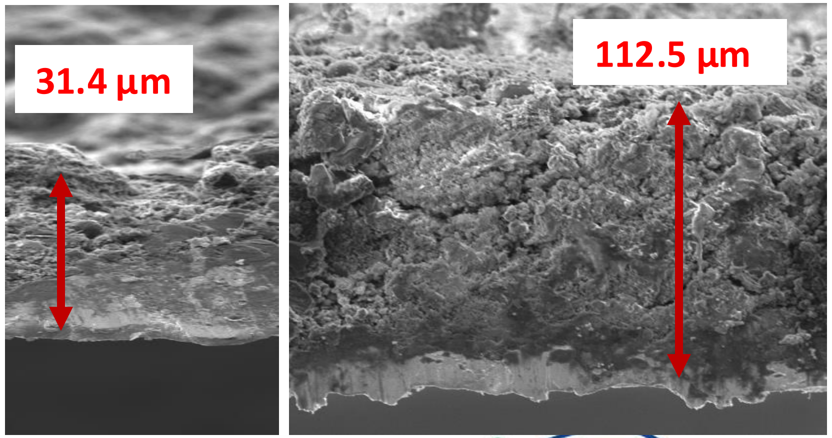
T Z1 490°C



M Z1 490°C



T Z23 490°C



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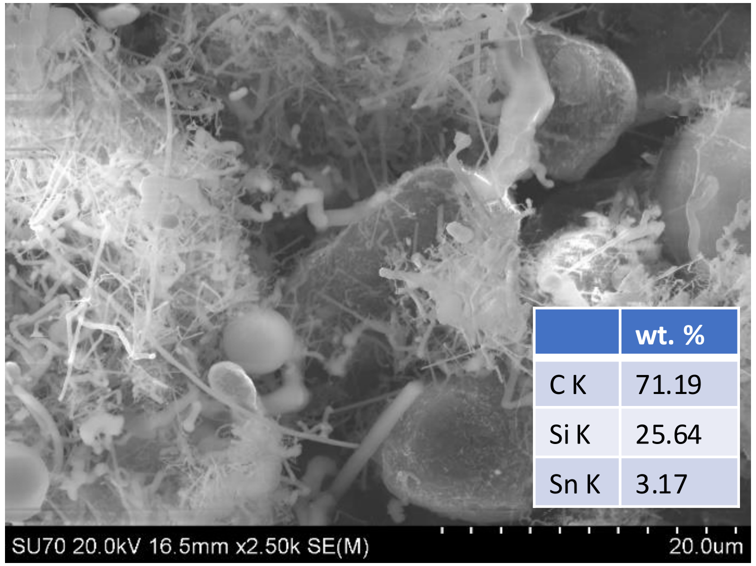
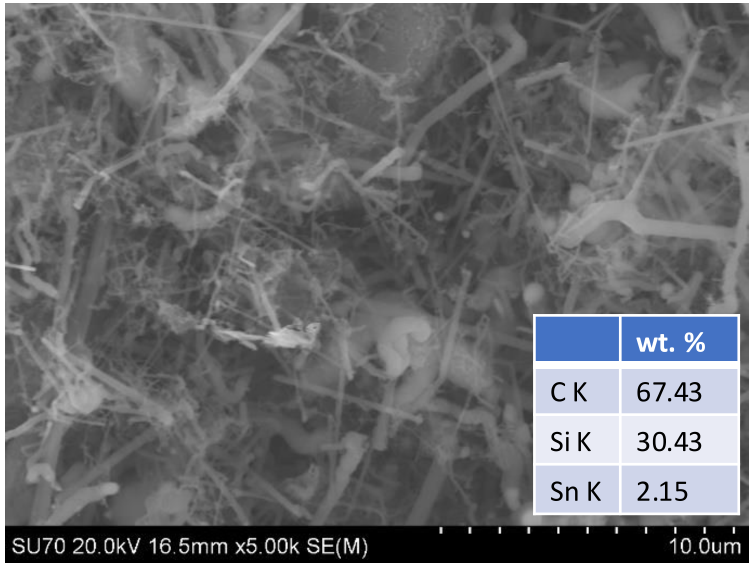
Electrolyte: 0.8 M LiPF6 + 0.2 M LiFSi (EC:EMC) + 10% FEC;
Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

Characterization of SiNW@Gr
Larger Batch: Electrochemical Results

Properties and categorization of mixture samples with Si contents of 24.93 - 26.62 wt.% and 29.39 - 31.83 wt.%



	wt. %
C K	71.19
Si K	25.64
Sn K	3.17



	wt. %
C K	67.43
Si K	30.43
Sn K	2.15

Based on Si Content, these materials are characterised as follows ;

Gen 2: ~25 wt.%

Gen 3: ~30 wt.%

Half Cell Counter Lithium foil
Electrolyte: 0.8 M LiPF6 + 0.2 M LiFSi (EC:EMC) + 10% FEC;
Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

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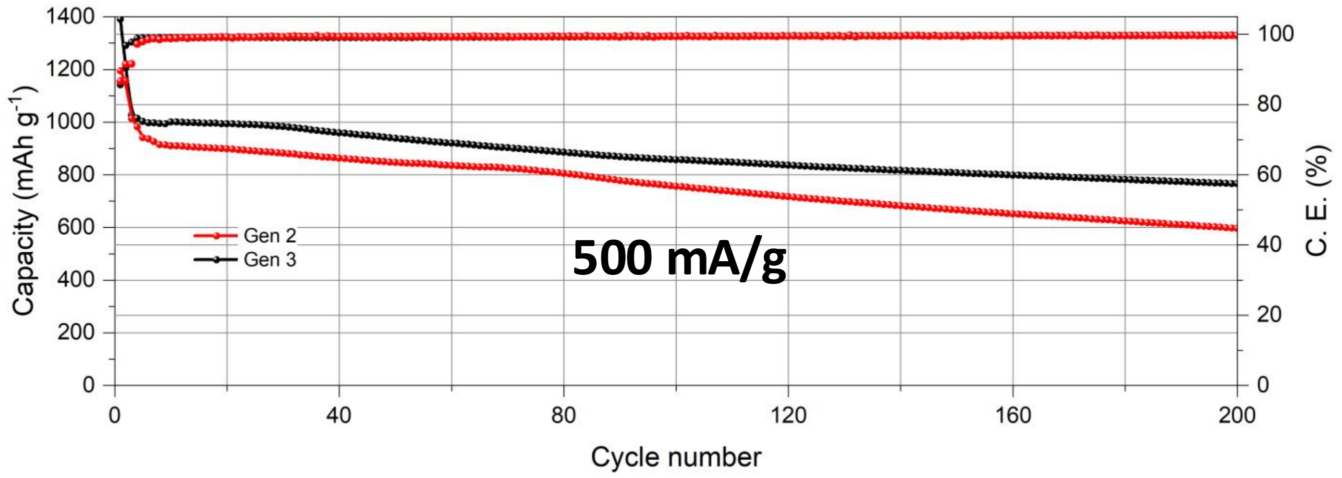
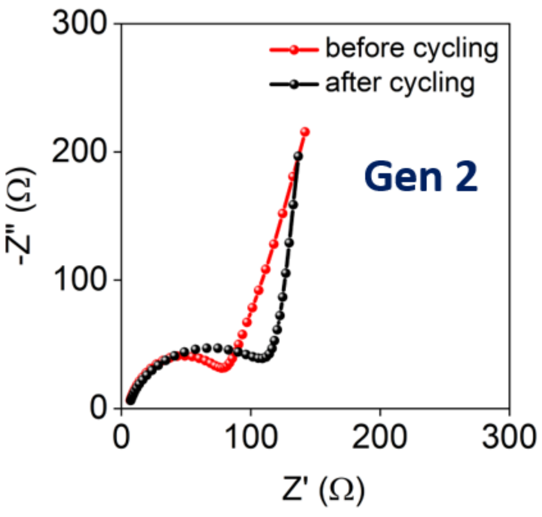
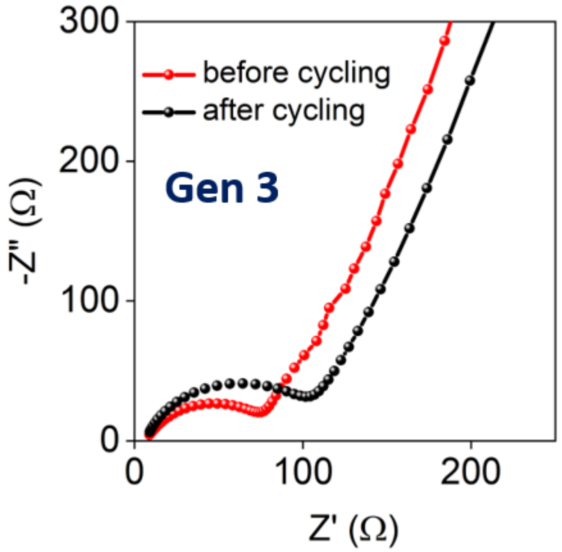
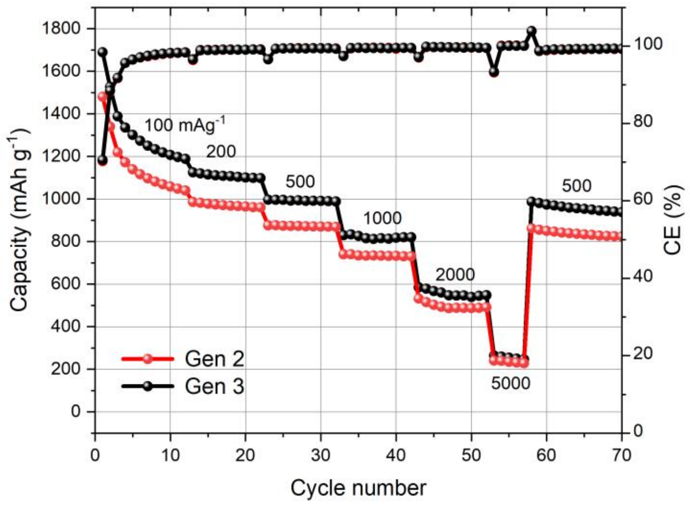
Characterization of SiNW@Gr

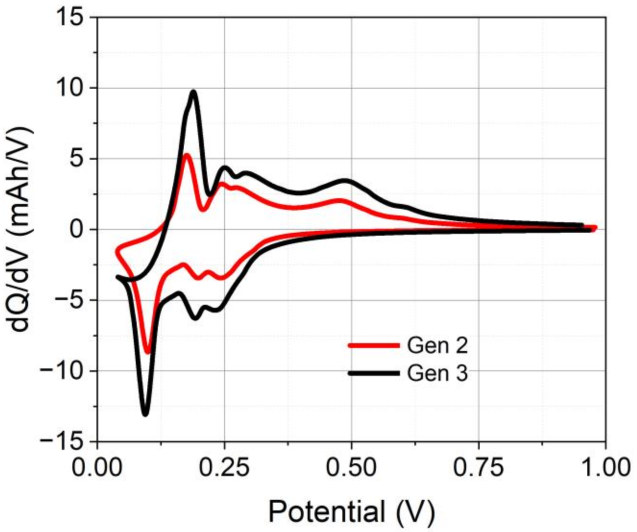
Larger Batch: Electrochemical Results Gen 2 vs. Gen 3



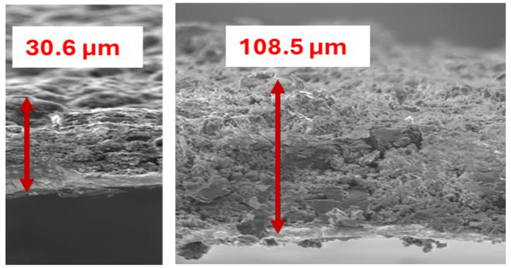




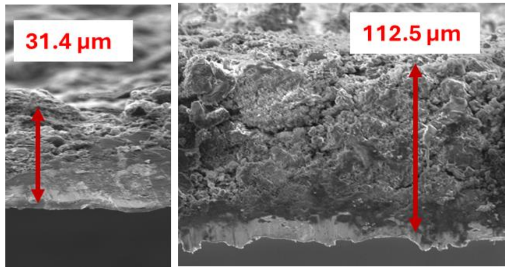




Gen 2



Gen 3



foil
Electrolyte: 0.8 M LiPF6 + 0.2 M LiFSi (EC:EMC) + 10% FEC;
Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

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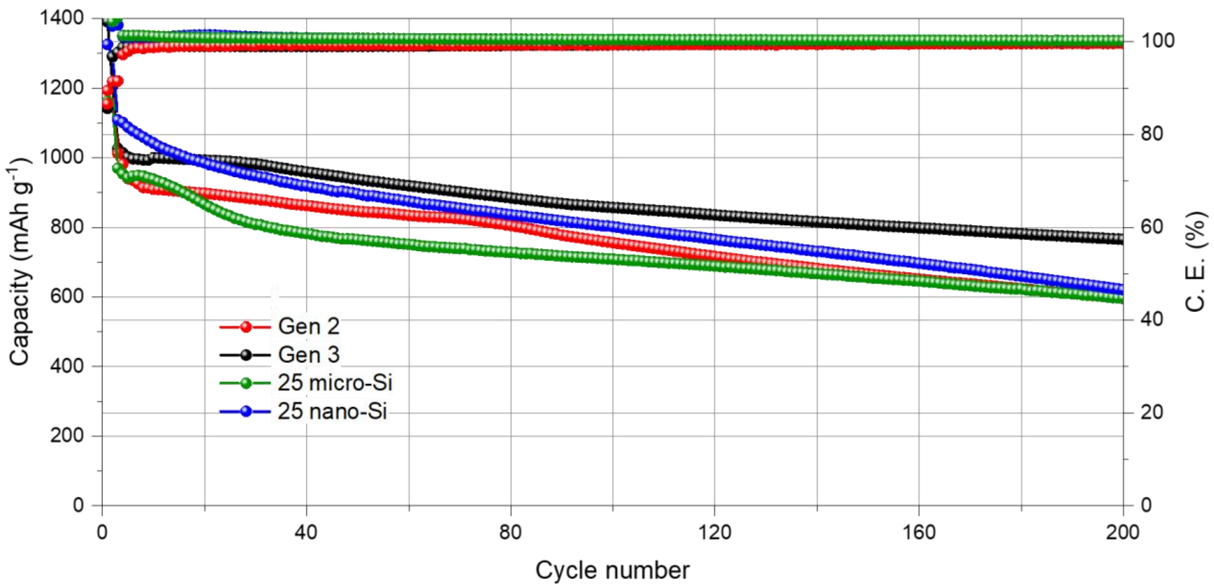
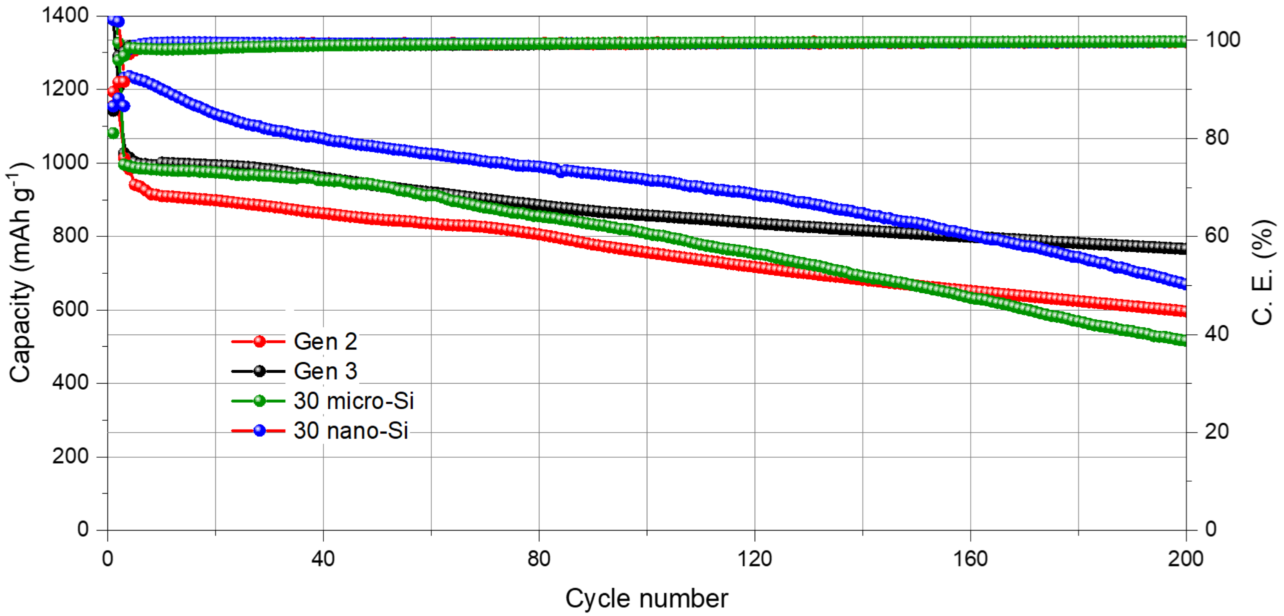
Characterization of SiNW@Gr
Larger Batch: Electrochemical Results

Gen 2 & Gen 3 vs 25 % nano and micro-Si system



Gen 2 & Gen 3 vs 30 % nano and micro-Si system



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Half Cell Counter Lithium foil
Electrolyte: 0.8 M LiPF6 + 0.2 M LiFSi (EC:EMC) + 10% FEC; Separator: GF/A + Celgard
Slurry Composition: 80 AM : 10 Binder : 10 Conductive Agent

Next Steps

- Continue development of SiNW/Gr material in Lab Scale as well in the large Batch Reactor.
- Development and more improved optimization of large batch reactor for more stable product.
- Full cell characterization

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Thank you for your attention!

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grant agreement No 101069738

Contact Us

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Website: signehorizon.eu

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BATTwin

Flexible and scalable digital-twin platform for enhanced production efficiency and yield in battery cell production lines

BATT4EU Success Stories Webinar

30 June 2026

Project Coordinator, Prof. Marcello Colledani

Politecnico di Milano, Department of Mechanical Engineering

POLITECNICO MILANO 1863

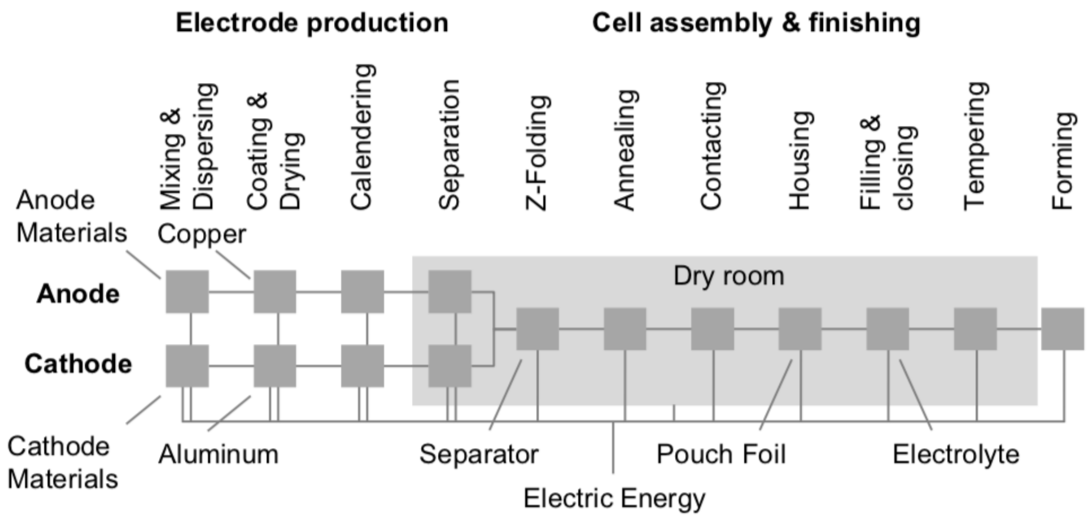
mecc

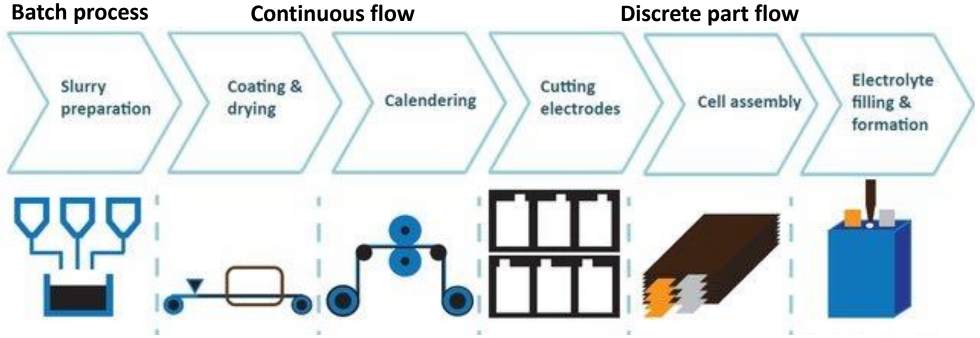
Funded by the European Union

This project has received funding from the European Climate, Infrastructure and Environment Executive Agency under grant agreement No. 101137954

Manufacturing process chains for Li-Ion batteries

Li-Ion battery manufacturing involves a complex process-chain integrating batch, continuous flow and discrete part flow process steps.

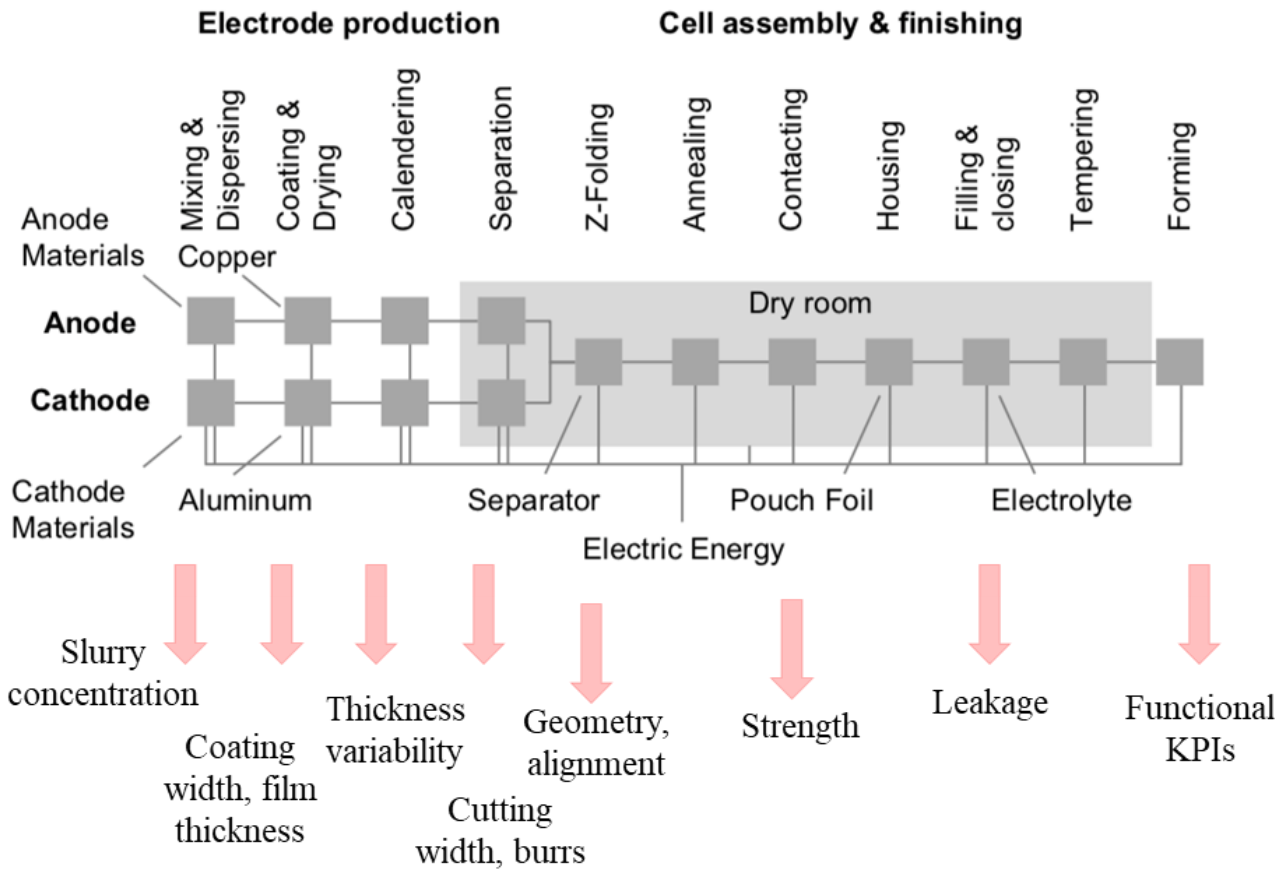


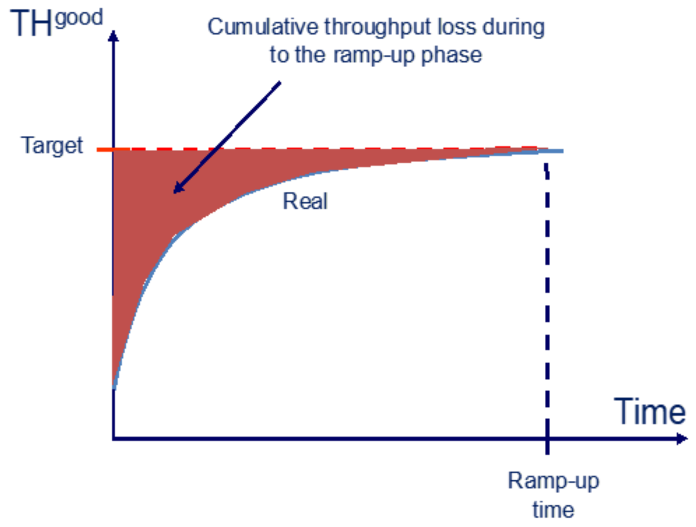


Funded by the European Union
This project has received funding from the European Climate, Infrastructure and Environment Executive Agency under grant agreement No. 101137954

Manufacturing process chains for Li-Ion batteries

Several distributed root causes for defect affect the achievement of target effective production rates (throughput of conforming parts), especially in the ramp-up phase.





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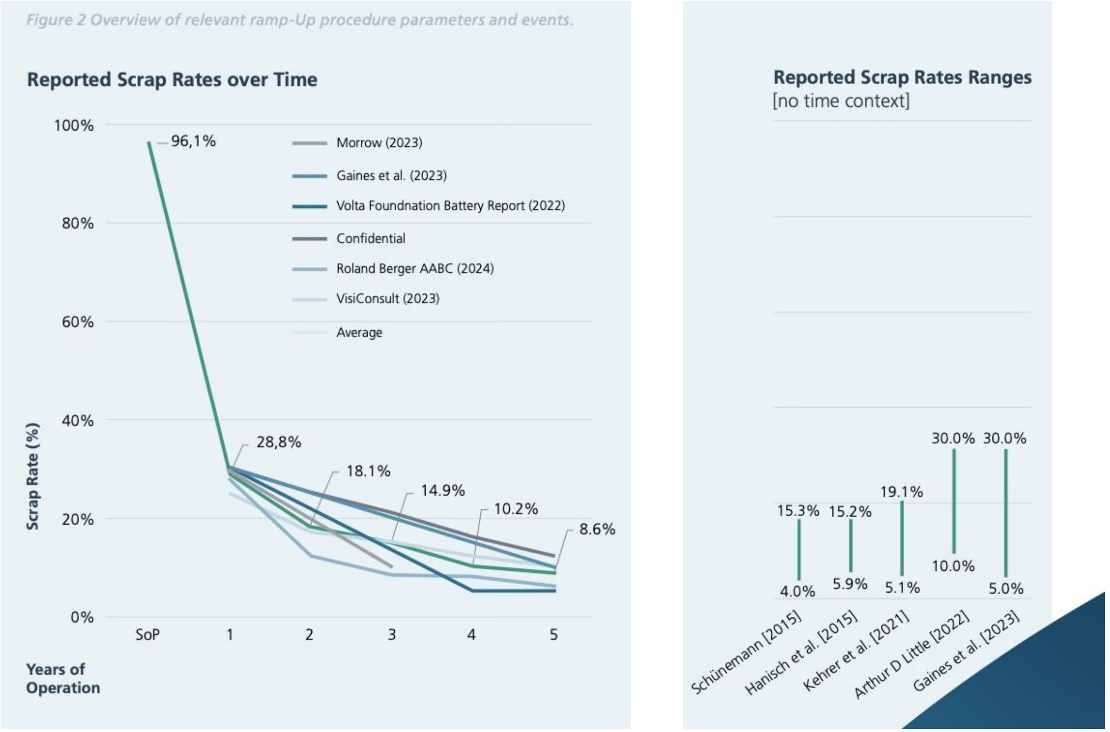
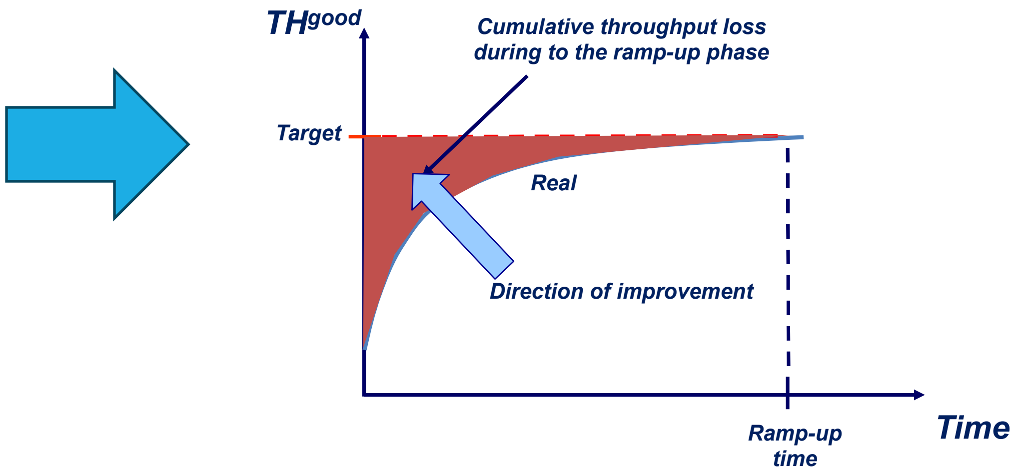
Manufacturing process chains for Li-Ion batteries: Scrap rates

Scrap rates for lithium-ion battery production are rumored to be **approximately 5% for the best producers**, 10% for typical producers, and as high as 30% or more during start-up phases.



Fraunhofer FFB, RWTH, "Mastering Ramp-up of Battery Production», 2024.

How to exploit the knowledge of European battery production equipment manufacturers to support future Gigafactories while handling defect generation and propagation during the ramp-up and steady-state production runs?



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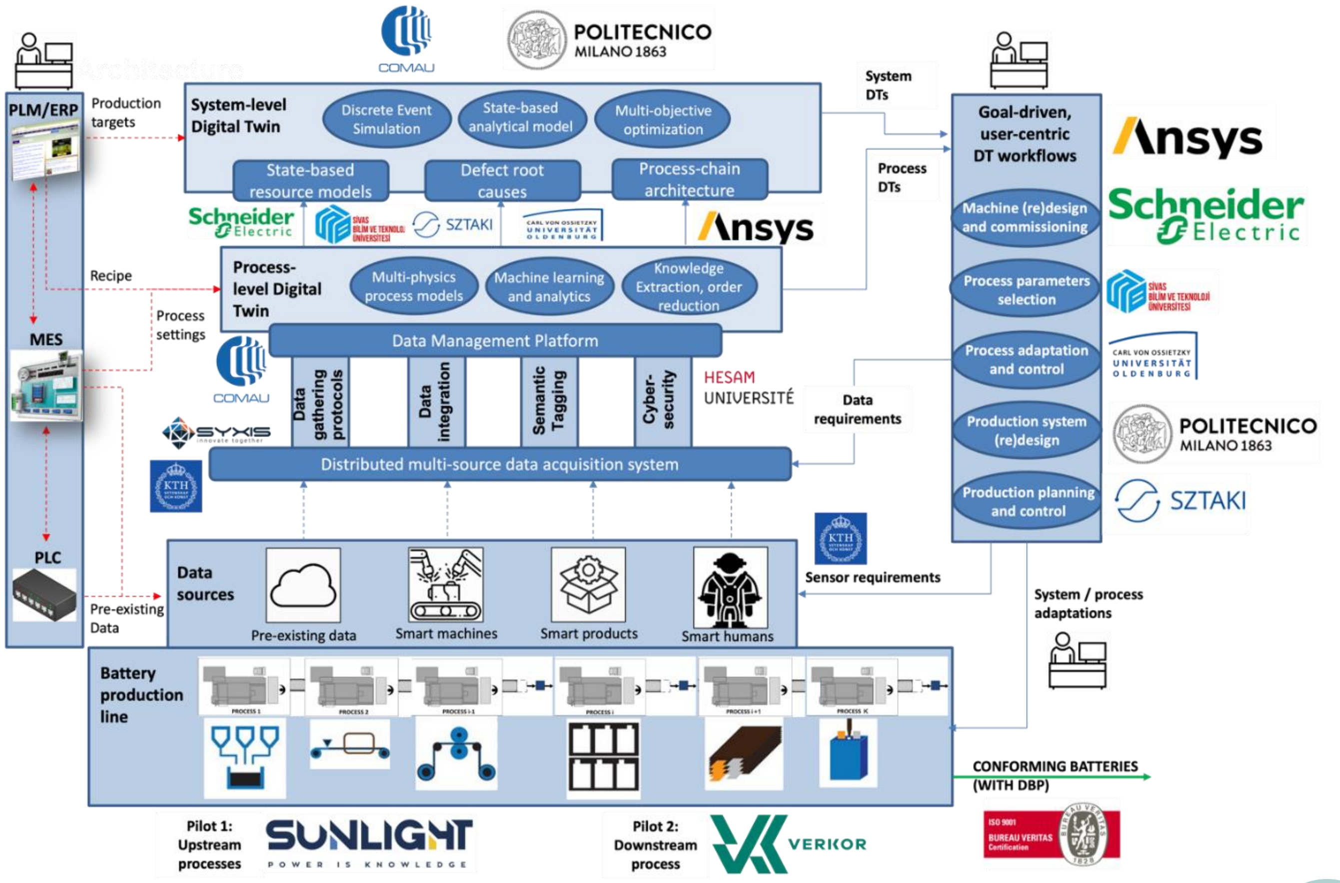
BATTwin: Flexible and scalable digital-twin platform for enhanced production efficiency and yield in battery cell production lines

***BATTwin** aims at designing, developing and demonstrating a novel Digital Twin Platform supporting a digitally-enhanced zero-defect manufacturing approach for the European battery manufacturing industry.*

- Coordinating partner: POLIMI.
- 16 partners.
- 10 companies, 4 SMEs.
- 10 EU member states, UK.
- Funding: 6.9 M€.
- Starting date: Dec 1[st] 2023.

"Zero Defect Manufacturing" is an emerging paradigm aiming at going beyond traditional six-sigma approaches in highly technology intensive and strategic manufacturing sectors through knowledge-based approaches.



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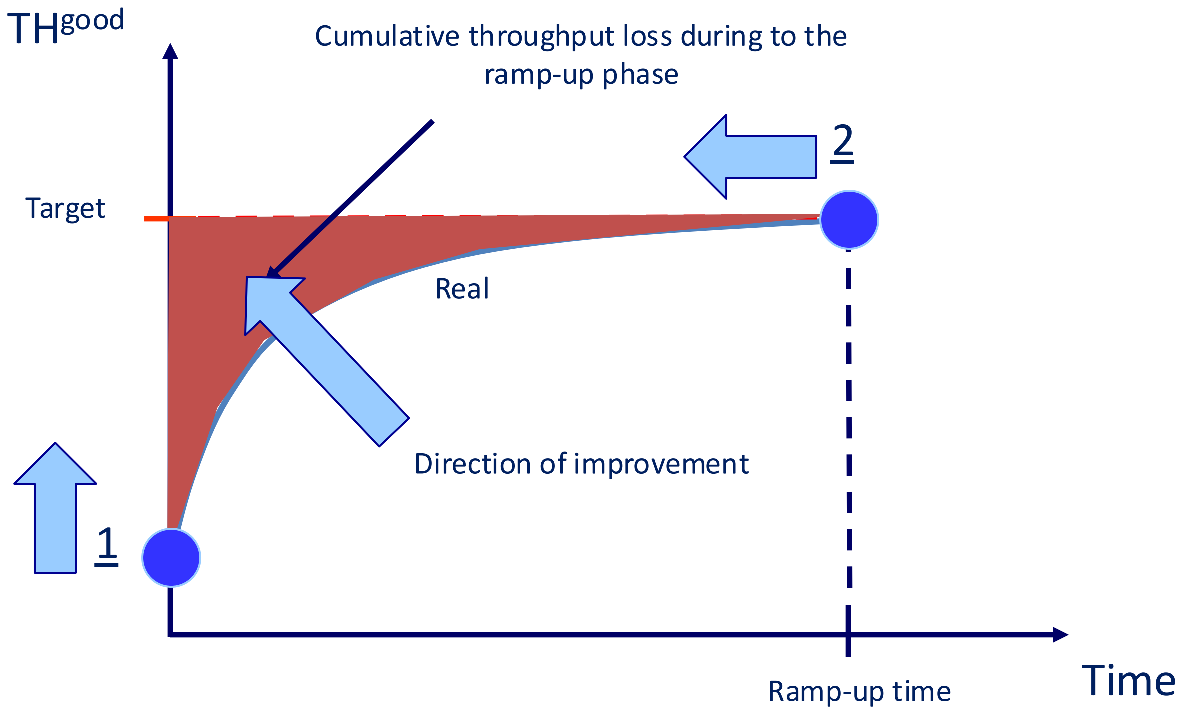

Strategy 1: anticipate the potential problems during the design phase.

Strategy 2: enhanced data-analytics and knowledge-based digital twins for limiting defect generation and propagation.

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Validation Use-Cases

- ***Verkor:*** Digital twin for supporting pilot production validation and future scale-up at high-throughput. Focus on downstream processes and process-chain level.
- ***Sunlight**:* Digital twin for supporting pilot production validation and future scale-up at high-throughput. Focus on upstream processes and process-chain level.

Use case	Scale/volume	Cell geometry	Cell chemistry	Critical process stages	Notes
Verkor	Target: 150 Mwh/year	Pouch	NMC	Notching, stacking	Automotive
Sunlight	Target: 100 Mwh/year	Prismatic	LFP	Mixing, coating, calendering, slitting.	Stationary application

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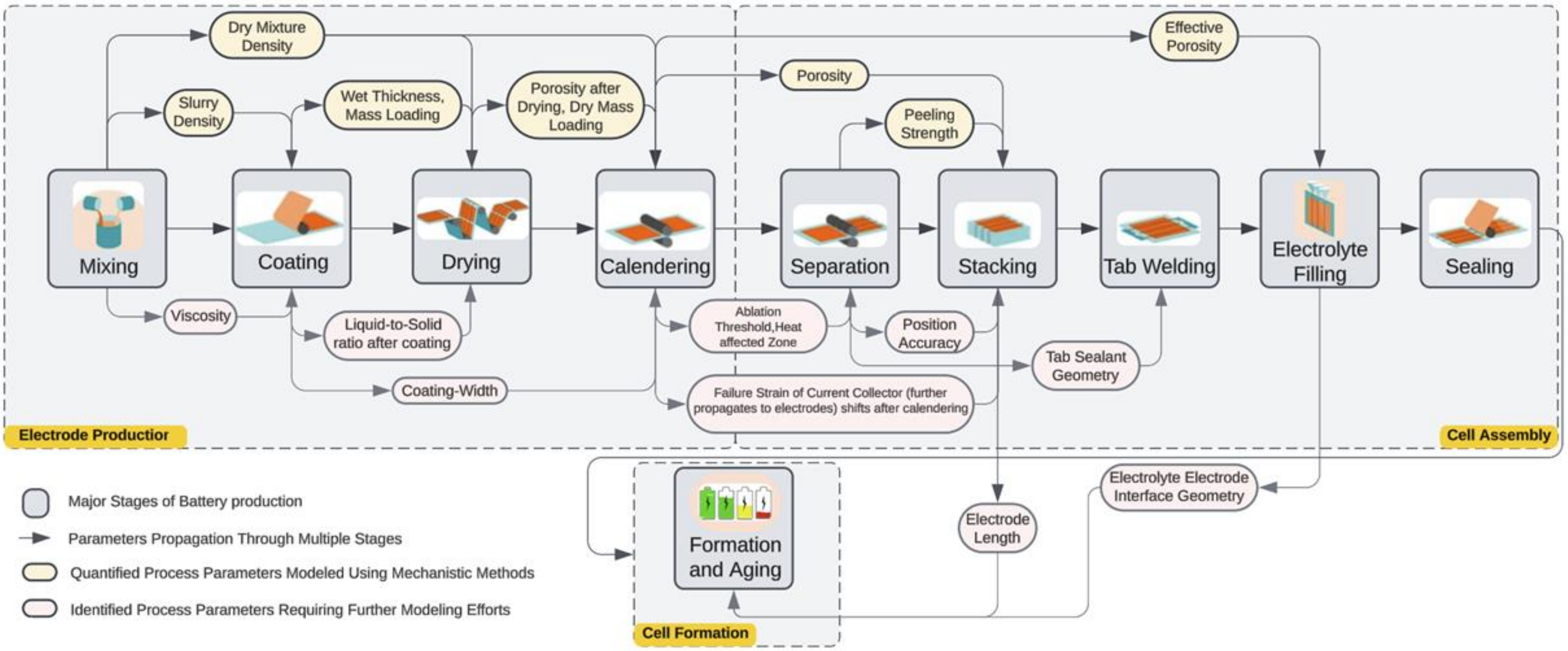
Process-chain map, highlighting key parameters propagation patterns



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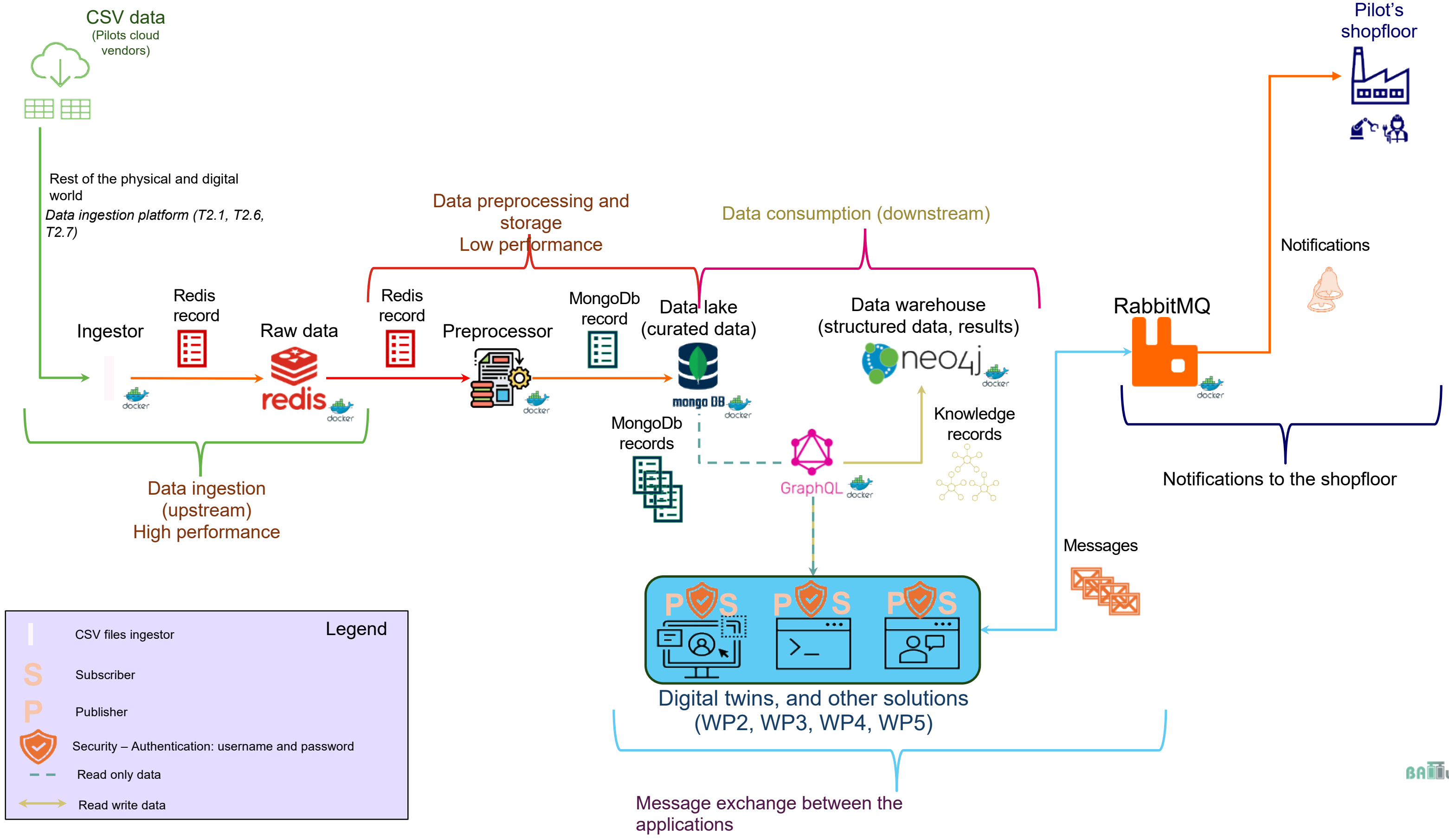
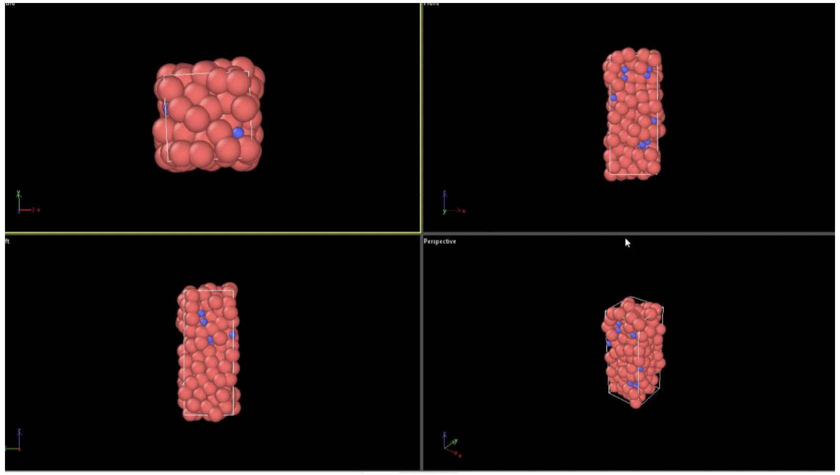
Multi-sensor data gathering and acquisition system architecture

<u>Multi-sensor data gathering and acquisition system architecture</u>, including core services, services interactions, back-end and front-end responsibilities, infrastructure needs, connectors responsibilities, security elements, scalability, integration principles.

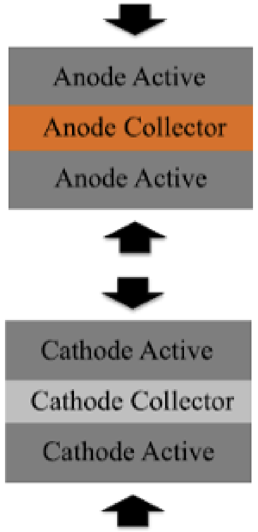


Multi-physics Digital Twin for critical process steps

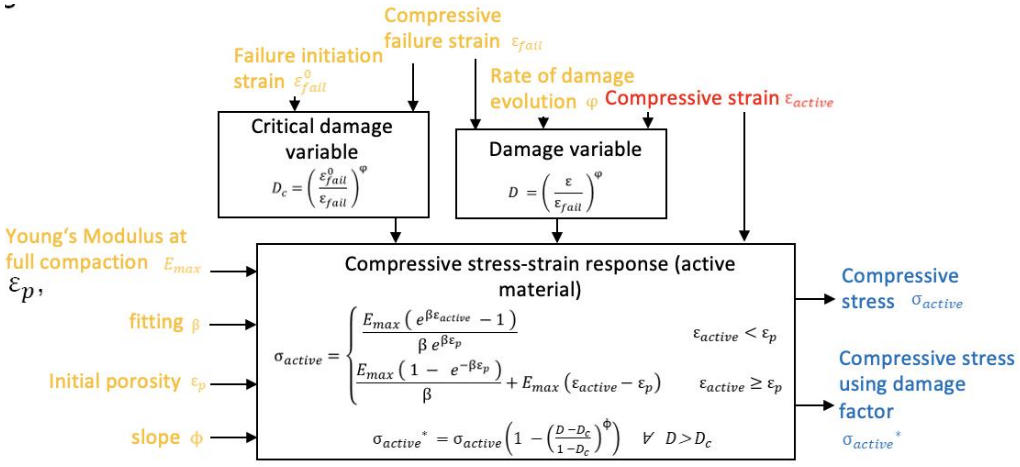
Multi-physics DTs for mixing, stacking, robotic handling and formation is ongoing.

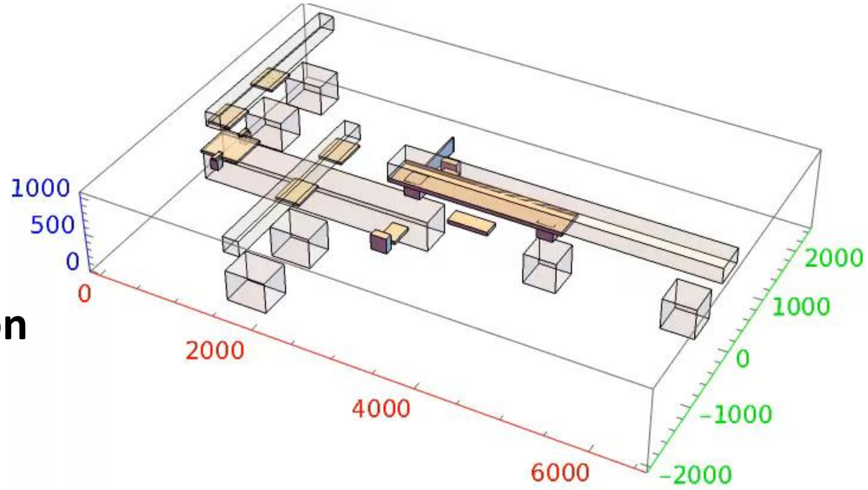


Coarse-Grained Molecular Dynamic Simulations for Mixing Process



Mechanical model of the stacking process





Kinematic simulation of stacking process

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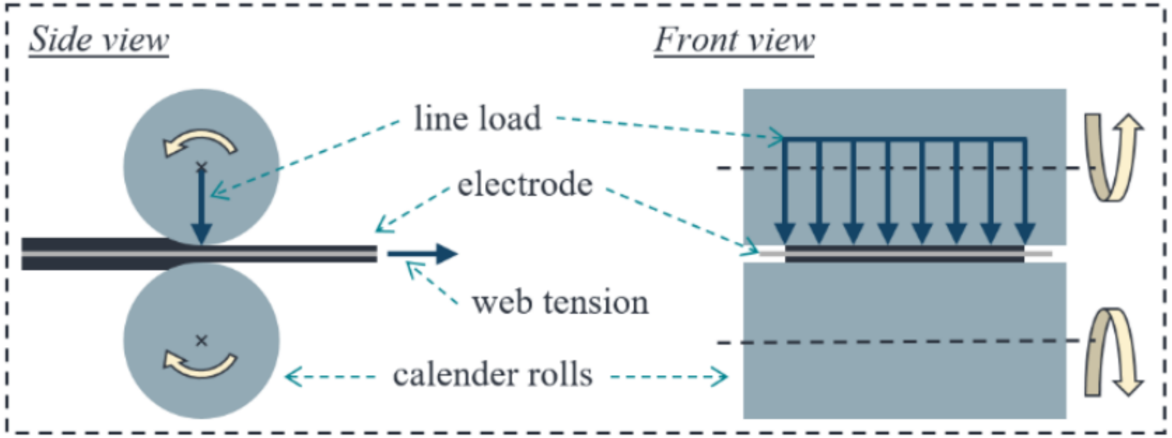
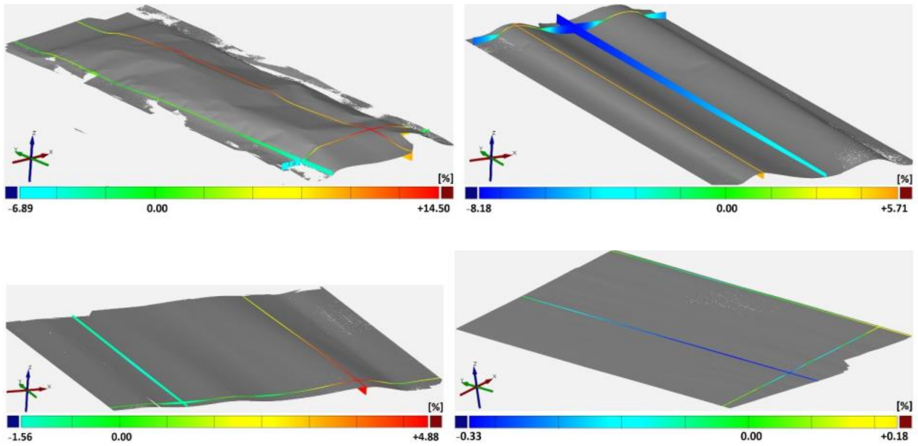
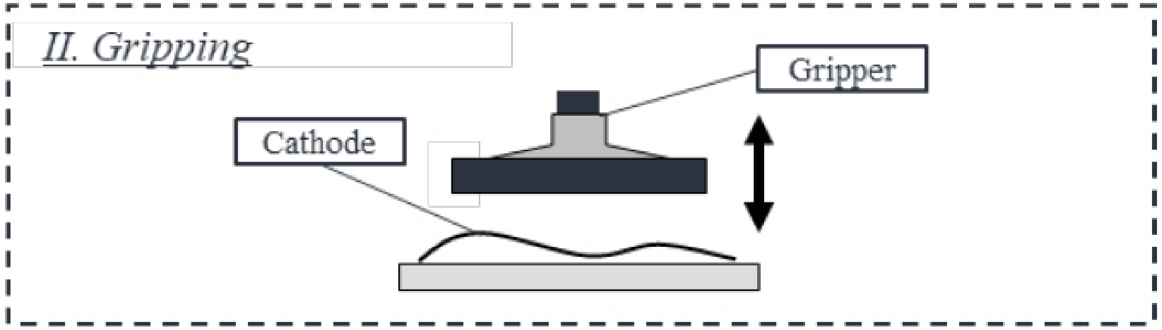
Multi-physics Digital Twin for critical process steps: feed-forward control example





Effect of web tension in calendaring on electrode geometry



The **actual** gripping

Mayer, D., & Fleischer, J. (2021). Concept for modelling the influence of electrode corrugation after calendering on stacking accuracy in battery cell production. *Procedia CIRP*, *104*, 744–749. https://doi.org/10.1016/j.procir.2021.11.125

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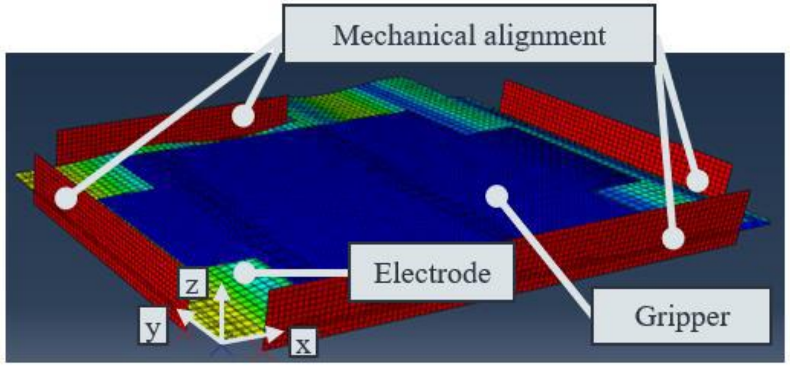
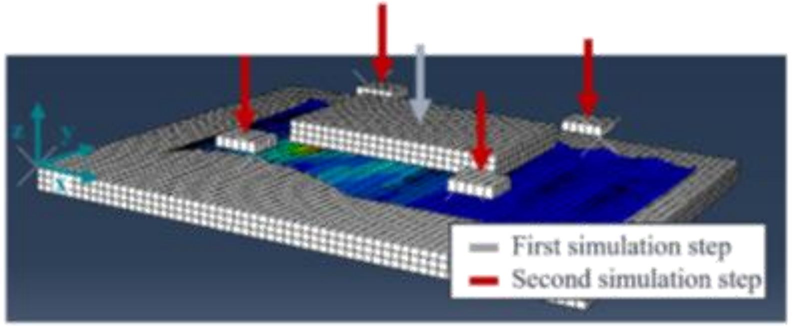
Multi-physics Digital Twin for critical process steps: feed-forward control example

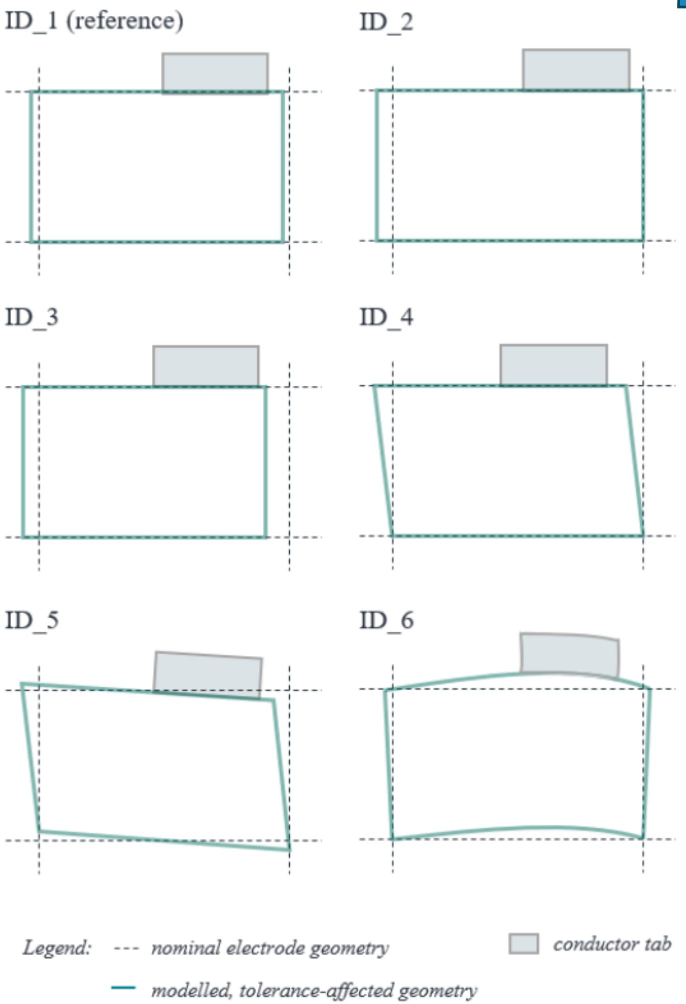
Mayer, D., Maier, T., & Fleischer, J. (2023). Simulation of the stacking process in battery cell manufacturing. *Procedia CIRP*, *120*, 1393–1397. https://doi.org/10.1016/j.procir.2023.09.182

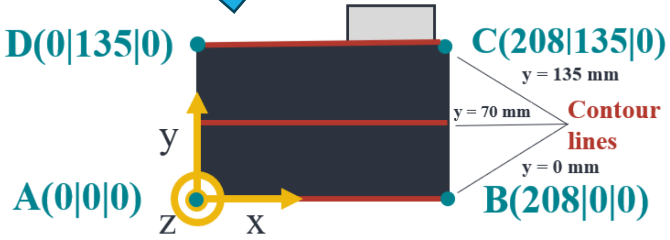


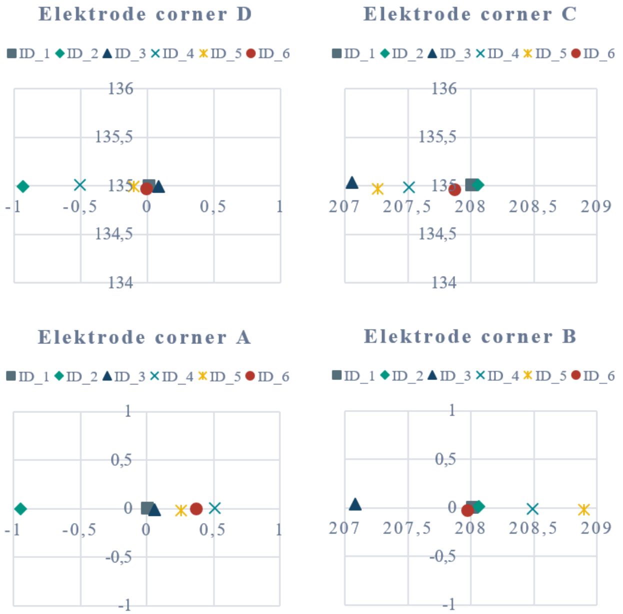


Expected deformation of electrode geometry

Displacement in stacking







Displacement of corner points in x- and y- axis

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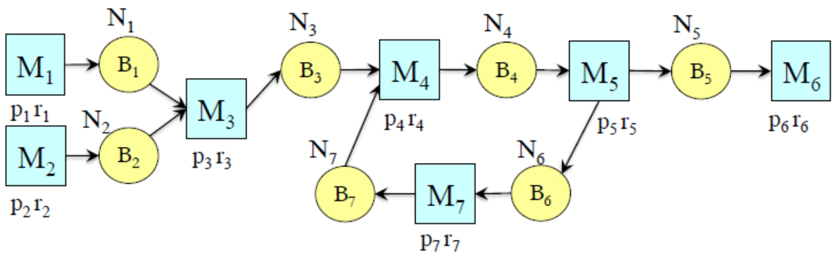
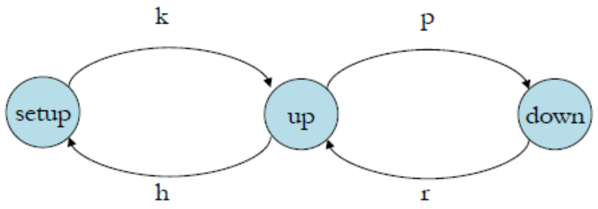
Digital Twin at system level: models and digital tools

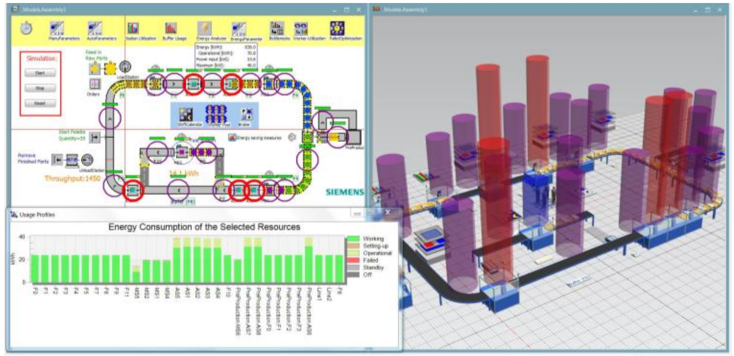
System-level modeling goal: To evaluate the main system performance measures, such as throughput, system yield, effective throughput, average wip, operational costs (if cost parameters are associated to system states).



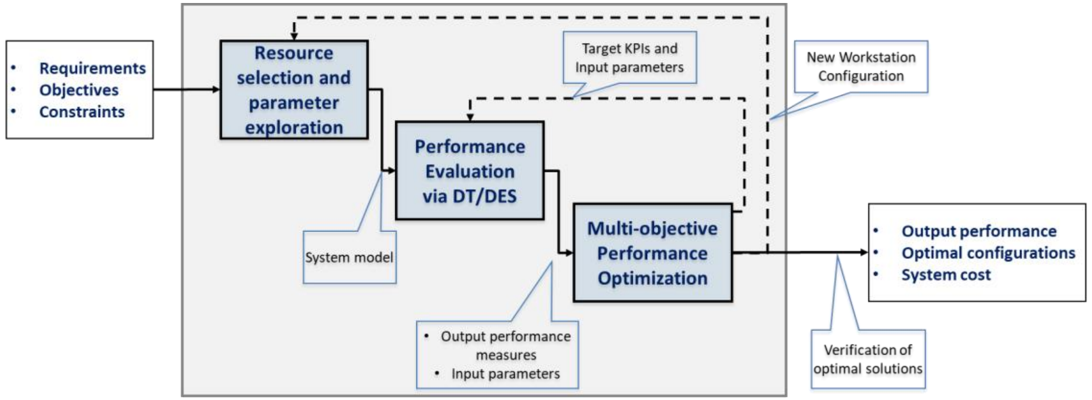
Approximate analytical model
(Faster, pre-filtering of scenarios)

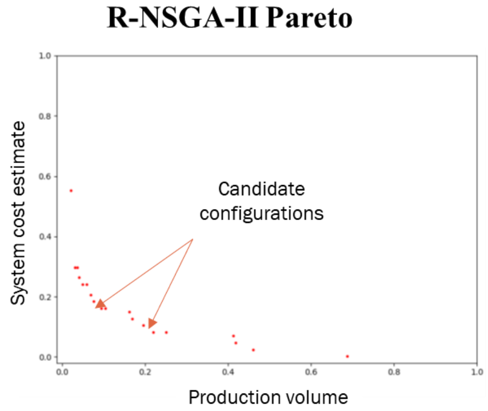


State-based modelling of Resources



Discrete Event Simulation
(Lower error in performance measure, in-depth analysis)





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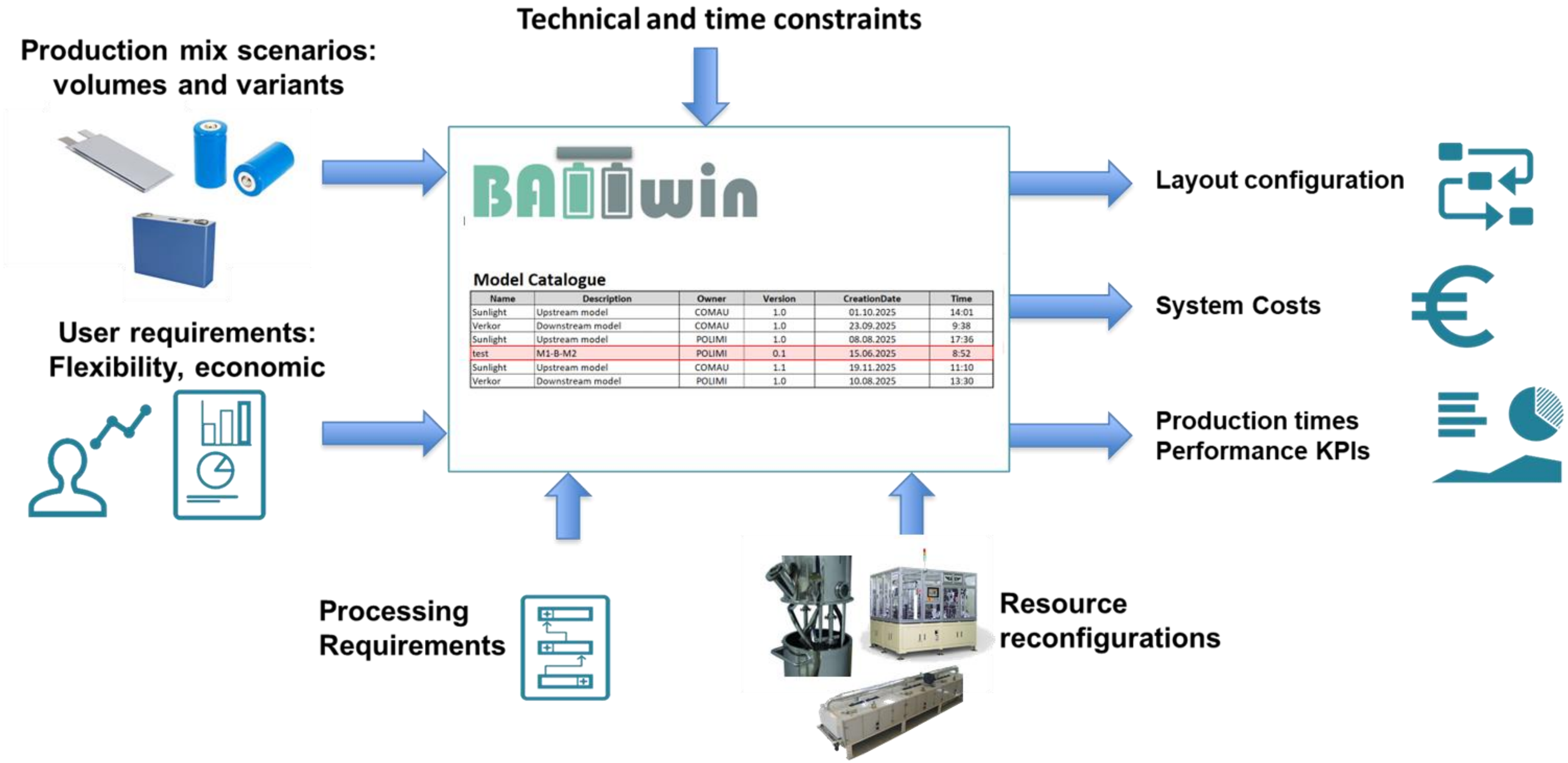
Digital Twin at system level: Green field design

System-level DTs can support the green-field design stage, for example in the scale-up from pilot to giga-factory volumes. Typical problems: buffer allocation, parallel machines sizing, inspection and rework allocation.



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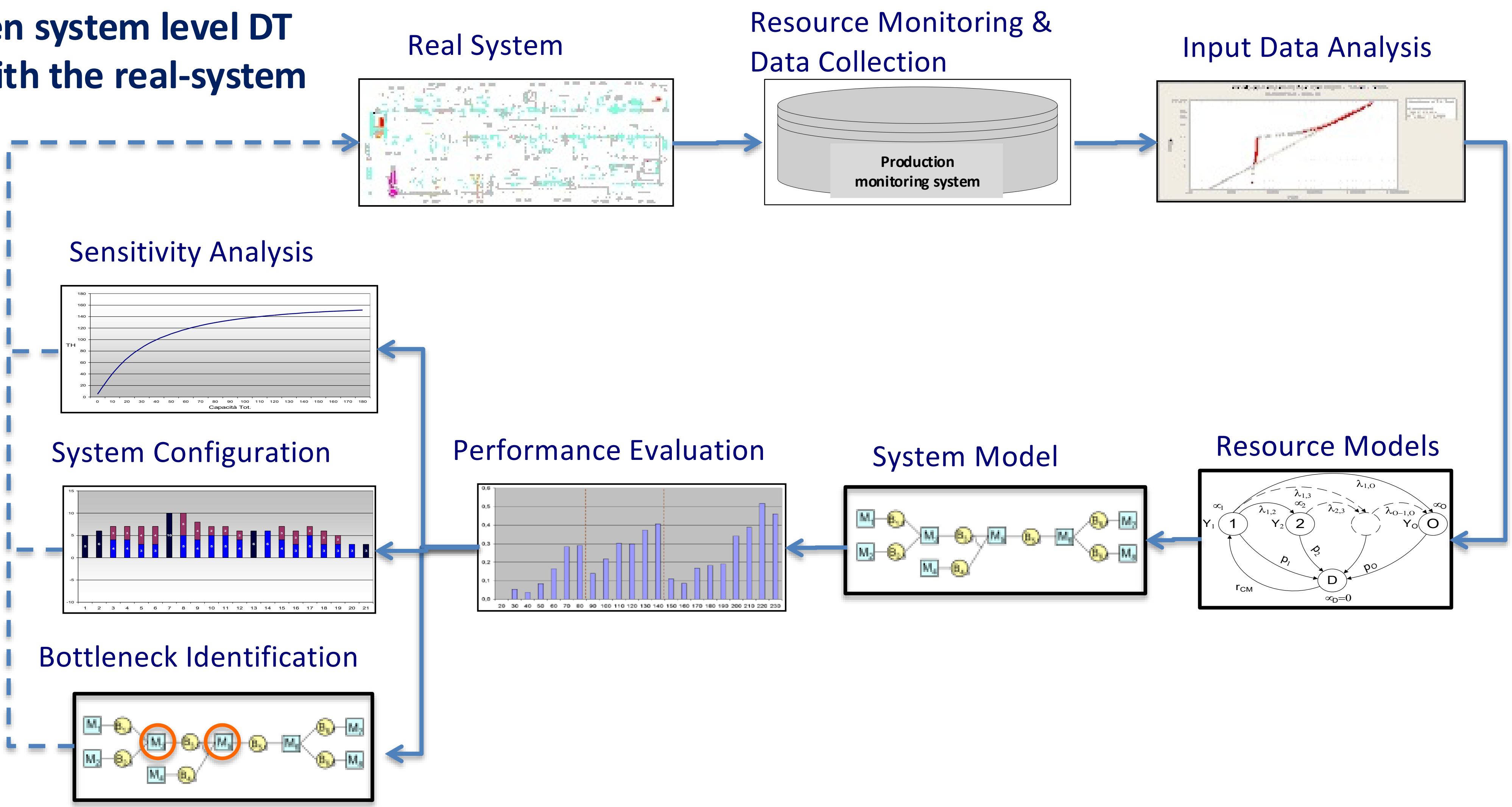
Digital Twin at system level: reconfiguration and continuous improvement

Data-driven system level DT coupling with the real-system



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User-centric workflow integration

BATTwin

Pilot needs
Industrial partners
SUNLIGHT
VERKOR
From WPs 1 & 6
industrial lines
user targets
quality constraints

GUI
BATTwin GUI platform
task-specific views
user inputs
results

Data bases
Data management layer
database / files / metadata / experiment records
redis
mongo DB
From WP2
database · files
metadata · records ·
Redis/MongoDB

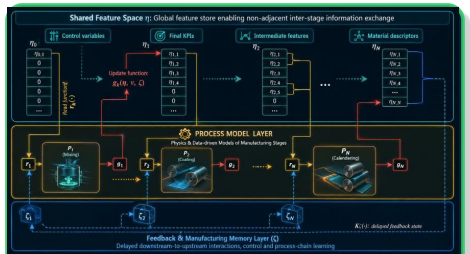
Cyber security
T5.7/8
Access control · input validation · anomaly detection · data integrity · communication monitoring

Orchestration layer
Orchestration layer
Python / PyAnsys / FMU-ready execution
Ansys
Ansys web app
Python · Ansys ·
FMU-ready execution
analysis request
→ **result**

task-specific support technologies: **machine · process · control · system design · planning** **industrial decision support**

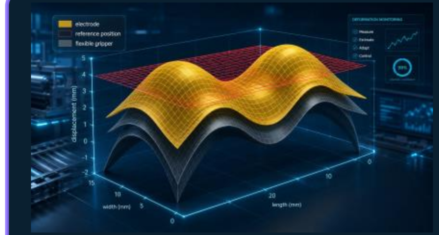
T5.2 Machine twin
CAD + motion + physics models for virtual commissioning.

Shorter ramp-up



T5.3 Process chain integration & optimisation
Forward analysis & inverse design for
process chain prediction, optimization & scrap mitigation.

Fewer trials / less scrap



T5.4 Adaptive control
Sense → estimate → adapt setpoints under variability.

More robust quality

T5.5 System (re)design
Compare line configurations and Pareto trade-offs before investment.

Resilient layouts

T5.6 Planning & control
Translate scenarios into schedules, resources and maintenance windows.

Less downtime

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User-centric workflow integration

Technical achievements

From individual process models to coupled workflow outputs that engineers can interpret and use.

- **Reusable process-chain execution:**

  Mixing → Coating → Drying → Calendaring → performance KPIs

- **Deterministic forward prediction of**

  manufacturability & *feasibility window* and parameters *traceability* views

- **Sensitivity analysis at**

  (i) local stage level and
  (ii) full-chain process KPI level

- **Probabilistic prediction of**

  confidence intervals, *variability* & *KPI-risk indication*

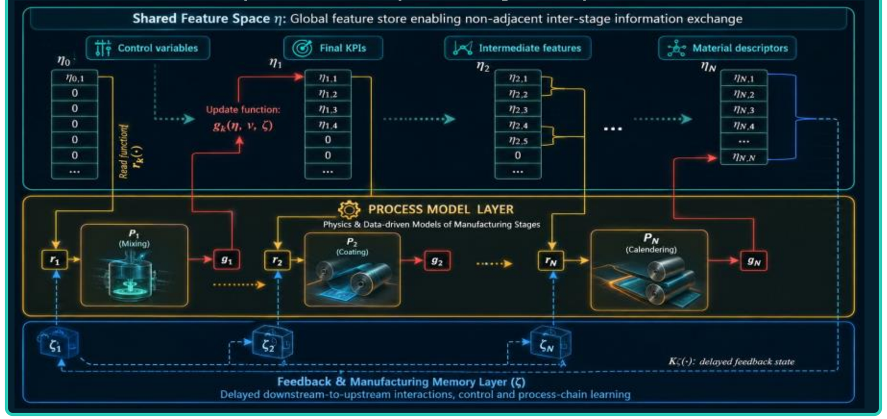
- **Optimizer of**

  feasible process windows,
  Pareto frontiers & trade-offs,
  & *candidate process parameter settings*

Predict

Forward & Inverse chain orchestrator

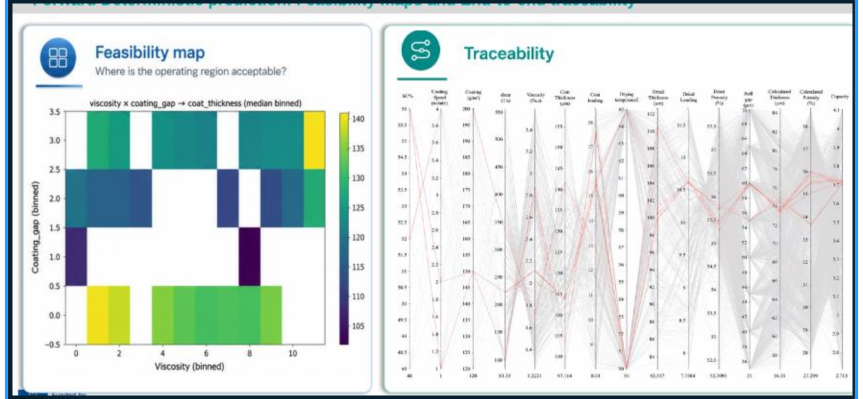
Expected KPI pathway and process-chain



Visualise

Feasibility + traceability analysis

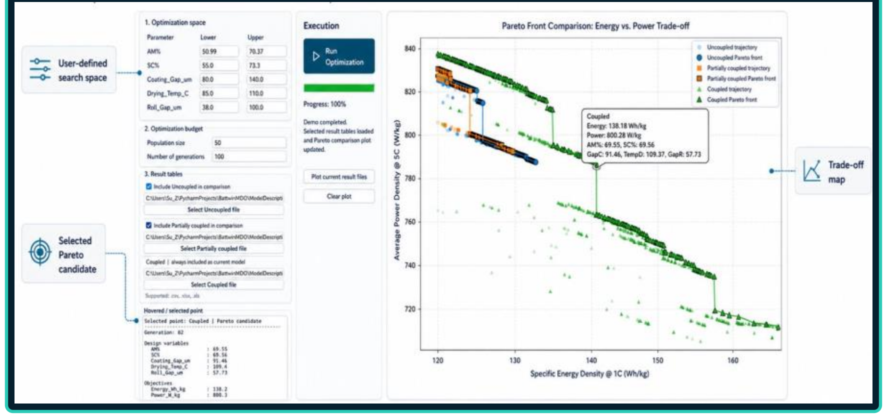
Operating windows and filtered chain



Mitigate

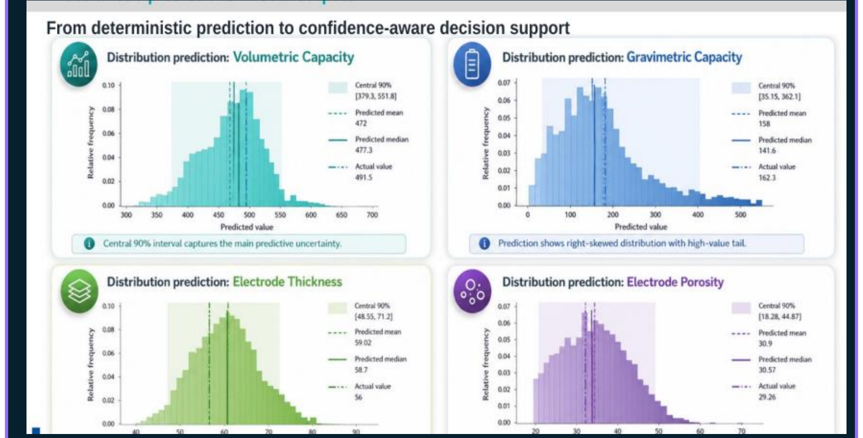
Optimisation and Scrap mitigation

Adjusting Downstream conditions to mitigate effect of faulty



Trust

Probabilistic scrap rate prediction



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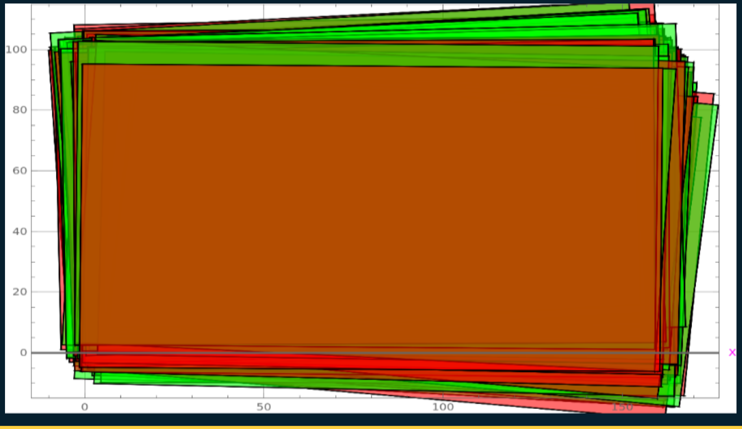
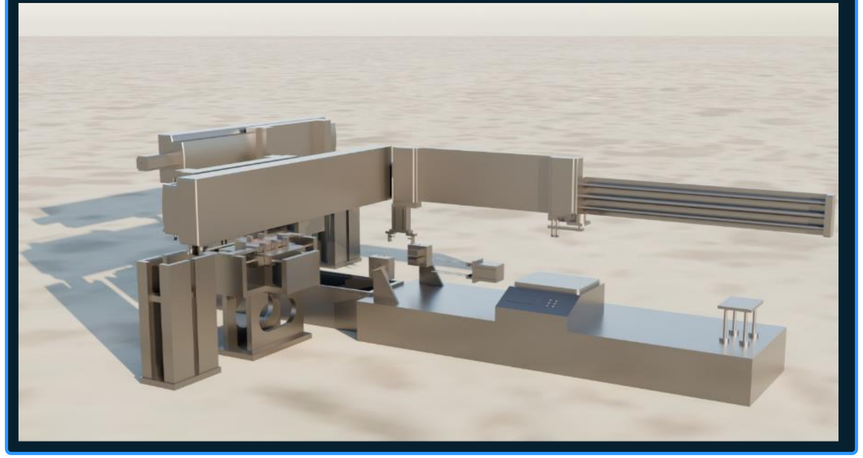
Predict

Error tolerances for stacking precision



Control

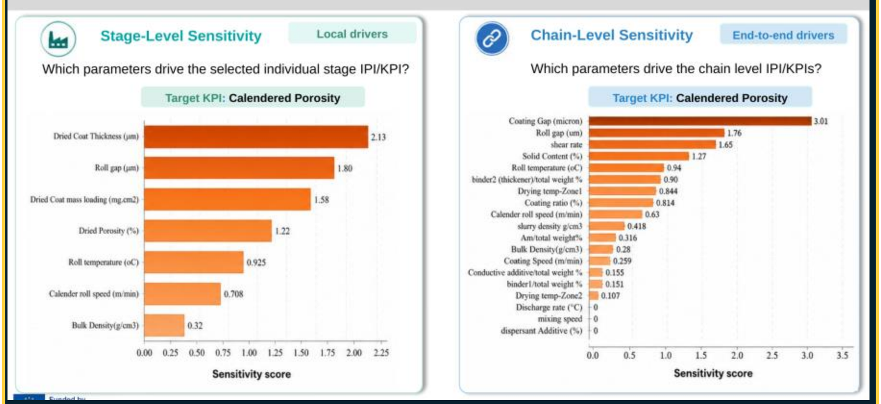
Stacking Machine Twin



Explain

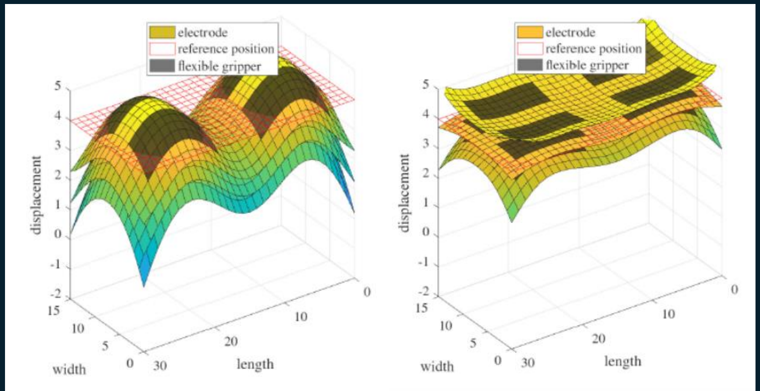
Sensitivity / key drivers

Local drivers versus end-to-end KPI drivers



Control

Electrode deformation & gripper control



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Flexible and scalable digital-twin platform for enhanced production efficiency and yield in battery cell production lines

Thank you!

Project Coordinator, Prof. Marcello Colledani
Politecnico di Milano, Department of Mechanical Engineering

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