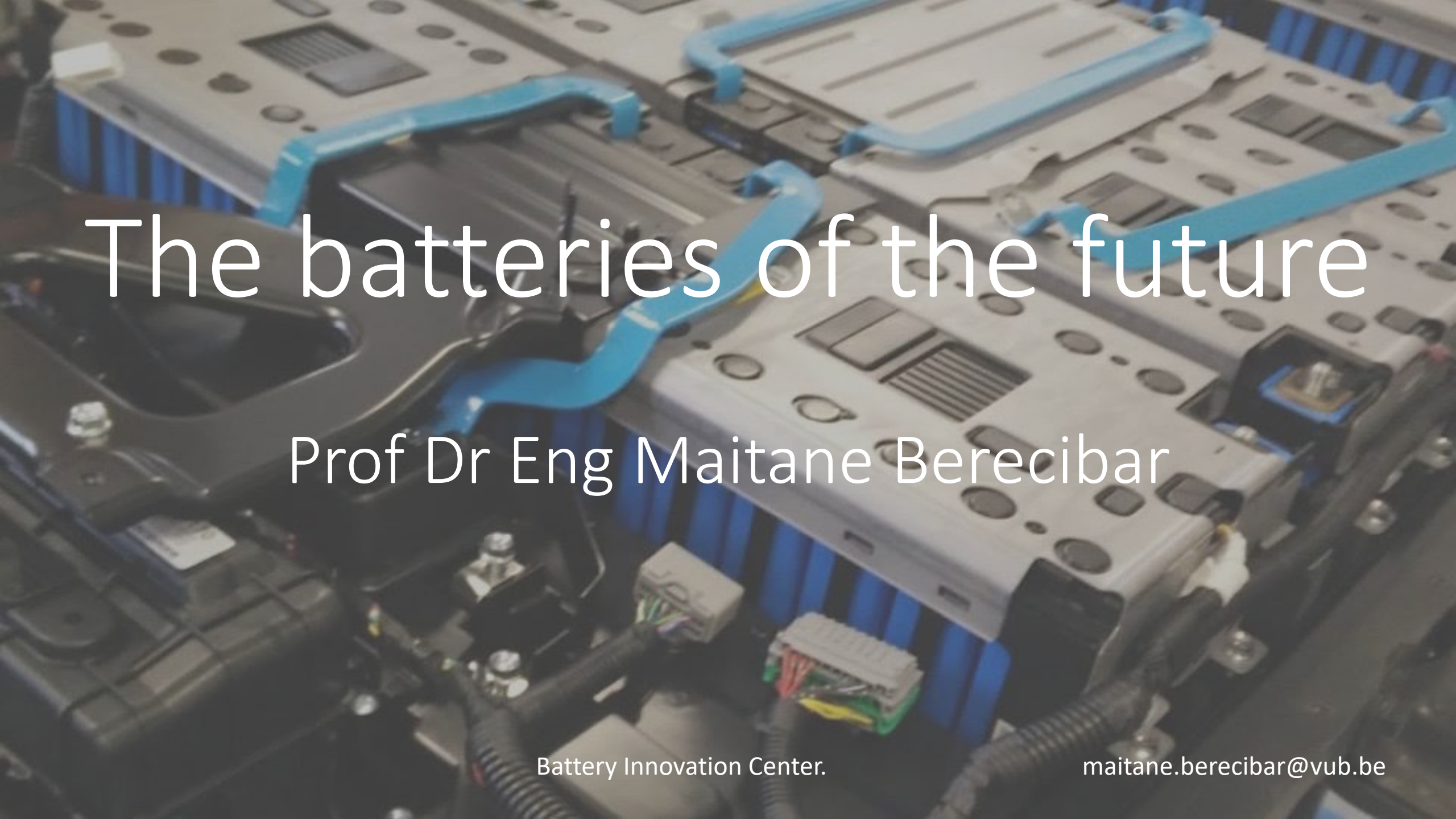

The batteries of the future

Prof Dr Eng Maitane Berecibar

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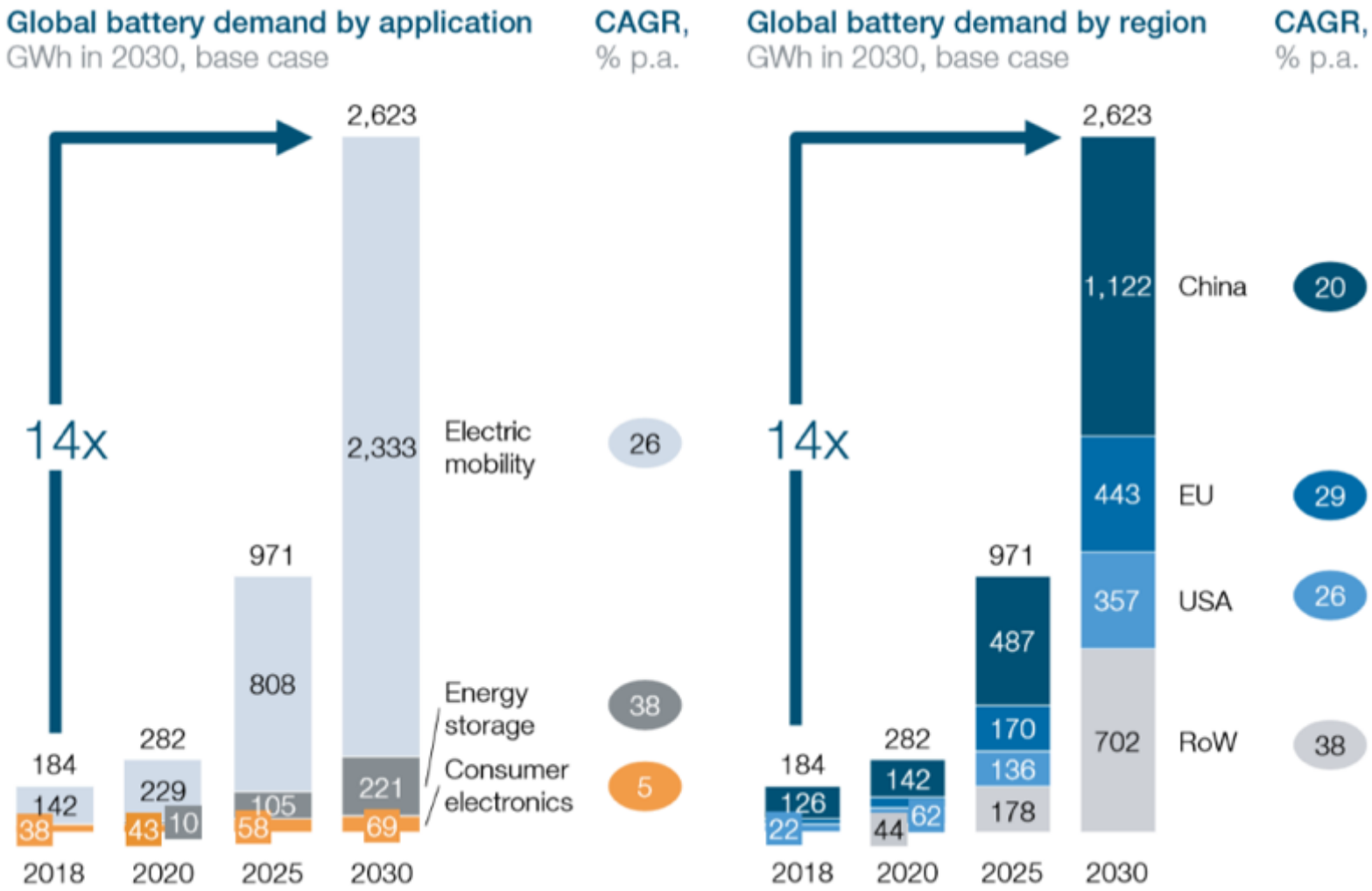
Expected growth in global battery demand by application (left) and region (right).



Battery2030+ Roadmap, March 2020

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Battery technology - Today

Type	Chemistry	Performance						Main Applications						
		Energy	Power	Calendar Life	Cycle Life	Safety/Stability	Cost	Consumer Electronics	Power Tools	Light Duty Vehicles	Cars	Trucks/ Commercial Vehicles	Buses	Grid
LFP (Lithium Iron Phosphate)	$LiFePO_4$	++	++	++	++	+++	+	•	•	•	•	•	•	•
NCA (Lithium Nickel Cobalt Aluminium Oxide)	$LiNiCoAlO_2$	+++	+++	++	++	+	+	•		•	•			•
LMO (Lithium Manganese Oxide)	$LiMn_2O_4$	+	+++	-	++	++	++	•	•	•	•			•
LCO (Lithium Cobalt Oxide)	$LiCoO_2$	++	++	+	+	+	+	•						
LTO (Lithium Titanate Oxide)	$Li_4Ti_5O_{12}$	-	+++	+	+++	+++	-				•		•	•
NMC (Lithium Nickel Manganese Cobalt Oxide)	$LiNi_xCo_xMn_xO_2$	+++	++	++	++	++	++	•	•	•	•	•	•	•
HE-NMC (High Energy Lithium Nickel Manganese Cobalt Oxide)	$LiNi_xCo_xMn_xO_2$	++++	++	+	+	-	++	•	•	•	•	•	•	•
HVS (High Voltage Spinel) *	$LiMn_{1.5}Ni_{0.5}O_4$	++++	++	+	+	-	+	•	•	•	•	•	•	•
Solid State**		++++	++	++	-	+++	++	•	•	•	•	•	•	•

* currently at TRL6-7
** currently at TRL4-5

Roadmap EMIRI

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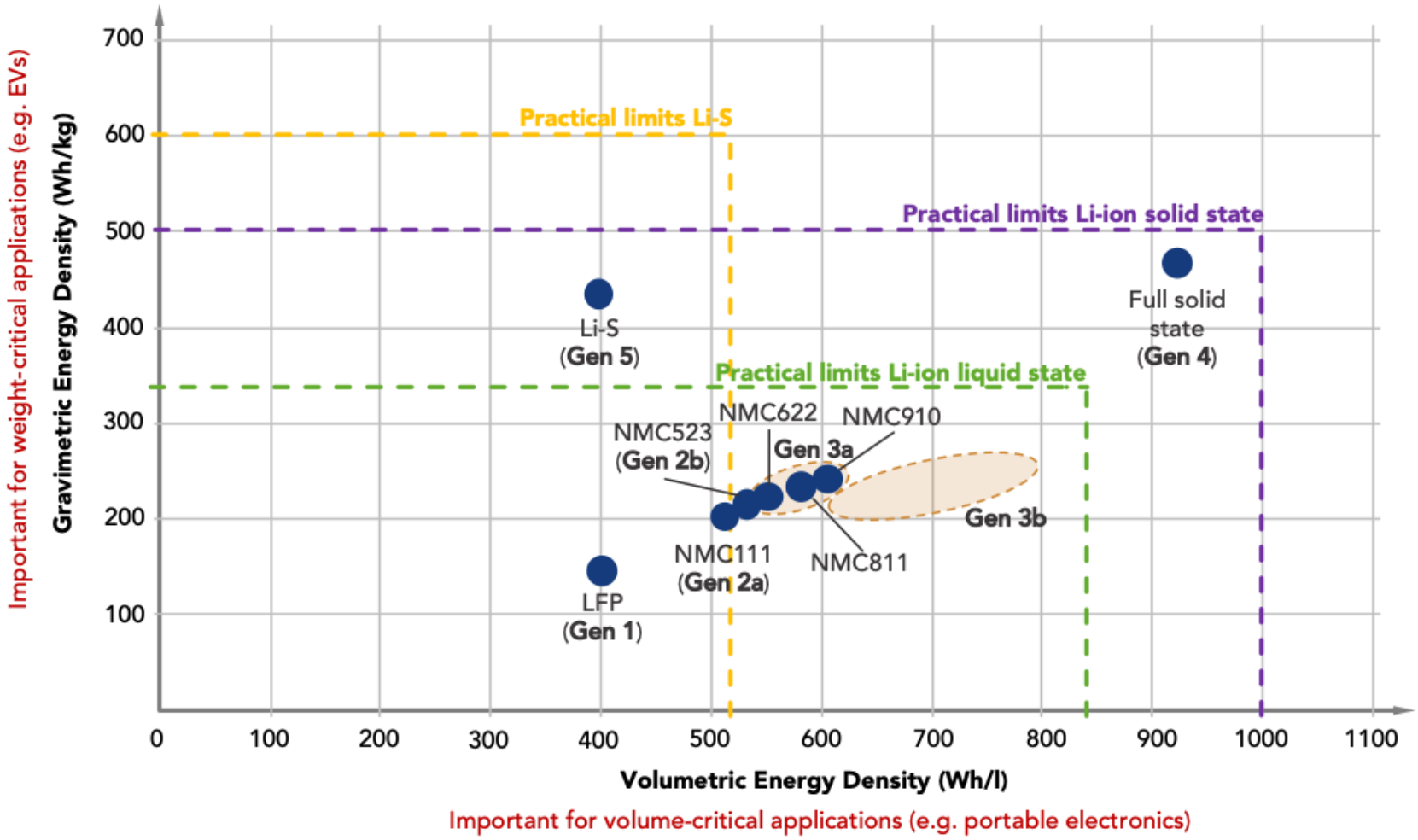
Battery technology – Next Gen



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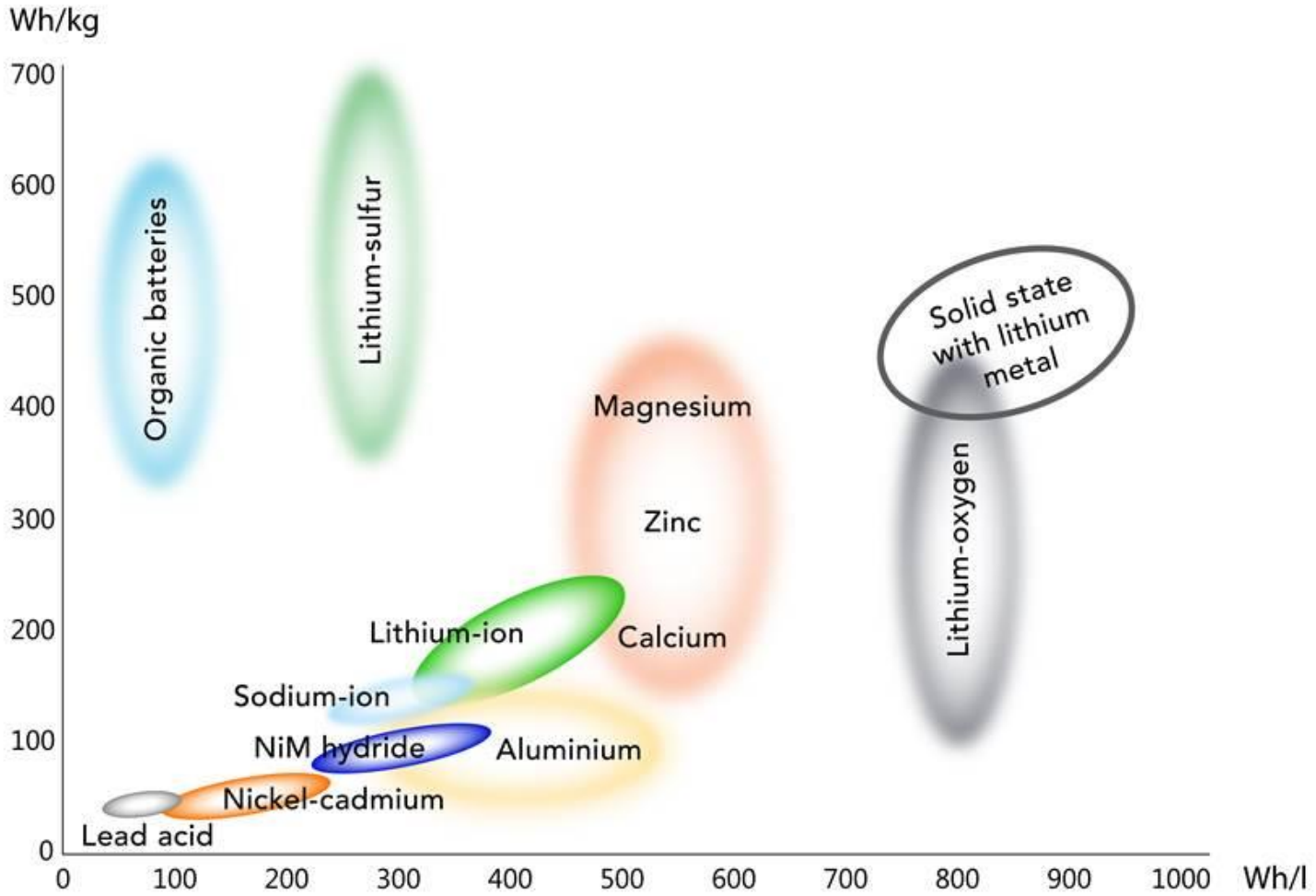
Battery technology – Future



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Solid State

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empowering research

- Development of a **functional** (intergranularly high Li-ion conductive) **coatings**.
- Different compounds
  - **PVDF-HFP based Solid polymer electrolyte** self-standing film
  - **LLZO ceramic filler** added in **Solid polymer electrolyte** to prepare the Composite solid polymer electrolyte

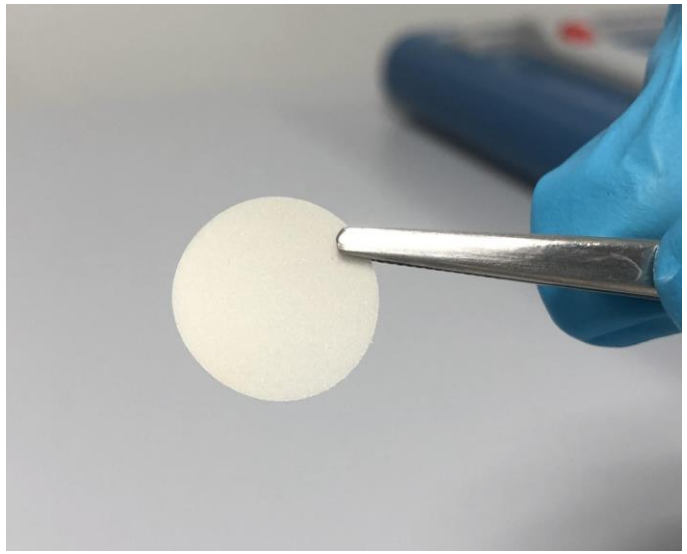

Figure : PVDF-HFP/LiTFSI based solid polymer electrolyte (SPE)

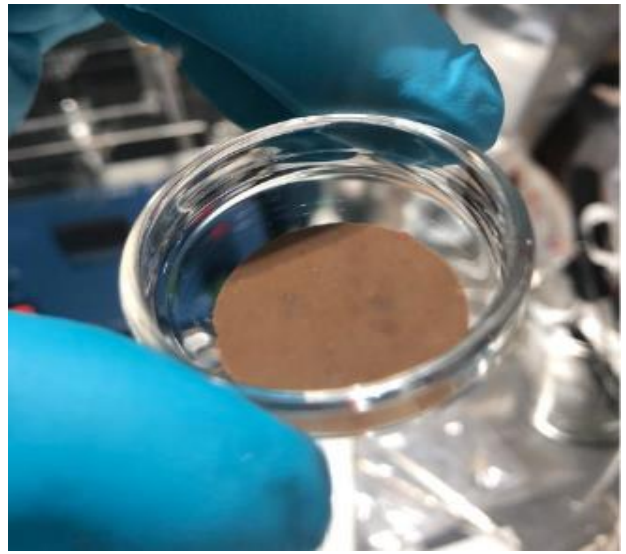

Figure : PVDF-HFP/LiTFSI/LLZO based composite solid polymer electrolyte (CSPE)

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Solid State

AM4BAT

Next-generation lithium-ion batteries will need to offer higher energy and power densities at a lower cost.

the aim is to develop a high-performance battery with **energy density of 400 Wh/kg** for electric vehicles through the use of **innovative manufacturing techniques and 3D printing**.

AM4BAT outcomes will contribute to the creation of a sustainable European **battery manufacturing** value chain, helping the EU to succeed in the **electric mobility rollout.**

https://cordis.europa.eu/project/id/101069756

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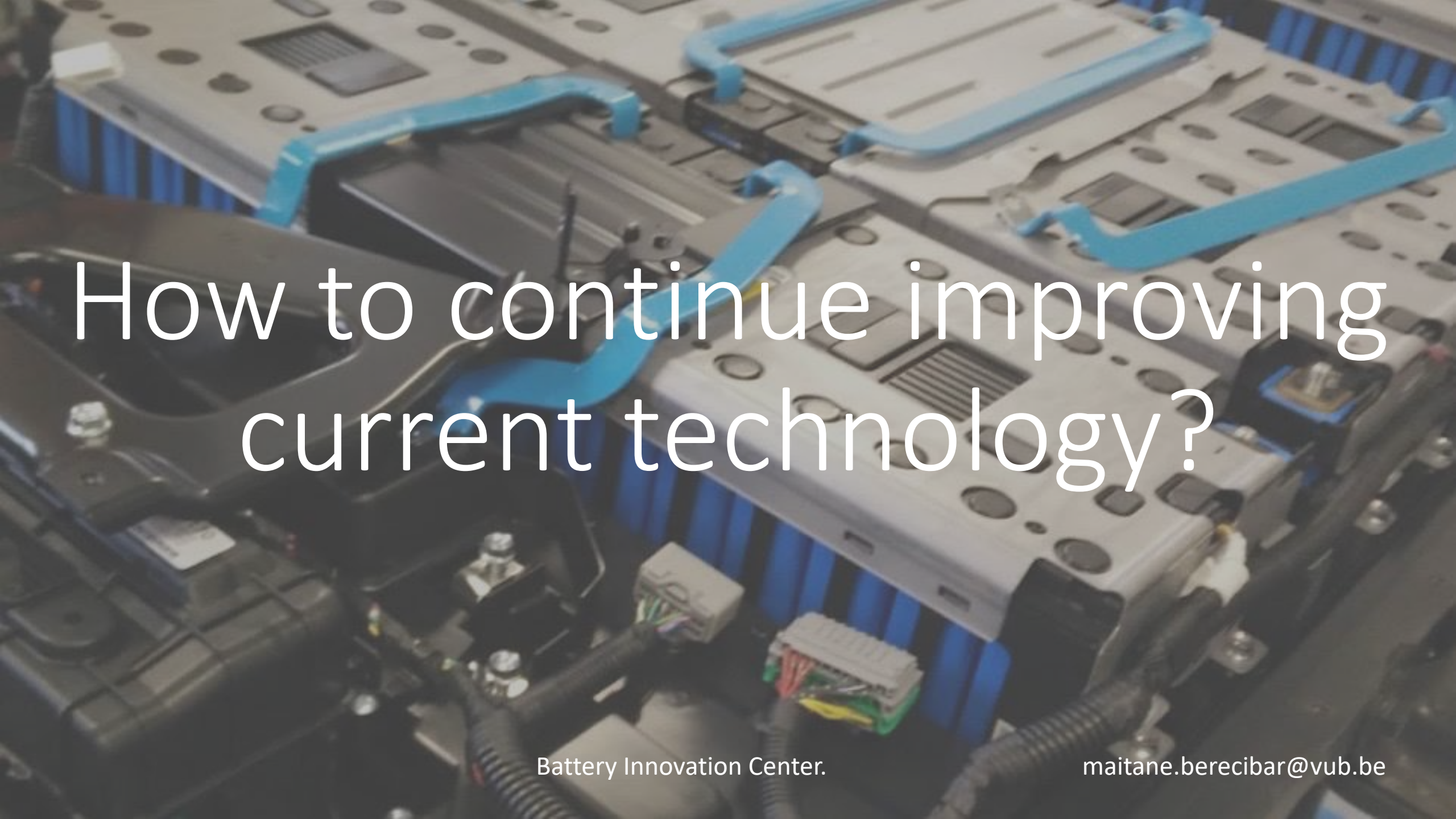

How to continue improving current technology?

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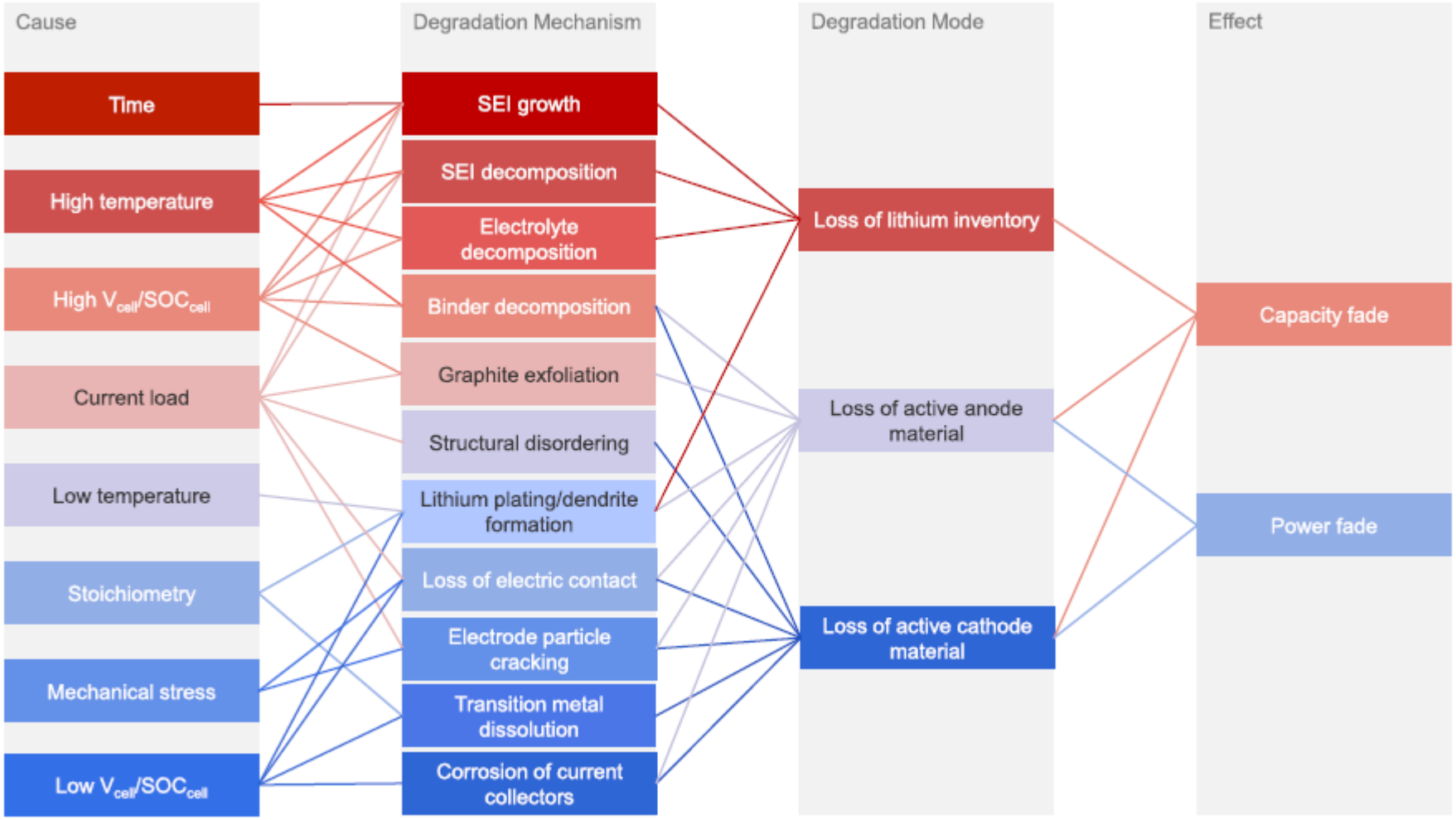
Battery Degradation



Birkl, Christoph & Roberts, Matthew & McTurk, Euan & Bruce, Peter & Howey, David. (2017). Degradation diagnostics for lithium ion cells. Journal of Power Sources. 341. 373-386. 10.1016/j.jpowsour.2016.12.011.

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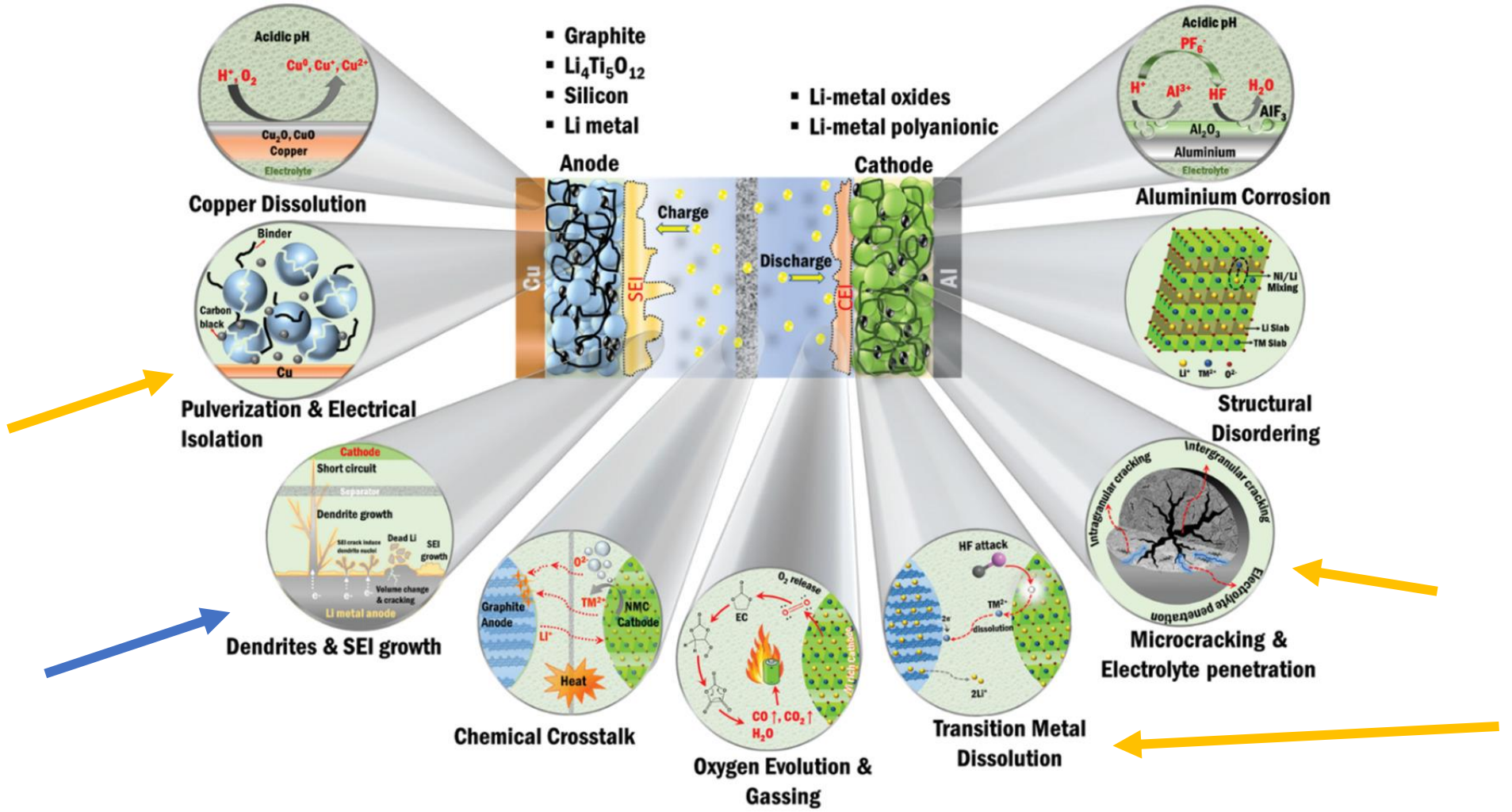
Battery Degradation



Ref: [Self-Healing: An Emerging Technology for Next-Generation Smart Batteries - Narayan - 2022 - Advanced Energy Materials - Wiley Online Library]

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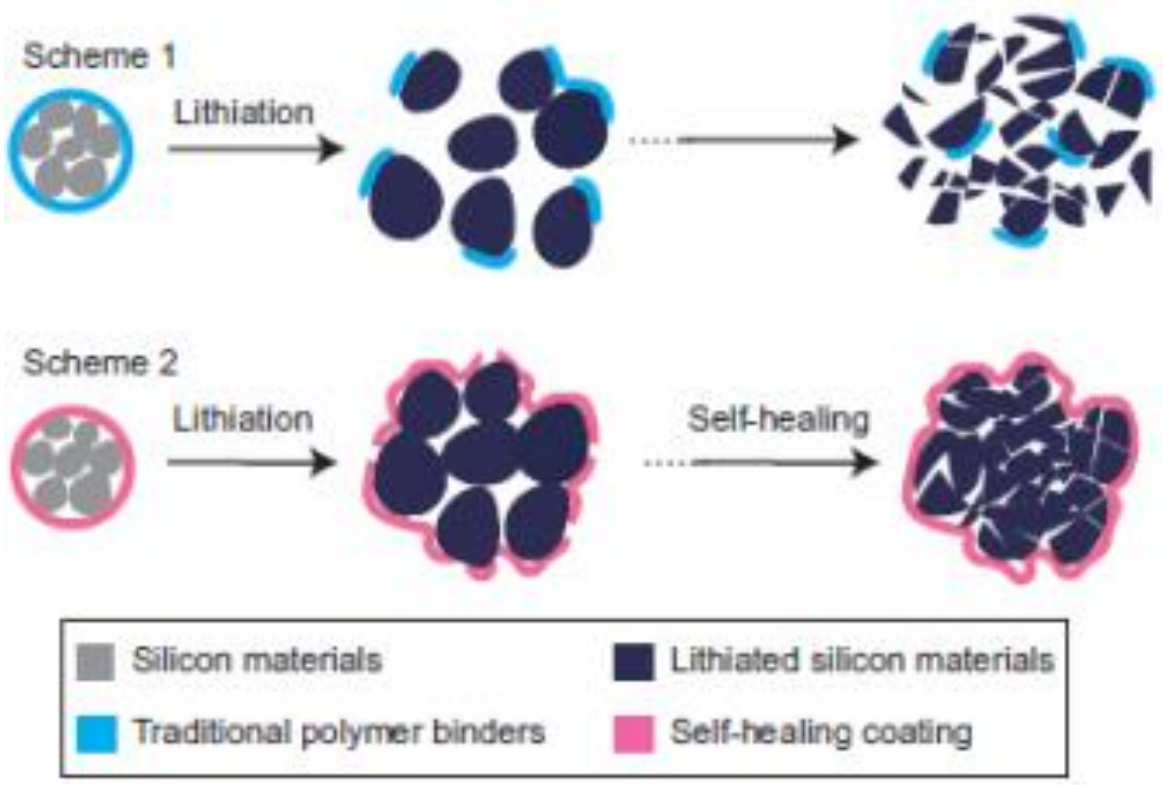
Self Healing

- Design and structure of a self-healing silicon electrode



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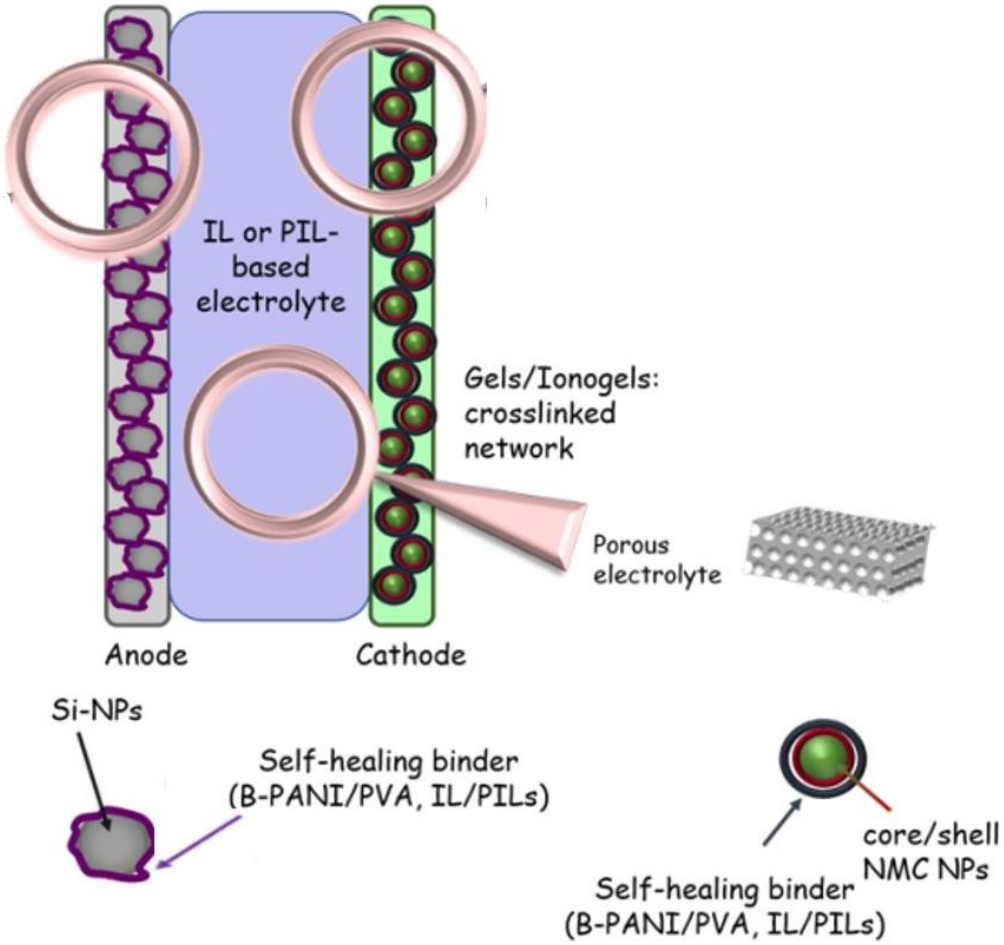
Bat4Ever

BAT4EVER
This project is funded by the European Union

- Silicon Particles Coated with **Self-healing Polymer Binder**
- Embedded into Ionogels as **High-capacitive Anode**
- **High-Energy Cathode** Material of Core-Shell Morphology



https://bat4ever.de/WordPress/

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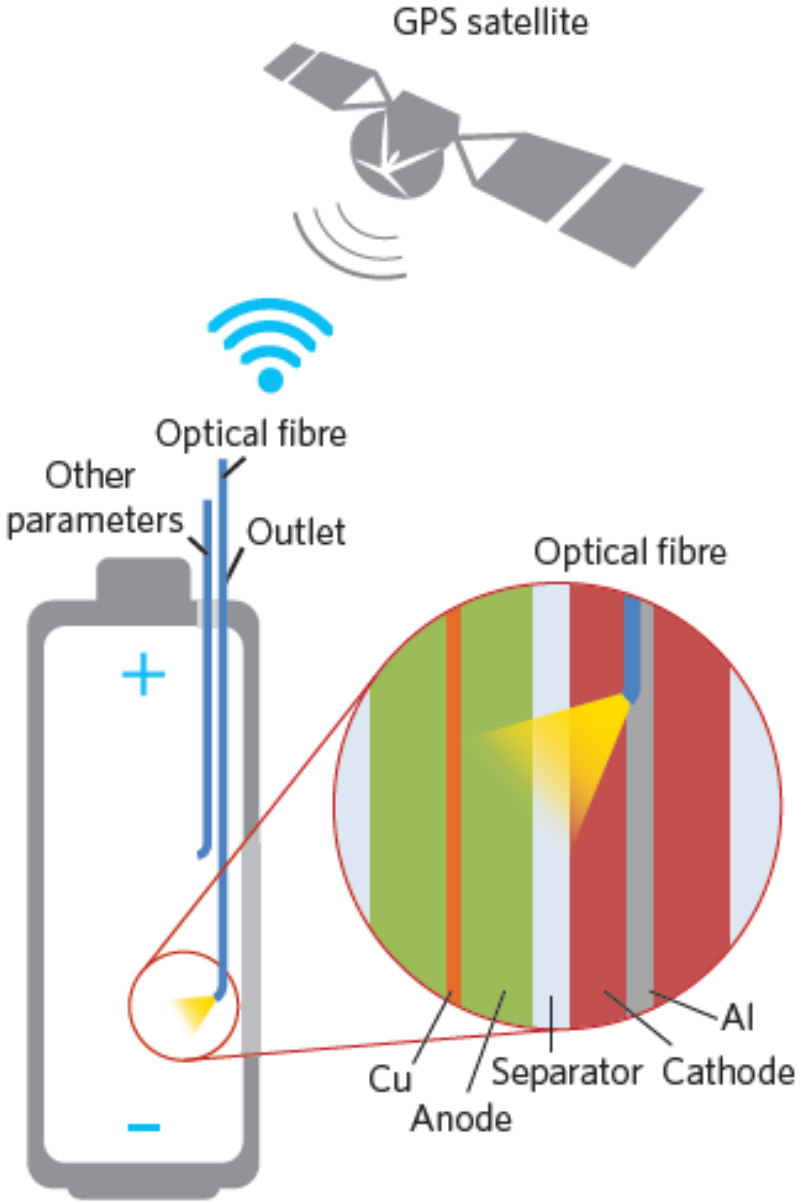
Sensors

A **future battery** with an output analyser connected to sensor (optical fibres, wires, etc.) in addition to the classical positive and negative electrodes.



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Sensors

Phenomena	Electro -chemical	Electrical (T, ε, P)	Acoustics	FBG	TFBG	Fiber spectroscopy
SOC	🟢	🔴	🟡	🟡	🟡	🟡
SOH	🟢	🔴	🟡	🟡	🟡	🟡
Thermal	🔴	🟢	🔴	🟢	🟢	🔴
Strain	🔴	🟢	🟡	🟢	🟢	🔴
Pressure	🔴	🟢	🟡	🟢	🟡	🔴
Crack	🔴	🔴	🟢	🟡	🟡	🔴
Molecules	🔴	🔴	🔴	🔴	🟡	🟢
Safety	🔴	🟡	🟡	🟢	🟡	🟡

Degree of appropriateness: Green, strong; Yellow, medium or to be explored; Red, weak

https://doi.org/10.1016/j.etran.2022.100207

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SPARTACUS

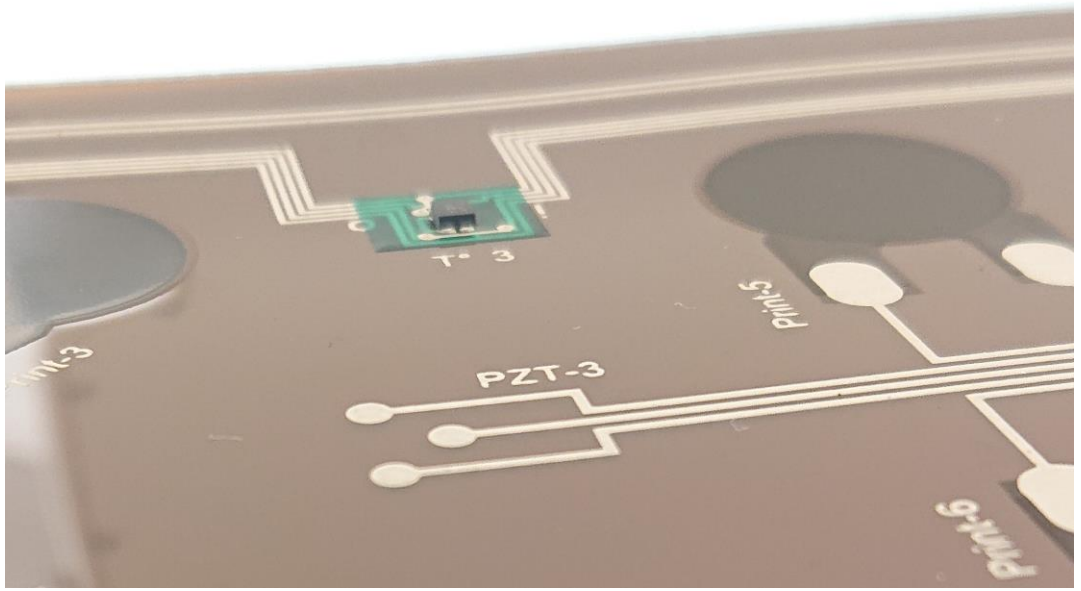
Sensors:

- Mechanical sensors
- Acoustic sensors
- Temperature sensors
- Electrochemical impedance spectroscopy.
- Novel SoX estimation algorithms for new Battery Management Systems

Applications

- Electric mobility (Auto, E-bus)
- Industrial applications
- Portable electronic devices
- Others (Medical devices, power tools, gardening tools, e-bikes, etc.).

https://www.spartacus-battery.eu



© A. Latour, CEA for SPARTACUS
Details of the **printed circuit board** for the battery sensor system with mounted **temperature sensor and printed ultrasonic sensor**s.

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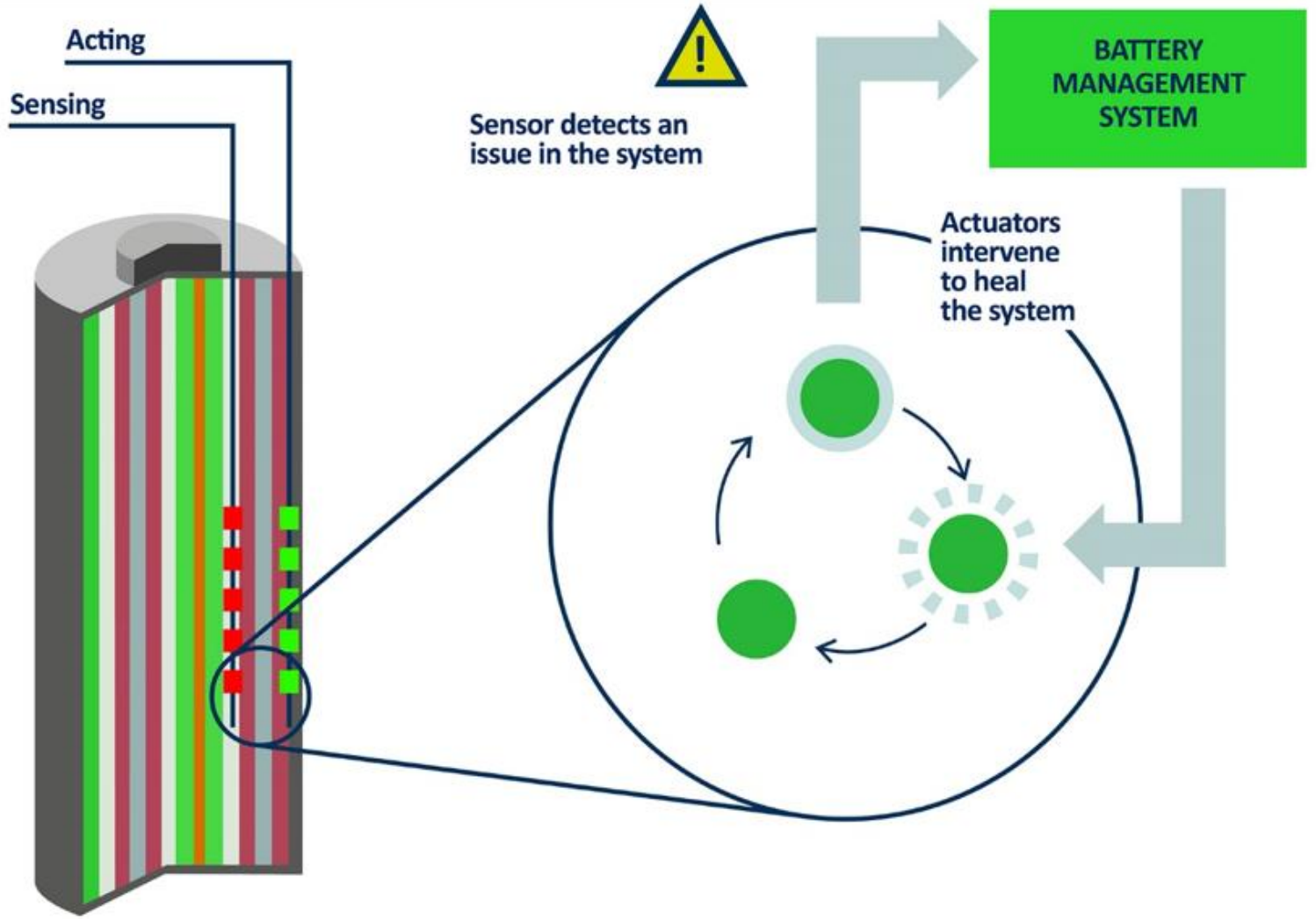
Integration of smart functionalities:

The synergy between **sensing, BMS, and self-healing**.



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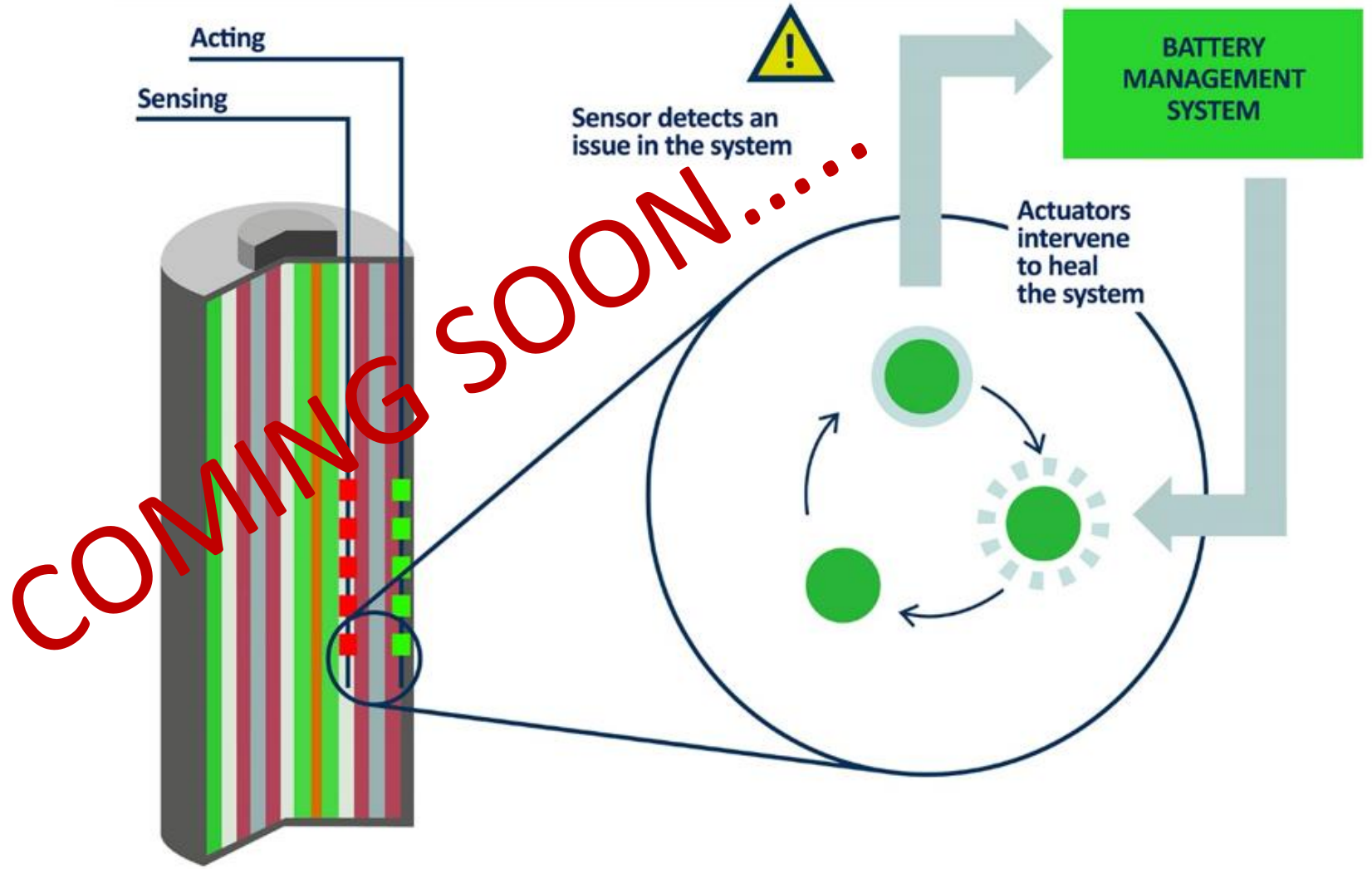
Integration of smart functionalities:

The synergy between **sensing, BMS, and self-healing**.



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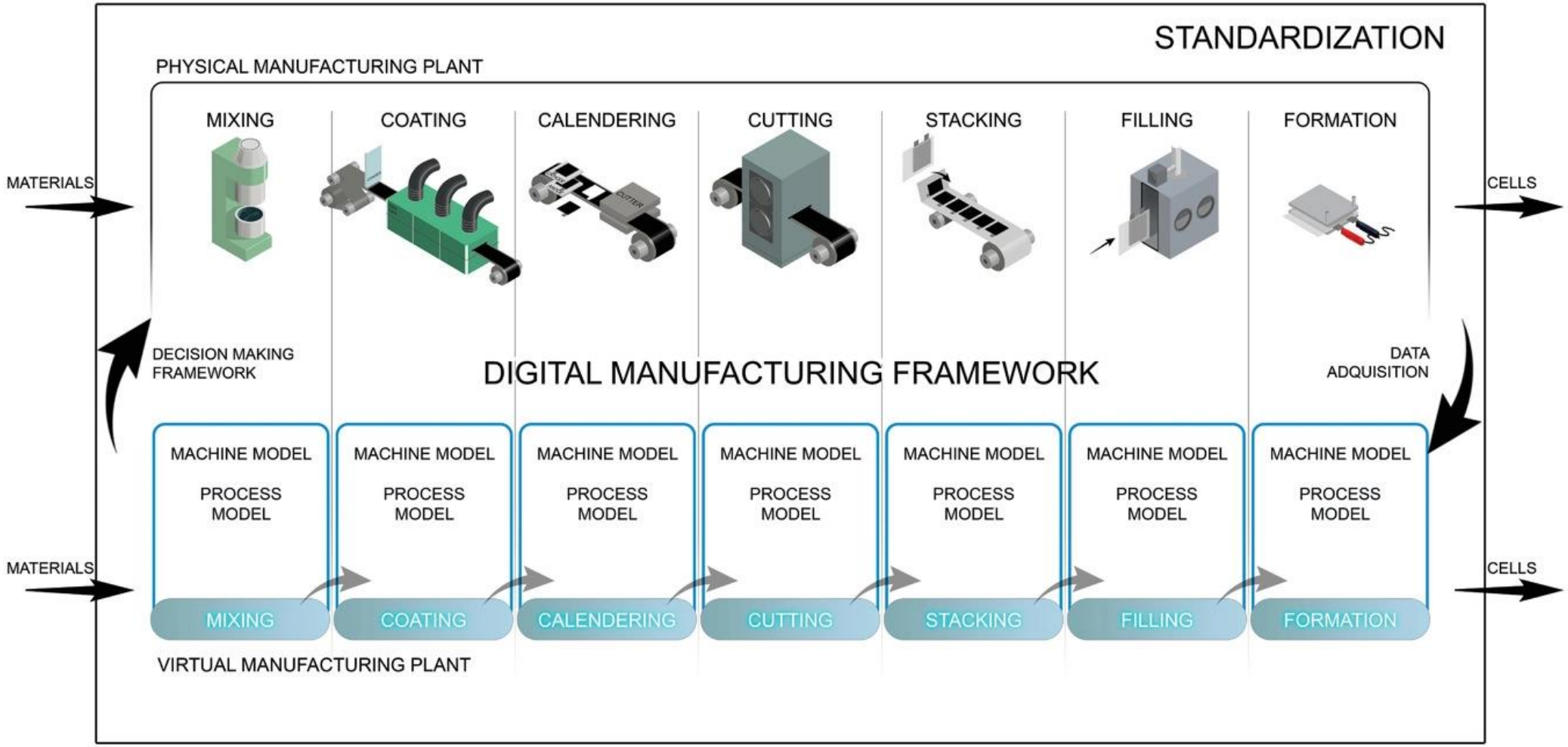
Manufacturing



https://doi.org/10.1002/aenm.202102696

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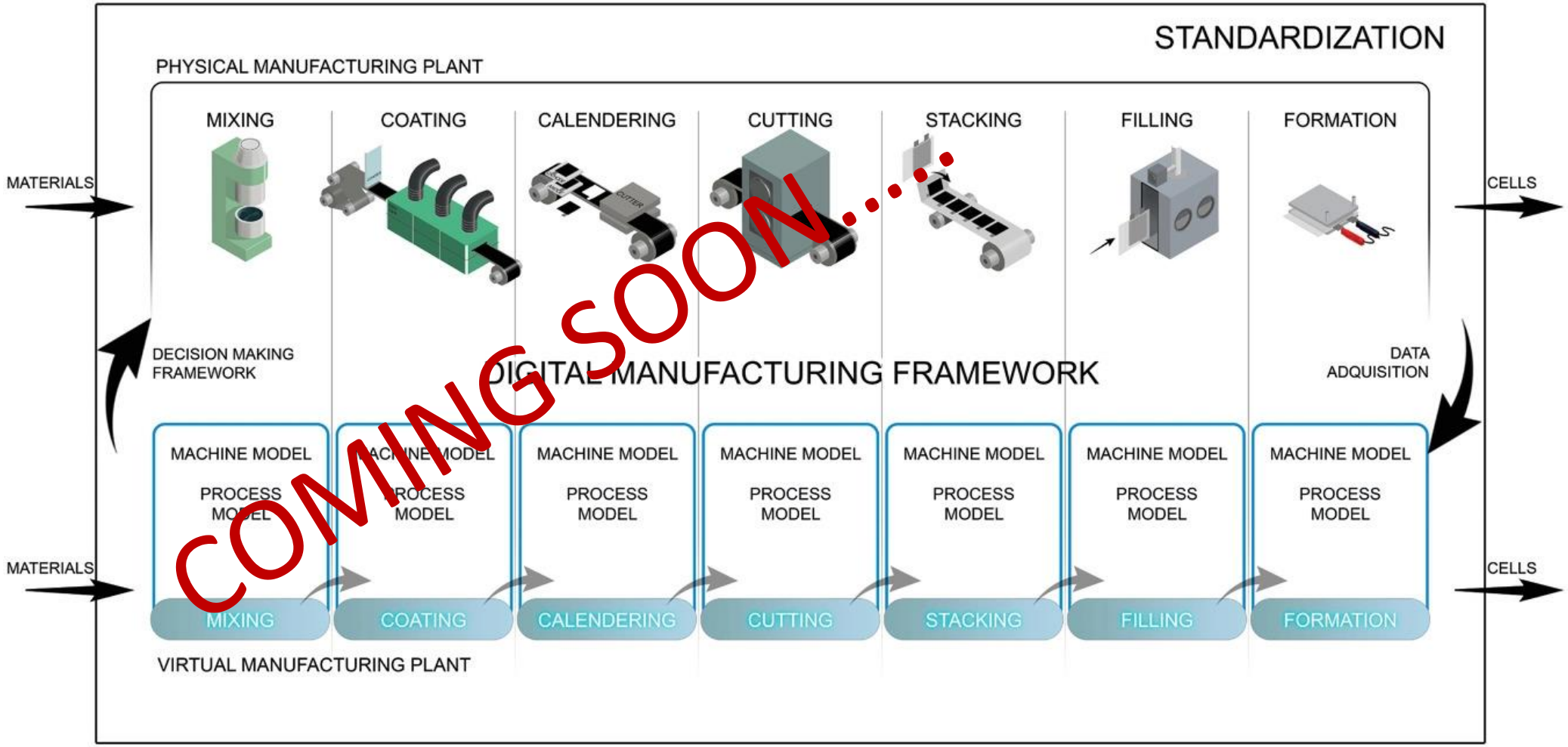
Manufacturing



https://doi.org/10.1002/aenm.202102696

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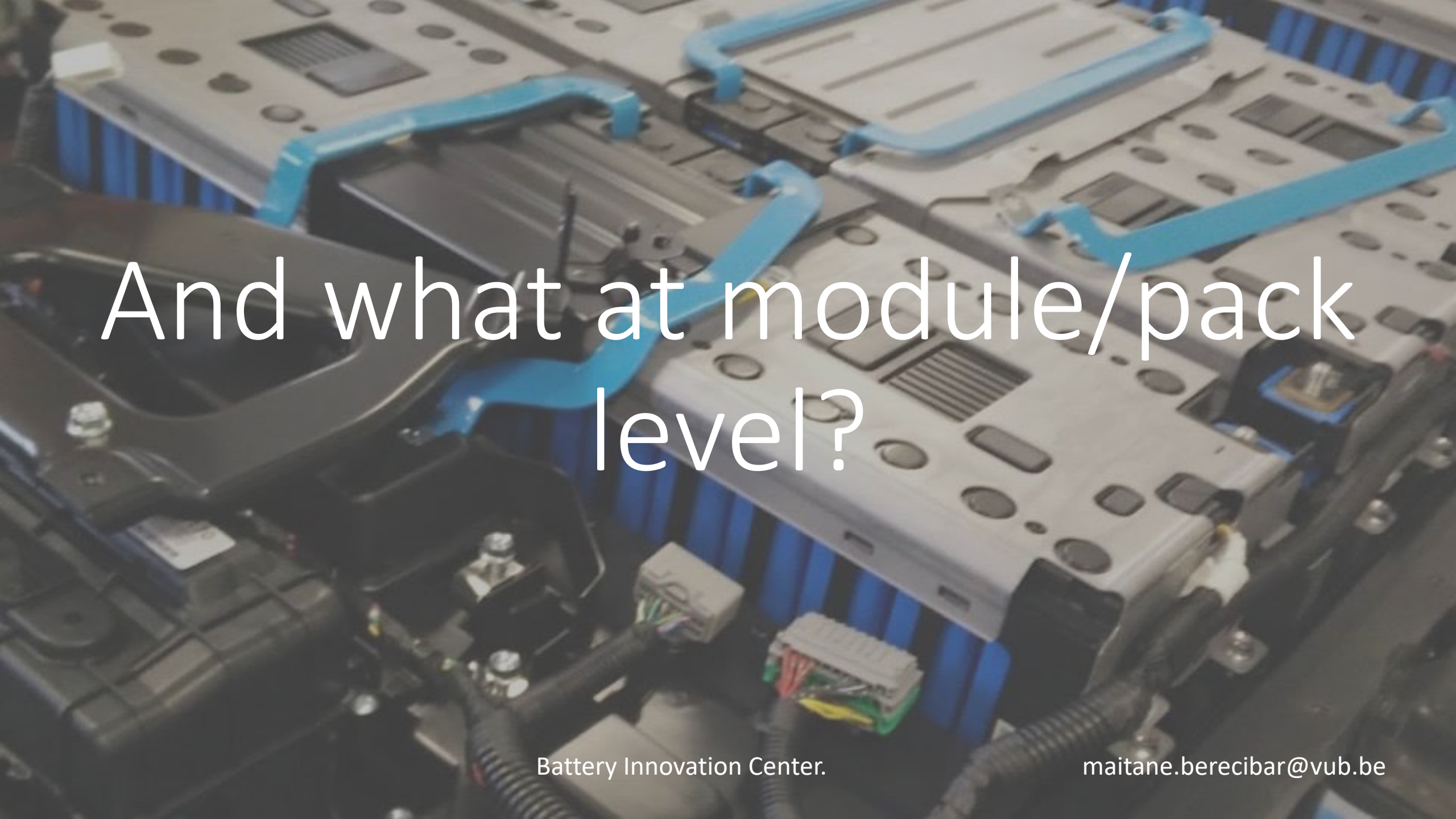

And what at module/pack level?

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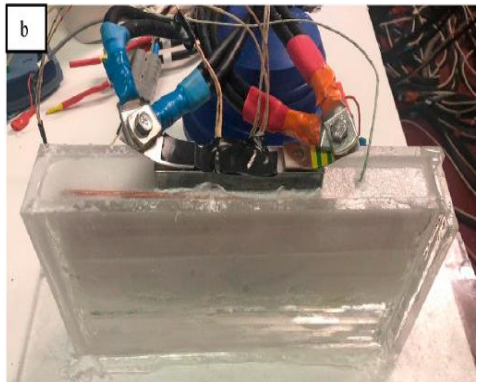
Thermal Management

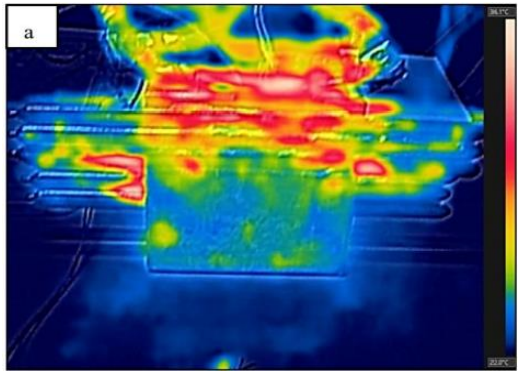
•**Objective:** To allow **fast battery charging up to 5C** under different weather conditions:

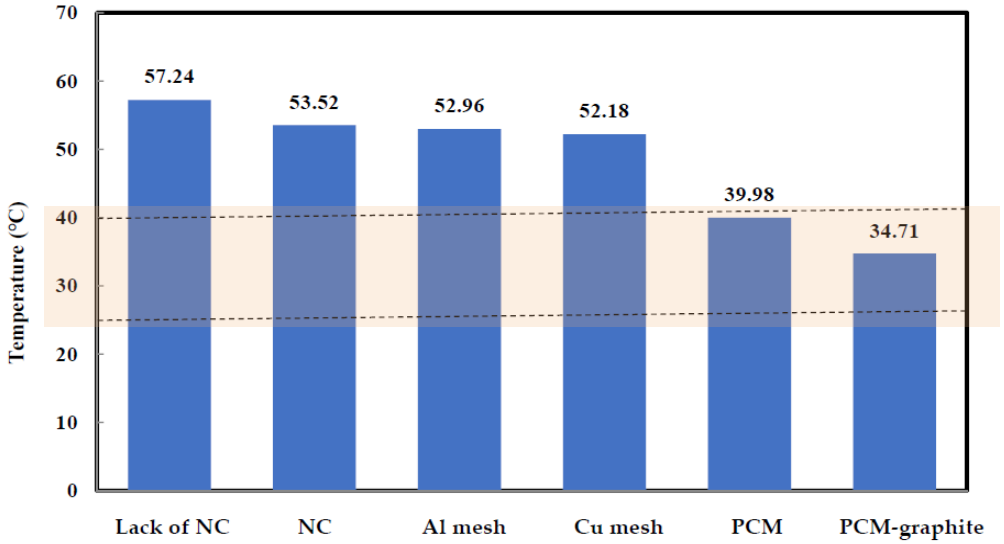
•A **smart modular battery pack**, which has excellent internal thermal conductivity properties, **a refrigerant cooling system and a PCM based thermal storage system** (heat buffer) capable of absorbing excess heat due to fast charging, and which is thoroughly **insulated from the outside**

•An **advanced battery thermal management system (BTMS),** that is capable to keep the **battery temperature effectively within the optimal window and to prevent overheating** (and battery degradation) due to **fast charging**.

Thermal Management







- Battery cell-level experimental research
- Several thermal management performance assessments
- Experimental validations and High-Fidelity thermal management models
- Module level assessments on novel solutions

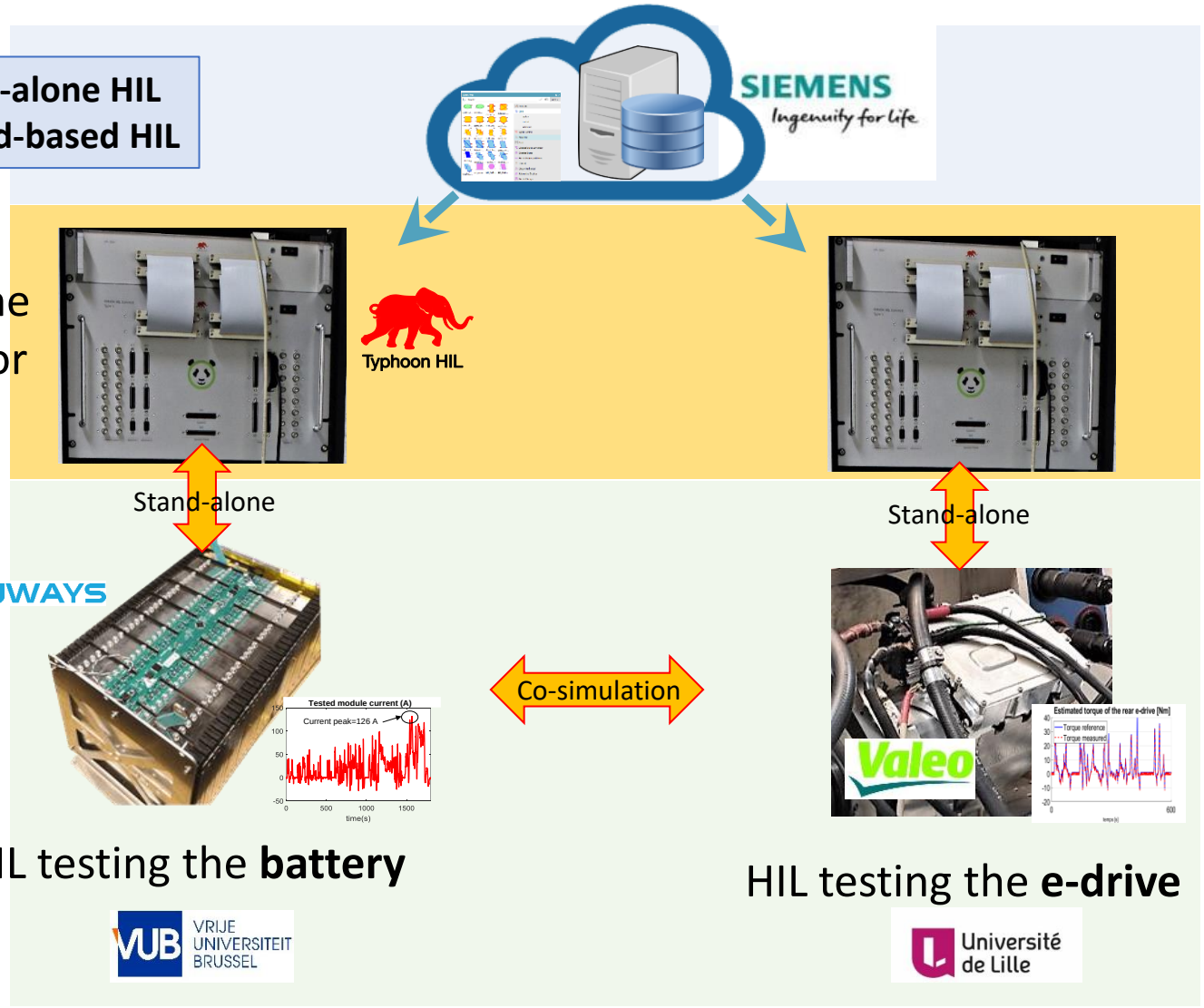
Real Time Cloud Simulations

Objective:
To reduce the development time (**time-to-market**) **by 20% through standardization of the model/simulation**, thereby enabling:

1) **Easy reuse of models** for different tasks and;
2) **Reduction of the real testing** of subsystems by virtual seamless testing.

Real Time Cloud Simulations

Stand-alone HIL & cloud-based HIL



- Models are uploaded in cloud
- Cloud models are linked to interphases and applications
- **Stand-alone** tests on EV components with Cloud models
- **Co-simulations in real time** with multi-le components and models
- Study cases: **EV**(ZOE) and **HEV**

Smart Charging

CEVOLVER
Connected Electric Vehicle Optimised for Life, Value, Efficiency and Range

Are big batteries crucial for long distance trips?
A smaller battery is beneficial for climate change

Objective:

- A dynamic connection to **big data and computational capabilities** in the cloud enables **optimising the EV's energy and thermal management level**.
- It leads to a **Reliable Range Prediction, Eco-routing and Eco-driving** as well as novel functionalities like **Smart Fast Charging and Assured Charging**.

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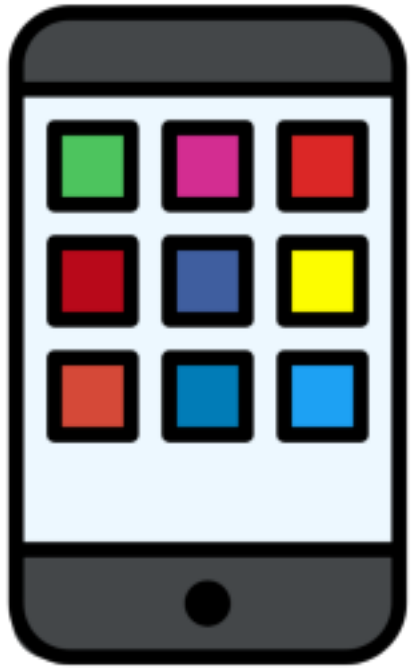
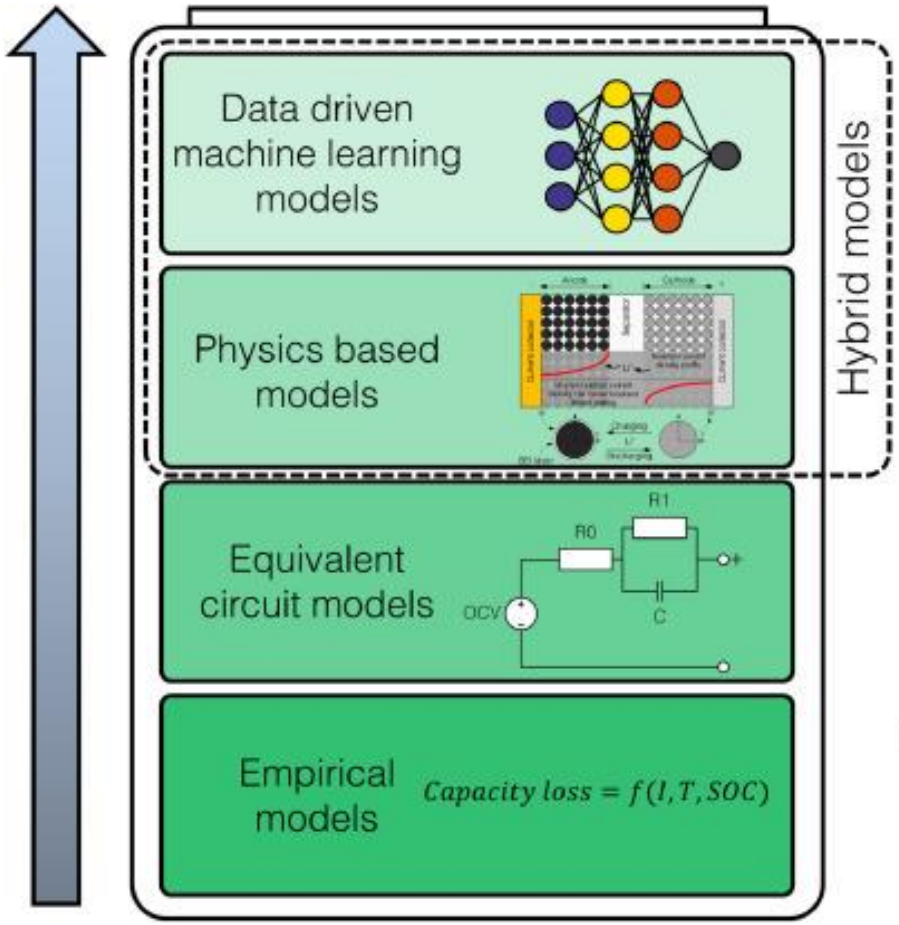
Smart Charging

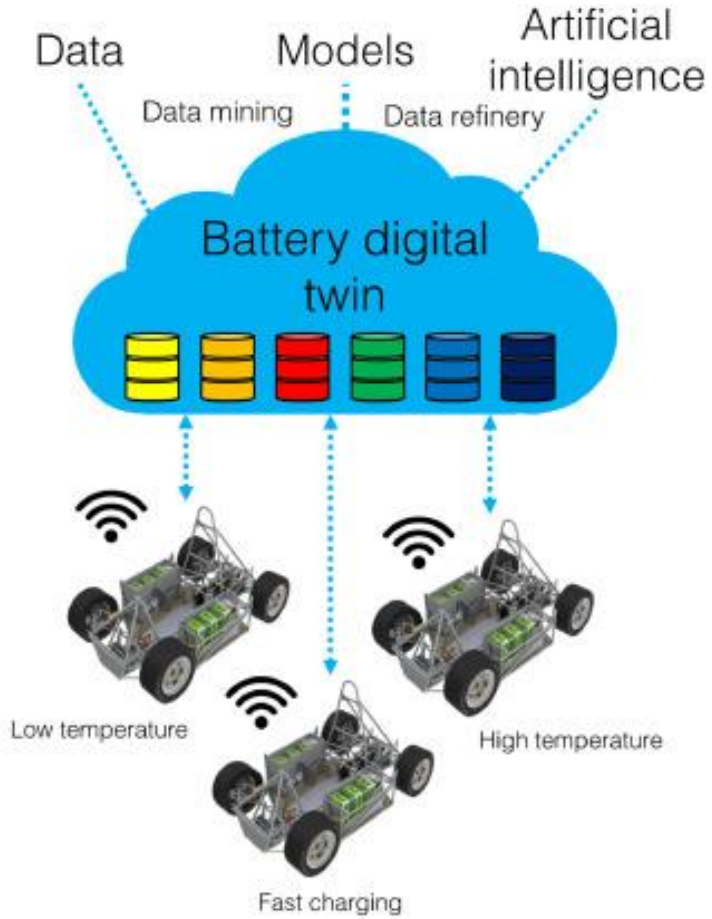
development of a virtual simulation framework that allows to **develop advanced energy and thermal management strategies** using connected information for different functional architectures of the thermal system.

the simulation framework will also serve to **compensate performance differences** in the demonstrator vehicles caused by noise factors in **environmental conditions**.



Battery Digital Twin





https://doi.org/10.1016/j.egyai.2020.100016

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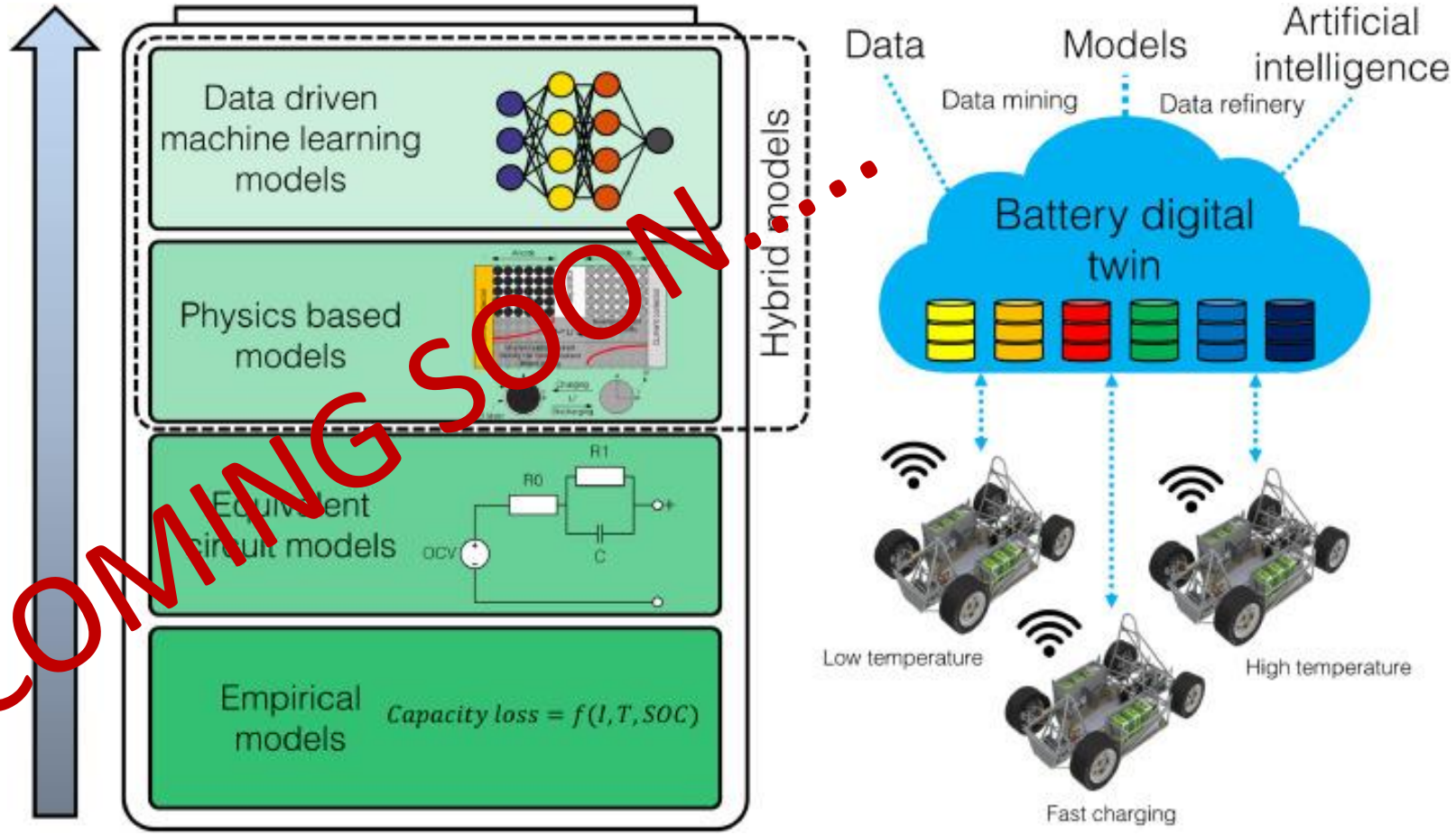
Battery Digital Twin



https://doi.org/10.1016/j.egyai.2020.100016

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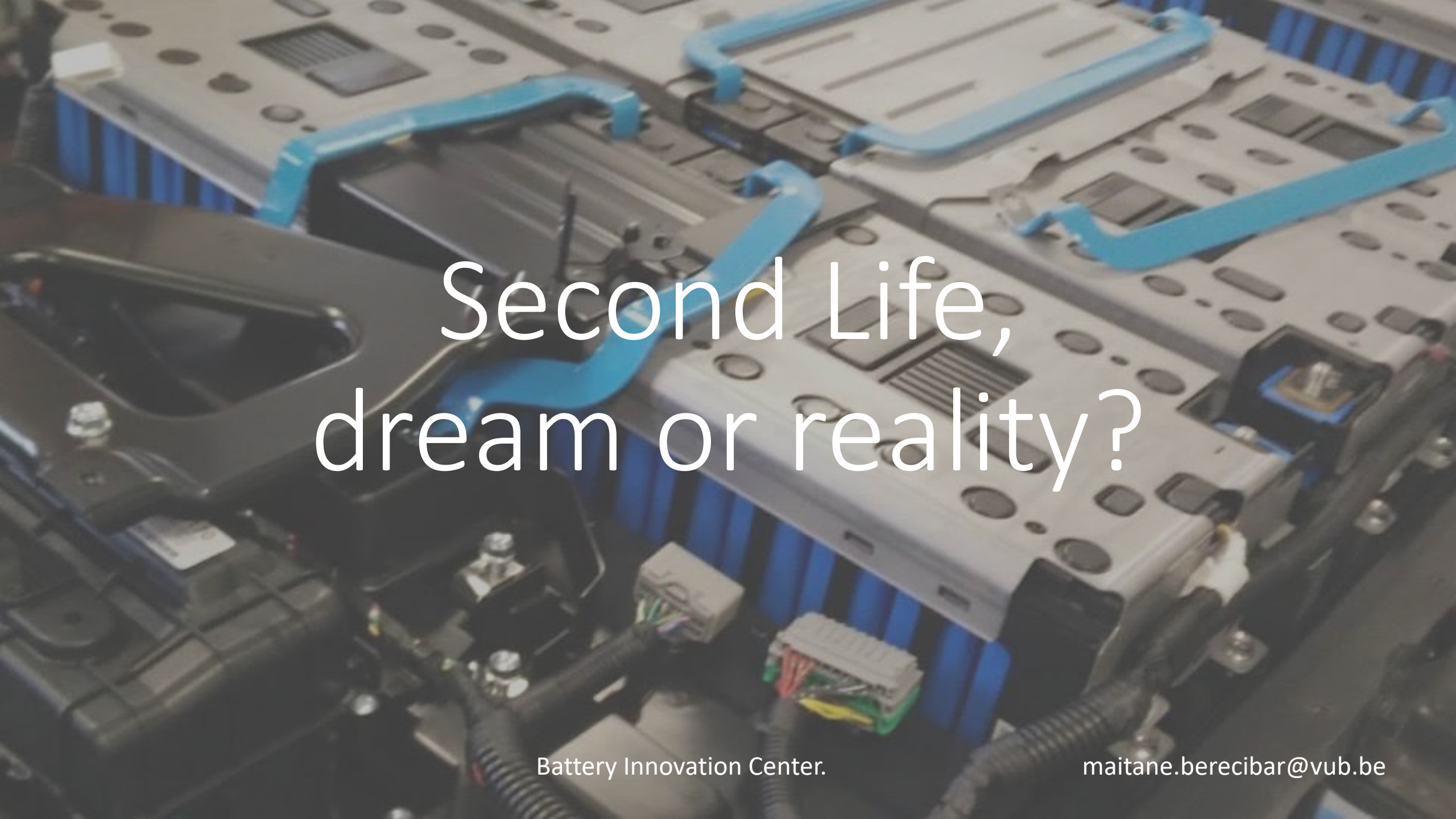

Second Life, dream or reality?

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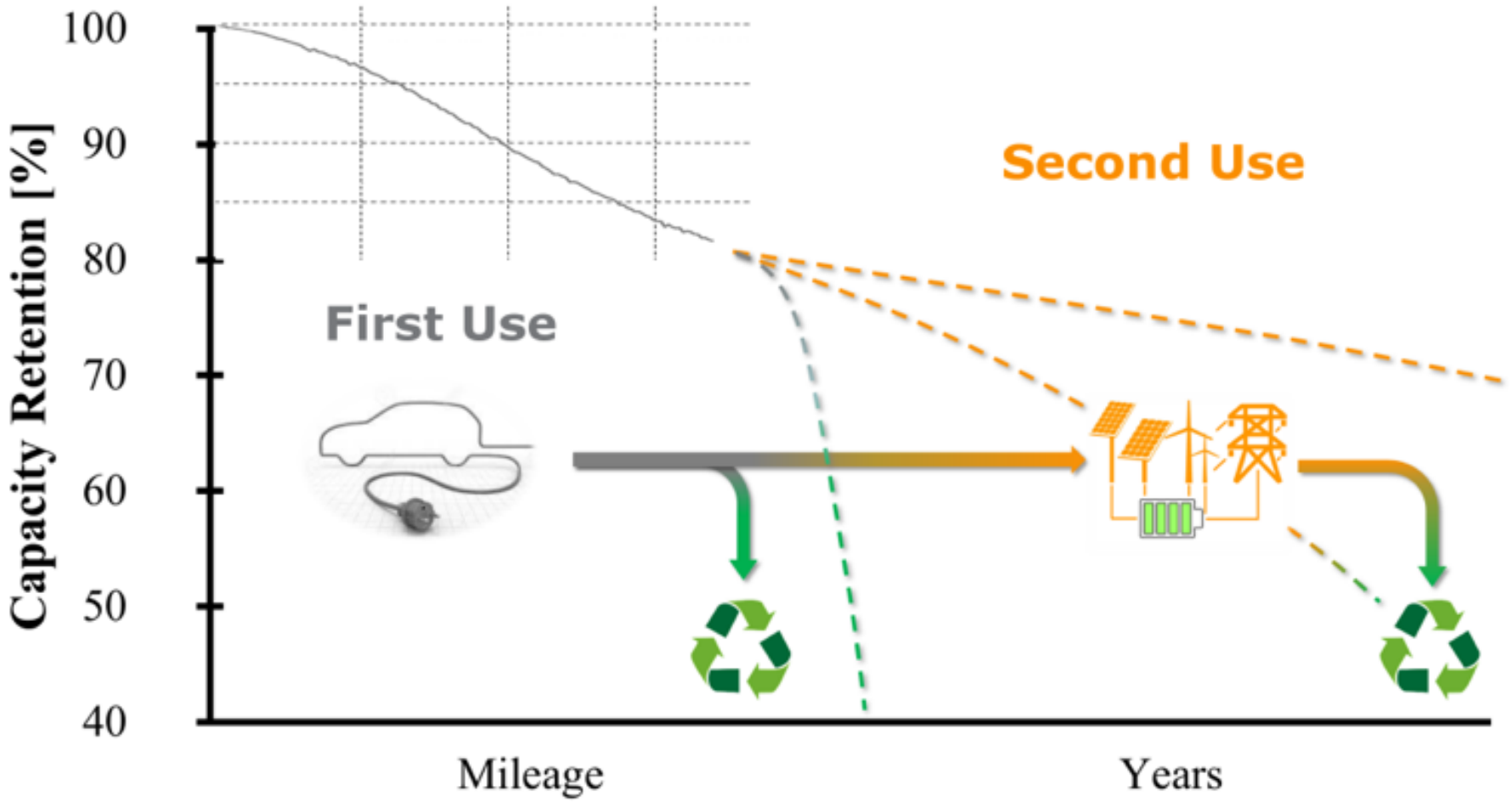
2nd Life



Sustainability Assessment of Second Life Application of Automotive Batteries (SASLAB) – JRC Technical Report

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Building Batteries - CLEVER

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empowering research

- Development of a **second life battery asset model that can be used for Energy Management System in industrial or commercial buildings and sites.**

- Development and demonstration of an energy management system for **a second-life battery storage system to perform peak-shaving.**

- Development of an intelligent cooperative EMS architecture which allow an EMS for a BESS and an **EMS for smart EV chargers to cooperate towards the same objective**.

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Grid Applications - REASSURE

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empowering research

Objective: Develop a multi-approach technique/platform to integrate and use smartly the different assets of a specific grid application

- **Understand different contexts with different operating assets (PV installation, battery, HVAC system, etc.)** and operating conditions.
- **Facilitating the integration of real-world datasets** originating from several different sources
- Investigate **exiting techniques.**
- **Standardization of data.**
- **From lab and demo** testing.

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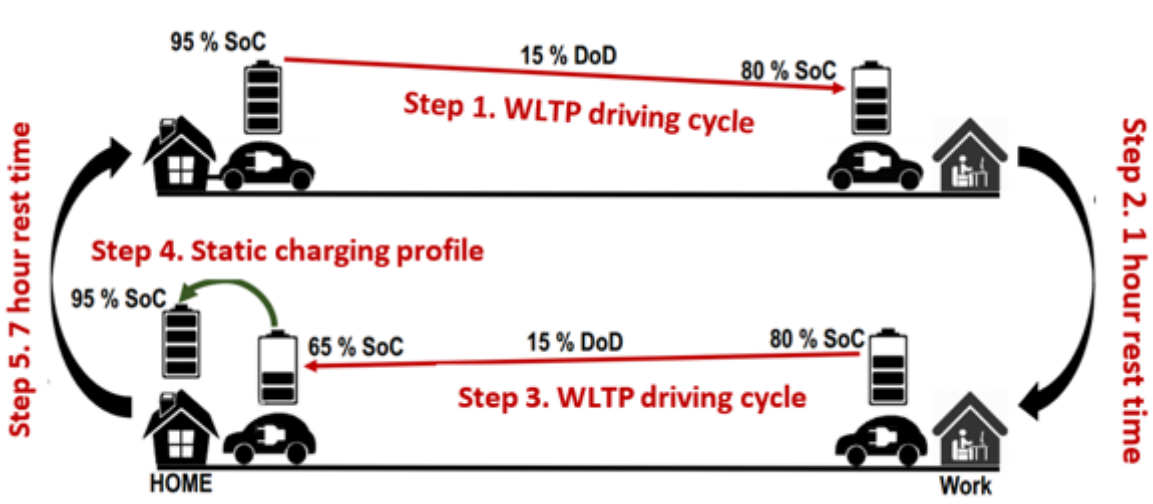
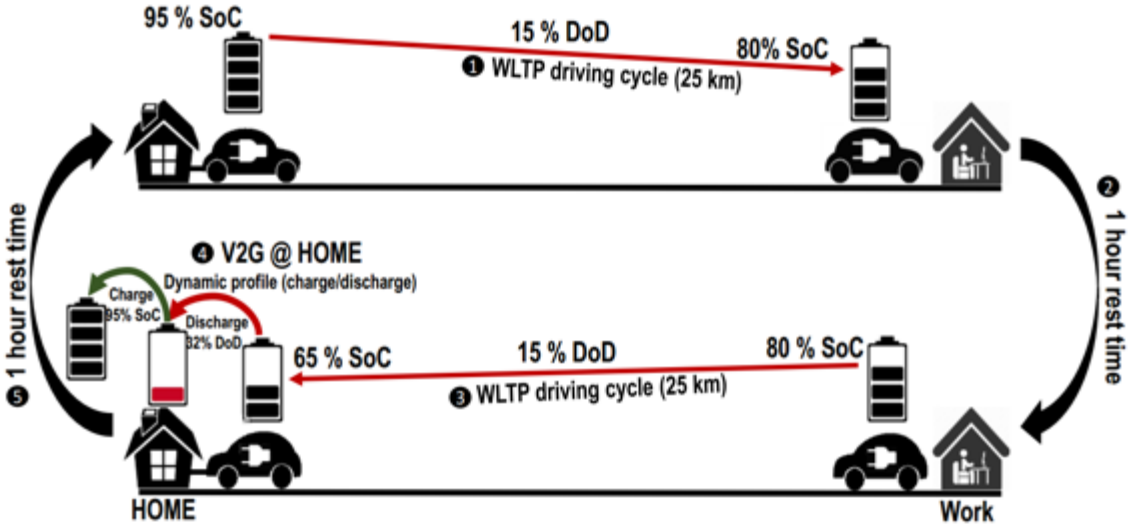
Vehicle to Grid

- Research shows that V2g has no immediate extra negative effect on the aging of the battery in comparison to normal behavior of the electric vehicles.





Yi Li et al., The impact of the vehicle-to-grid strategy on lithium-ion battery ageing process, EVS31

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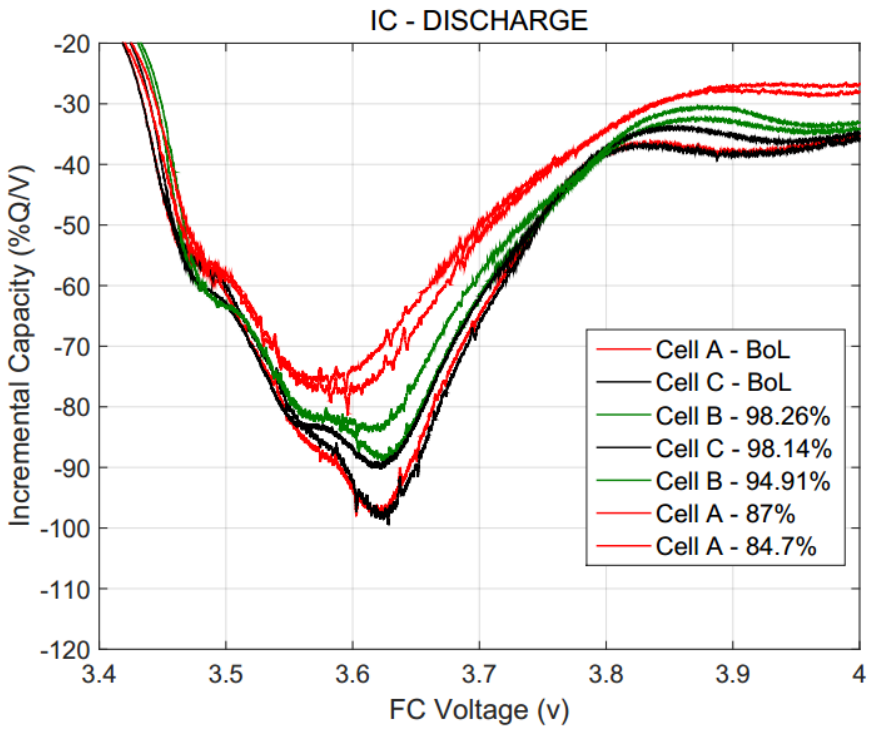
2nd Life Batteries – SoH/RUL

- Create **physics-based and hybrid based models** related to the energy storage application profiles.
- **Identify the degradation** modes based on the use-cases.
- **Combine** and create flexible models for remaining lifetime assessment and performance degradation estimation.



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Our Research Activities & Lab Facilities

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Battery Innovation Center

VUB BATTERY INNOVATION CENTRE

Raw Materials
- Social aspects
- Life Cycle Assessment
- Eco-Design and cost evaluation

Next Generation Battery Technologies:
- Si based, Solid state, Li Metal, other
- Self Healing

Manufacturability
- Upscaling
- Fabrication and Optimization
- Sensing

2nd Life & Recyclability:
- Post Mortem
- Adaptation of Modelling
  Evaluation of Second Life:
  - Repair
  - Reuse
  - Remanufacture
  - Recycle
- Safety Task Chair at Batteries Europe

Usage
- E-Mobility & Stationary
- Modelling: Electrochemical, Thermal, Electrical, Lifetime
- Smart State Estimations: SoC, SoH, SoF, other
- Thermal Management & Cooling Strategies
- Standardization: TC69 (secretary), TC21 (expert)

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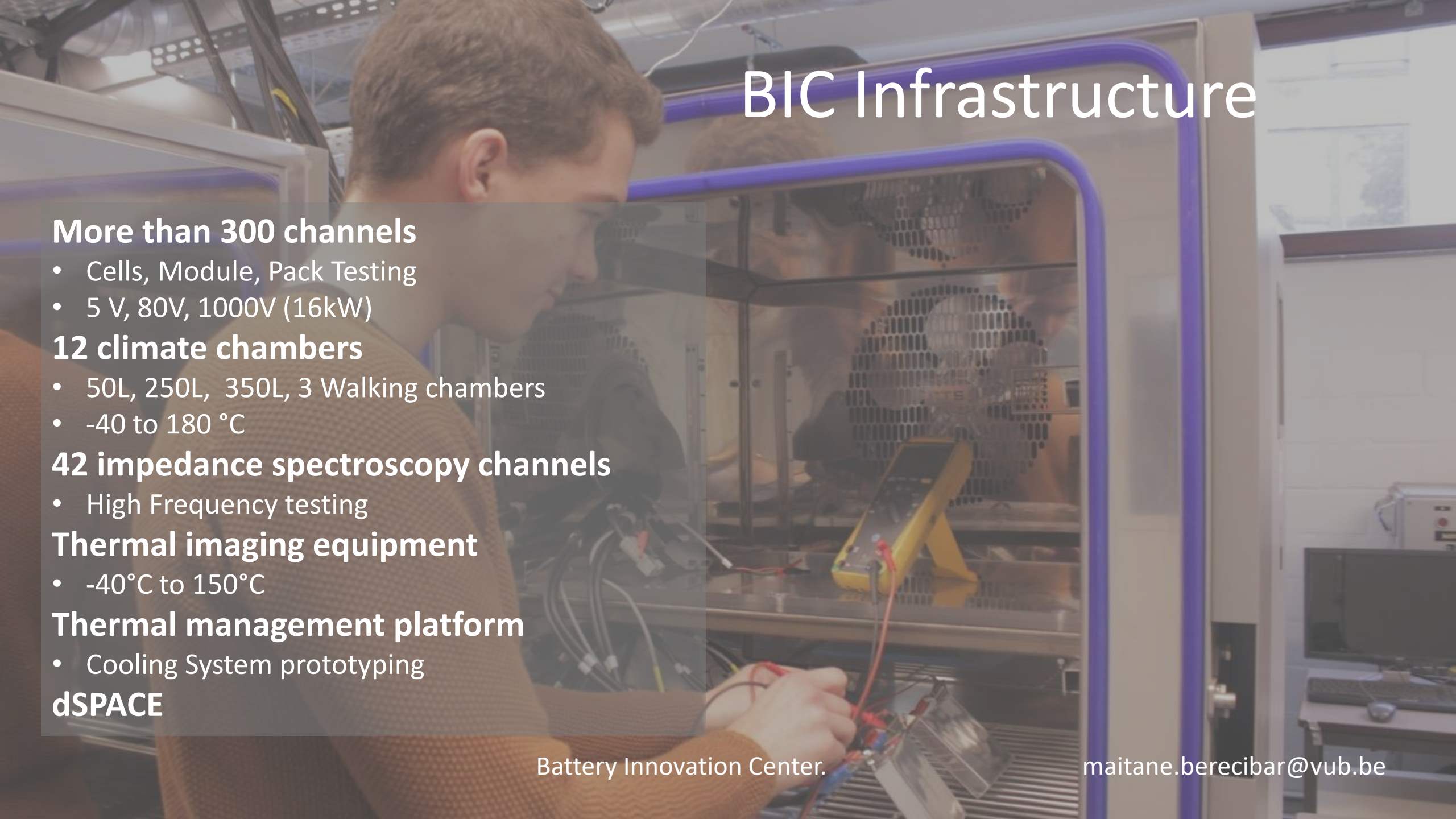
BIC Infrastructure



More than 300 channels

- Cells, Module, Pack Testing
- 5 V, 80V, 1000V (16kW)

12 climate chambers

- 50L, 250L, 350L, 3 Walking chambers
- -40 to 180 °C

42 impedance spectroscopy channels

- High Frequency testing

Thermal imaging equipment

- -40°C to 150°C

Thermal management platform

- Cooling System prototyping

dSPACE

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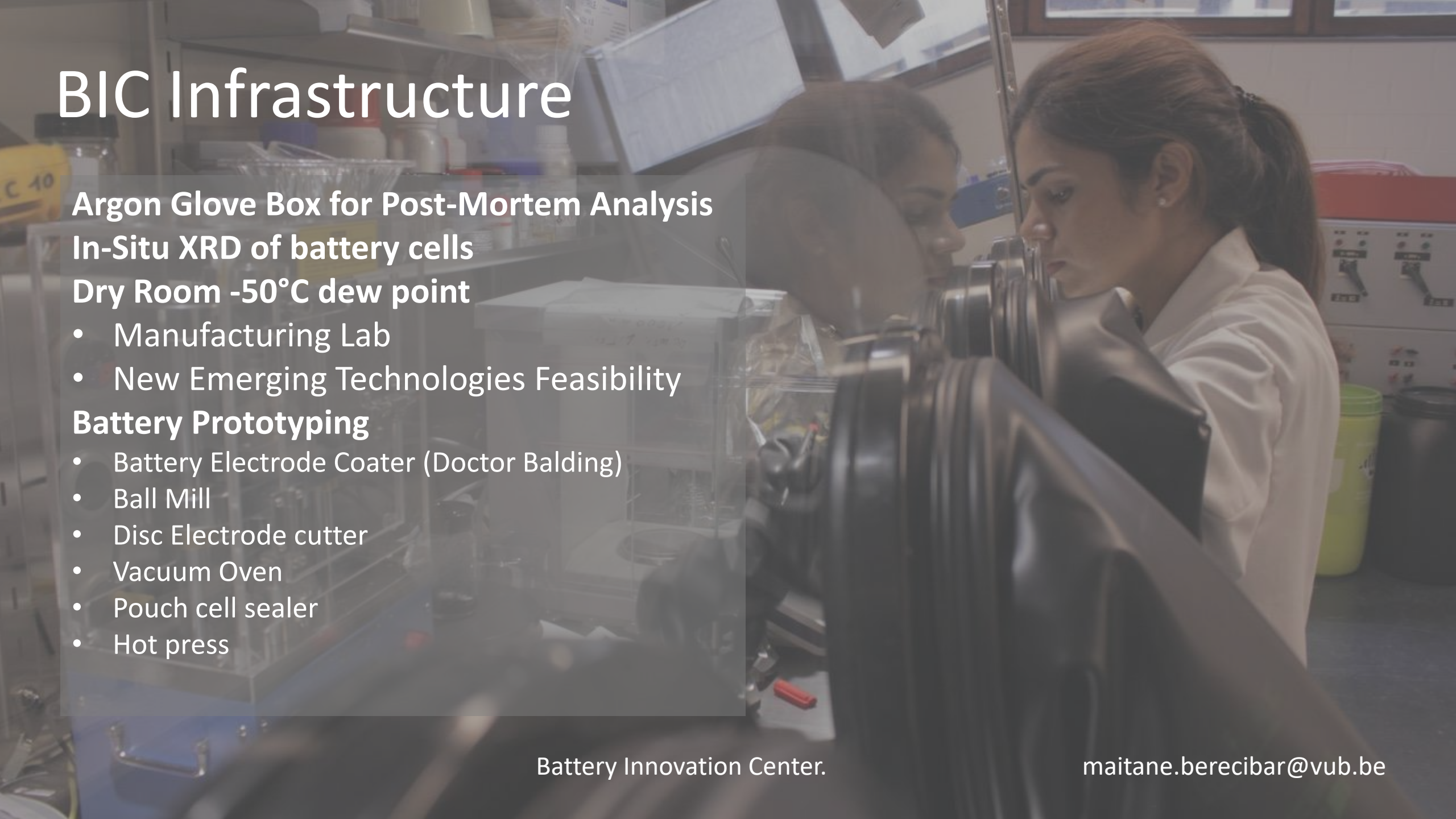
BIC Infrastructure



Argon Glove Box for Post-Mortem Analysis
In-Situ XRD of battery cells
Dry Room -50°C dew point

- Manufacturing Lab
- New Emerging Technologies Feasibility

Battery Prototyping

- Battery Electrode Coater (Doctor Balding)
- Ball Mill
- Disc Electrode cutter
- Vacuum Oven
- Pouch cell sealer
- Hot press

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45 m²
-50°C dew point
MSK-800-2K

Conclusions

- **Higher energy density** batteries are currently under research.
- **Smart functionalities** based on self healing properties and sensor integration are now under research to increase the lifetime and safety of batteries.
- **Battery manufacturing** is under research to produce homogeneous and high-quality battery cells.
- **Fast charging** is becoming feasible with the adequate thermal management strategies
- **Real time cloud simulations** can reduce the time to market.
- **Smart charging** can be used for efficient sizing and usage of the battery.
- **2nd life** is under research for **buildings and grid applications, SoH / RUL estimation**

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