CELL-INTEGRATED SENSING FUNCTIONALITIES FOR SMART BATTERY SYSTEMS WITH IMPROVED PERFORMANCE AND SAFETY

GA 957273

D6.4 – I SENSIBAT ADVISORY BOARD WORKSHOP

LC-BAT-13-2020 - Sensing functionalities for smart battery cell chemistries

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Summary

The objective of this deliverable D6.4 - 1st SENSIBAT Advisory Board Workshop is to provide an overview of the meeting, especially focused on the feedback received from the project advisory board members on project developments, their boundaries and how to overcome these, and finally define exploitation strategies for the future.

The first SENSIBAT's Project Advisory Board workshop took place in an online meeting on 3rd of March 2022. During the workshop, SENSIBAT partners presented the general objective of the project, the two sensors that will be developed, the module to be constructed with Level 1 integrated sensor cells and the exploitation plan that will be followed with the outcomes of the project. The workshop got the opportunities to present the results achieved till month 18 (half of the project) and put the bases for future developments.

As a result of this first Project Advisory Board workshop, the advisory board members congratulated the project for its relevance and ambition. They also raised some relevant points that have to be considered during the following years of the project.

SENSIBAT first Advisory Board (AB) workshop was planned to be organised at the premises of BeDimensional (BDM) at Genova Italy in month 18 of the project. In order to reduce the travels of the different participants, it was decided to hold the workshop the day after the General Assembly (GA) of the SENSIBAT project to be held on March 2, 2022, also in Genova. Due to Covid pandemic situation and travel restrictions of some companies, both the GA and AB workshop were held online. Due to the planned date of the GA and AB workshop, beginning of month 19 of the project, this deliverable is submitted with one month delay compared to what is defined in the Annex I of the Grant Agreement. This delay has no effect on other task or activities within the project.

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Abbreviations

Symbol / Abbreviation	
AB	*Advisory Board*
BMS	*Battery Management System*
CSA	*Coordination and Support Action*
EIS	*Electrochemical Impedance Spectroscopy*
EV	*Electric Vehicle*
GA	*General Assembly*
IC	*Integrated Circuit*
IPR	*Intellectual Property Rights*
KER	*Key Exploitable Results*
MFG	*Manufacturing*
SOC	*State Of Charge*
SOE	*State Of Energy*
SOH	*State Of Health*
SOP	*State Of Power*
WP	*Work Package*
WPL	*Work Package Leader*

1 Introduction

The deliverable D6.4 is one of the outcomes of "Task 6.1 - Communication and dissemination strategy" and the "Subtask 6.1.1 Communication and dissemination tools and materials" and it presents the development, feedback and major conclusions from the first SENSIBAT's project Advisory Board Workshop, which took place via conference call on March 3rd 2022.

The main purpose of an Advisory Board is to provide current knowledge, critical thinking and analysis to increase the confidence of the decision-makers who represent the project. In summary the role of an Advisory Board is not to make decisions. Within SENSIBAT project an external Advisory Board is set up consisting of relevant external experts which have the following responsibilities:

- Support SENSIBAT and its activities actively, inter alia by giving feedback on questions asked by SENSIBAT team members, and
- Participate in Advisory Board meetings or workshops when needed, and
- Provide feedback, advice, and support to SENSIBAT on the exploitation, and dissemination and communication channels relevant to SENSIBAT.

SENSIBAT project organized the first AB Workshop to discuss with the members of the AB about issues, problems and results achieved till month 18 of SENSIBAT project. The AB workshop was an important opportunity to summarize all results achieved and also to drive the future activities within the project.

2 Advisory Board

In this section the specific aspects of how the defined Risk Management will be implemented in the SENSIBAT project is explained.

In this section the most relevant details of the Advisory Board will be provided together with the information on the members that are part of the SENSIBAT project Advisory Board.

2.1 Advisory Board Definition

The SENSIBAT AB is an independent group composed by external experts in batteries and sensing technologies that provides guidelines and expert advice to the project in order to maximize the impact of the project results. The Board is advisory, and that the ultimate responsibility for decisions about strategy, policy, financial expenditure and management remain with the partners of the project.

The relation between the AB and the SENSIBAT project is ruled by a "Cooperation and Non-Disclosure Agreement for External Experts in the SENSIBAT Advisory Board" signed by both parties. According to this document, the AB responsibilities include:

- To support the Project and its activities actively, inter alia by giving feedback on questions asked by any partner of the project and consortium body.
- To participate in general assembly, Advisory Board meetings or workshops when needed.
- To provide feedback, advice and support to project partners on the exploitation, and dissemination and communication channels relevant to the Project.

According to what is defined in the Annex I of the SENSIBAT project Grant Agreement, the AB members are expected to meet at least twice during the whole period of the project, once every 18 months and the conclusions of this meetings should appear in formal and public project deliverables (D6.4 and D6.5).

2.2 Advisory Board Composition

The project Advisory Board is formed by high-level experts representing important institutions having specific expertise on key technologies, on battery and sensors field in the case of SENSIBAT project. As in every EU project, several experts from different fields were contacted to be part of the SENSIBAT AB, some of them had express their interest through letters of consents during the project proposal writing phase of SENSIBAT project.

After SENSIBAT project kick-off meeting on September 2020, the consortium members contacted an initial panel of experts in order to launch the AB activities. Although, some of them indicated that current circumstances would prevent them from being able of taking care of SENSIBAT project AB tasks. Three of the contacted experts, confirmed their interest in participating in the project. The SENSIBAT Advisory Board is composed by:

- Philippe JACQUES - EMIRI
- Wolfgang Mildner - MSWtech
- Dr. Enrico Baldasso - Lithium Balance

2.3 AB members short bibliography

2.3.1 Philippe JACQUES - EMIRI

Chemical Engineer graduated from the University of Louvain-la-Neuve, Belgium, Philippe JACQUES joined Solvay in 1988 in Brussels, Belgium, and moved to various Intellectual Property, R&D management and senior leadership roles. Qualified European Patent Attorney, he managed Solvay Patent Department before joining Corporate R&I Management Team in 2011. After a 5-year assignment in Solvay biggest R&I Center in Lyon, France, he is since October 1st 2018 part-time seconded as Managing Director of the Energy Materials Industrial Research Initiative (EMIRI) Association based in Brussels, to address the innovation-related challenges ahead of the industry of advanced materials for clean and sustainable energy & mobility.

2.3.2 Wolfgang Mildner - MSWtech

Wolfgang Mildner is Founder and Owner of MSWtech in Stein (Germany). MSWtech supports companies and other organizations to find value in new technologies – especially printed and flexible electronics. Wolfgang was Managing Director of PolyIC (a leading company for printed electronics) from 2004 – 2014. Before Wolfgang Mildner worked in various business positions for Siemens (New business development, Business responsible for Industrial PC's, Failsafe PLC's and other). Wolfgang Mildner was responsible for a number of projects turning promising technologies into business. Wolfgang Mildner studied Computer Science at the Technical University of Erlangen.

2.3.3 Dr. Enrico Baldasso - Lithium Balance

Dr. Enrico Baldasso currently works at LiTHIUM BALANCE, founded in 2006 as an ambitious start-up at the Danish Technological Institute. From the very beginning LiTHIUM BALANCE was determined to push the battery-based electrification technology forward by developing, manufacturing and selling Battery Management Systems (BMS) for lithium-ion battery technologies. Before joining LiTHIUM BALANCE Enrico obtained a PhD from DTU (Technical University of Denmark) Mechanical Engineering with extensive expertise in numerical modelling, including sensitivity analyses, optimization routines, and data science. Enrico has a proven track of translating challenges into numerical models and supporting business decisions through simulation tools.

3 First AB Workshop

This section describes the details about the organization, development and discussions of the SENSIBAT 1st Advisory Board Workshop.

Even that according to what is defined in the Annex I of the SENSIBAT project Grant Agreement the 1st AB Workshop was to take place at BeDimensional facilities in Genova (Italy) together with a SENSIBAT General Assembly meeting that was going to take place after the month 18 of the project, beginning of March 2022. Unfortunately, due to Covid-19 pandemic restrictions incompatibilities to attend the meeting physically by some partners, this tentative presential workshop was called off and an alternative online workshop was scheduled for the same dates, as it was done for the General Assembly.

As mentioned before, the main goal of this first workshop was to have AB members providing SENSIBAT partners with feedback regarding the relevance and potential impact of the project outcomes, identifying specific recent or ongoing research and developments that the project should be aware of, and any other suggestion that could improve SENSIBAT's ongoing work.

Fig 2 is illustrating a photo of the participants at the workshop. The list of participants is reported in Annex1.

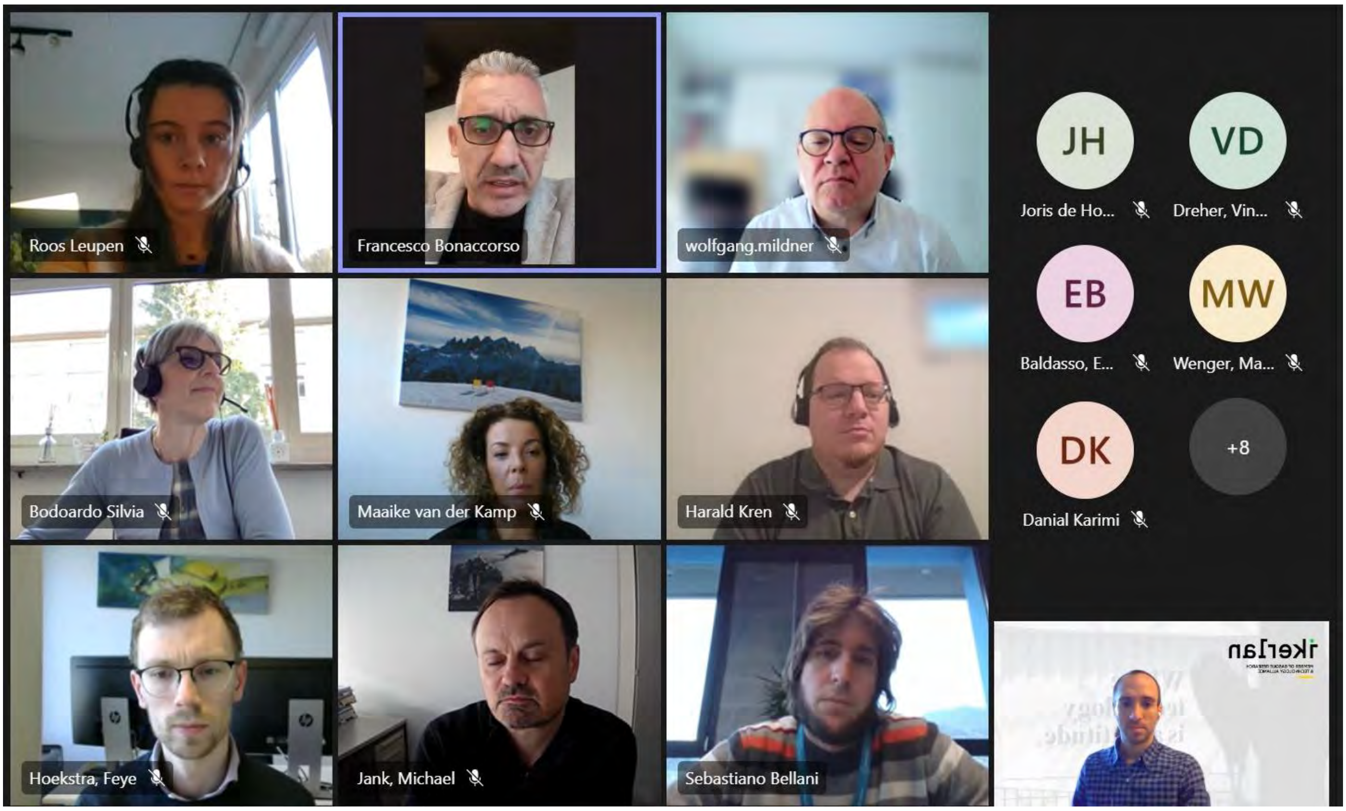


Figure 3-1 Photo with part of the participants at the 1st AB workshop

3.1 Agenda of the workshop

The first SENSIBAT AB workshop took place via online on March 3rd 2022, hosted by Uniresearch and operated via Microsoft Teams, according to the agenda presented in the following table.

Item	Start-end time	Topic	Presenter
1	08:30 – 09:00	**Welcome and introduction participants**	-
2	09:00 – 09:30	**Introduction to Battery2030+**	Simon Perraud (CEA)
3	09:30 – 09:50	**SENSIBAT introduction**	IKERLAN
4	09:50 – 10:40	**Temperature and pressure sensors (Level 1)**	FRAUNHOFER
5	10:40 – 11:20	**Impedance sensor (Level 2)**	BEDIMENSIONAL
6	11:20 – 11:40	Coffee break	-
7	11:40 – 12:30	**Module development**	FLANDERS MAKE
8	12:30 – 13:00	**Exploitation and education**	VARTA (exploitation) & POLITO (education)
9	13:00 – 13:15	**Conclusions and closure**	IKERLAN

Figure 3-2 1st AB workshop agenda

3.2 Battery 2030+research initiative

The workshop was opened by an introduction of Battery 2030+research initiative given by Simon Perraud from CEA, the deputy coordinator of the Battery 2030 + initiative. The Battery 2030+ is a large scale, long-term European research initiative with the vision of inventing the sustainable batteries of the future. The objective of the initiative is to provide European industry with disruptive technologies and a competitive edge throughout the entire battery value chain and enable Europe to reach the goals of a climate-neutral society envisaged in the European Green Deal.

The initiative consists of seven projects; one coordination and support action (CSA) coordinated by UU, Sweden, and six research and innovation projects: BAT4EVER, coordinated by VUB, Belgium; BIG-MAP, coordinated by DTU Denmark; HIDDEN, coordinated by VTT Finland; INSTABAT, coordinated by CEA France; SENSIBAT, coordinated by IKERLAN in Spain, and SPARTACUS, coordinated by Fraunhofer in Germany.

The Battery 2030+ initiative has a chemistry-neutral approach to facilitate the invention of the batteries of the future. The research directions presented in the Battery 2030+ roadmap outline a generic toolbox for transforming the way we develop and design batteries. The roadmap presents three overarching research themes and six research areas needed in order to invent the sustainable batteries of the future.

- Accelerated discovery of battery interfaces and materials – Battery Interface Genome (BIG) Materials Acceleration Platform (MAP)
- Integration of smart functionalities – sensing and self-healing
- Cross-cutting areas – manufacturability and recyclability

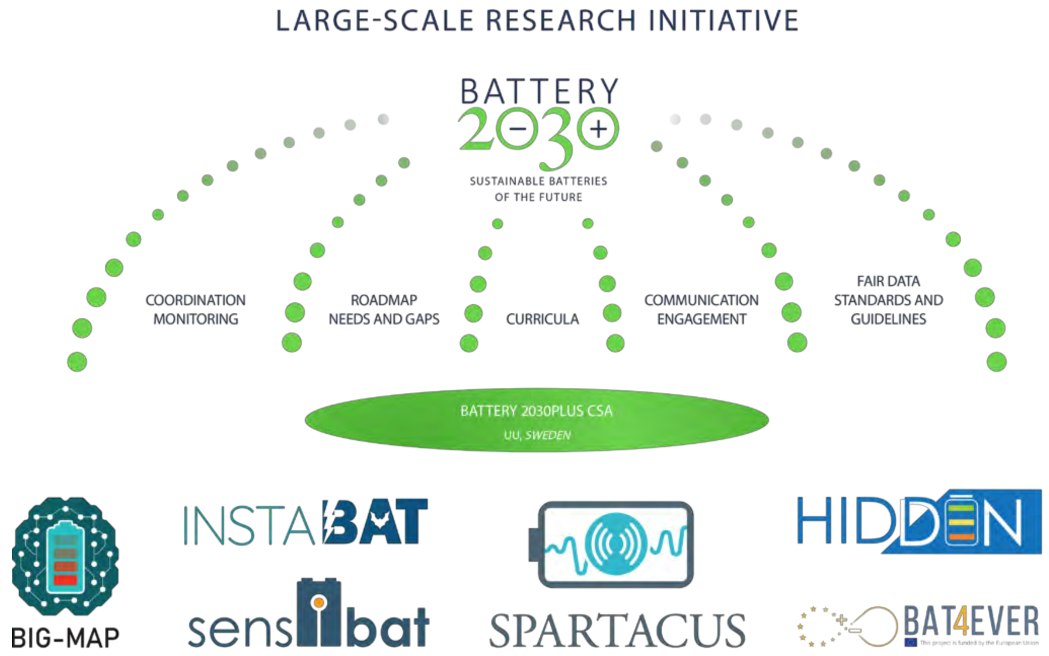


Figure 3-3 SENSIBAT project as part of Battery2030+ initiative

3.3 SENSIBAT introduction

After the Battery 2030+ introduction, Iñigo Gandiaga (Ikerlan) SENSIBAT project coordinator, introduced the SENSIBAT project emphasizing the current challenges of the battery industry, explaining the overall objectives and targeted impact of the SENSIBAT project, together with the expected outcomes, its main innovations and the project's overall work plan.

He also explained the 1st AB workshop objectives, introduced all the workshop attendants and the means to provide feedback. Uniresearch also informed that the session would be recorded and required consent form all participants previously to starting to record.

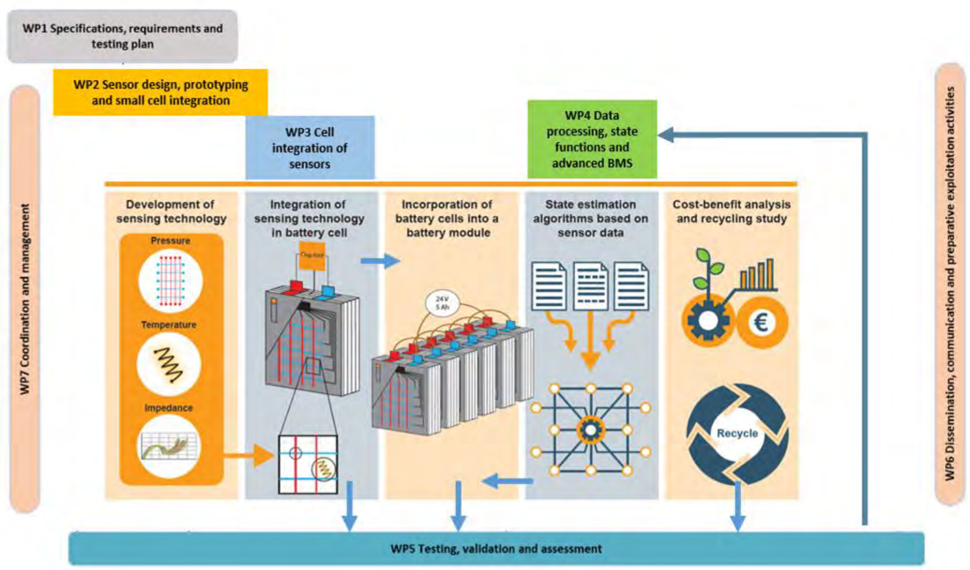


Figure 3-4 SENSIBAT project overall workflow.

3.4 Temperature and pressure sensors (Level 1)

SENSIBAT uses two instances of sensors for derivation of relevant physico-chemical parameters in situ, i.e. inside the battery cells. The integration with the battery electrode stack demands for a flexible thin-film electronics approach. Level 1 sensors under consideration focus on proven sensing principles and arrange temperature and pressure sensors in a matrix style that allows the read out with spatial resolution. The goals of the sensor adaptation process are:

- Selection of appropriate sensing principles and materials to fulfil the requirements
- Definition of sensor devices, layouts and layer stacks
- Sampling of test devices and assessment of materials and layouts
- Integration of an appropriate addressing system and respective wiring architecture with the sensors on one side and the battery management system (electronic read out) on the other

Michael Jank from Fraunhofer IISB provided a high-level view of the developed Level 1 sensors (Fig.4)

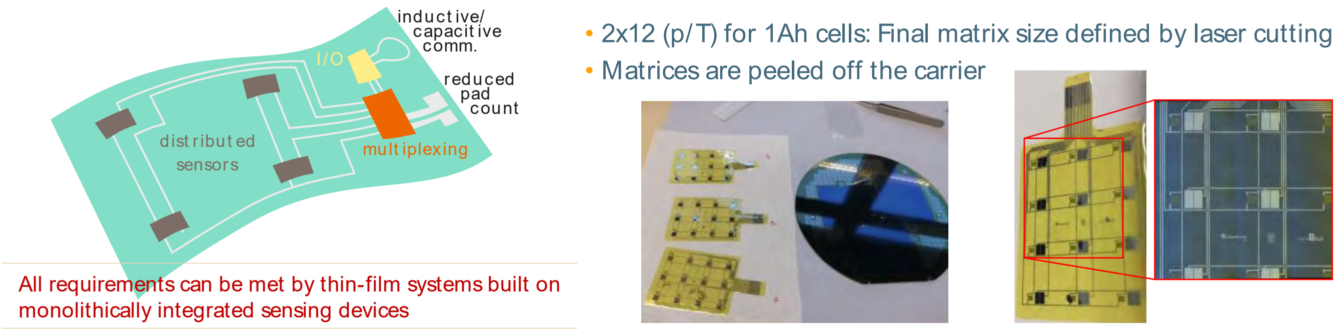


Figure 3-5 Temperature and pressure sensors

During the Level 1 sensor presentation some questions were proposed by the SENSIBAT project partners to the AB members, which lead to a fruitful discussion. On one hand questions related to the high-end, disposable or lab-type product:

- Is the application “complete”? What else is needed?
- What should a test system look like? Lab standards?
- “Retail price”, sensor sheet vs read-out system?
- Marketing and commercialization strategies?
- Cost model/commercial partners for mfg and retail?

On the other hand, about the large-volume application of the sensor:

- Print vs vacuum?
- Materials availability for print?
- Cost model vs entrance barrier?
- What is the BMS point-of-view

AB members gave their view from BMS perspective, explaining that it is very helpful to try to understand how the aging of the battery is taking place and so to extend the lifetime to have an optimised lifetime profile for example in an electric vehicle. In addition, the AB suggests to work together with an algorithm company, to offer sensors together with algorithms; the sensor alone does not have the complete value.

The obtained high volume of data from the sensor is seen as a possible memory bottleneck for the BMS. The AB thinks that a connection with a cloud database will be needed to process all the generated data by those novel sensors.

Finally, sensor reliability is another important factor introduced by the AB, also taking into account whether battery will influence sensor on longer term, not just other way around: If encapsulation and electrolyte show no interaction, SENSIBAT partners expect that this will not impact the sensing element (no diffusion of electrolyte into sensing element). However, there may be an effect of the encapsulation on the response time. But given the current low thickness there should be a fast reaction of the T-sensor. For P-sensor another encapsulation method is used, there may be long-term effect by mechanical changing behaviour of encapsulate. This needs to be clarified in the course of the project.

3.5 Impedance sensor (Level 2)

One of SENSIBAT's overall objective is to develop a sensing technology for Li-ion batteries that measures in real-time cell's impedance (separately for the anode, cathode, and electrolyte) and the internal battery electrolyte conductivity. Novel sensing technology consisting of printed reference electrodes that enables in situ Electrochemical Impedance Spectroscopy (EIS) and reliable in operando measurement of the electrolyte conductivity and its change during the cell operation will be developed.

Impedance sensors (Level 2) were presented by Sebastiano Bellani from BeDimensional.

More than 200 electrically conductive pastes have been formulated by systematically varying the SLG/FLG:CB weight ratio to optimally balance the electrical, mechanical and thermal properties.

Product name	Component content (wt%)				Resistivity
	Active material (LTO or LFP)	*PVDF*	*SLG/FLG*	*CB*	(Ω·cm)
LTO-A	25	25	25	25	0.07
LTO-B	50	25	12.5	12.5	0.11
LTO-D	65	10	12.5	12.5	0.26
LFP-A	25	25	25	25	0.06
LFP-B	50	25	12.5	12.5	0.06
LFP-D	65	10	12.5	12.5	0.09

- ❑ All the reference electrodes exhibit a satisfactory resistivity (since common potentiostats/galvanostats have input current lower than 100 pA, the resistance of reference electrode up to 10 kΩ are, in principle, acceptable to avoid relevant voltage losses in DC-mode).
- ❑ The reference electrode is an important parameter to consider for electrode impedance electrical modeling. In particular: if the resistivity of reference electrodes is lower than the one electrolyte, it is possible to use mesh-like impedance modelling, as detailed in the next slides

Figure 3-6 Electrical specification of analysed reference electrodes

Together with the Level 2 sensor presentation some questions were proposed by the SENSIBAT project partners to the AB members, which lead to a fruitful discussion about the reference electrode based impedance sensor

- What are traditional reference electrode configurations?
- What are the current limitations of both wire- and mesh-like reference configurations?
- What are (or could be) the advantages of our printed reference electrodes?
- What are the impedance contribution of our reference electrodes (how modelling them)?

Additional point highlighted are:

- High-throughput deposition of our reference electrodes on flexible substrate (i.e., Celgard 2500)
- Extra-cost of our reference electrode-coated separators

- Additional separator (can it affect the pouch cell manufacturing chain?)
- How to perform in-situ reference electrode preconditioning (risk of electrode overcharging)?

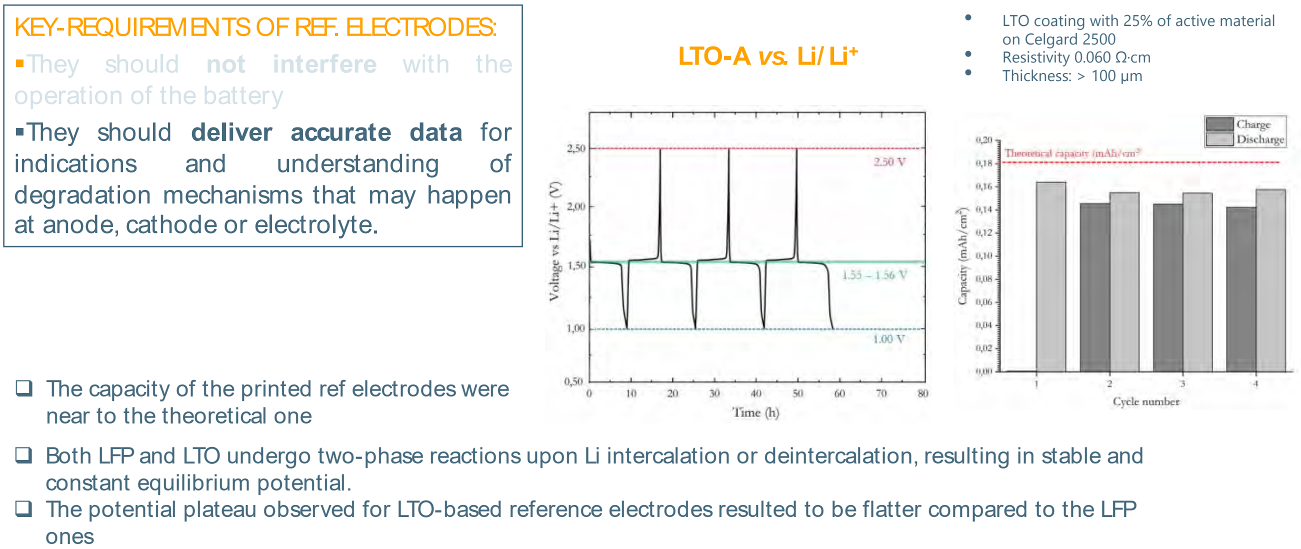


Figure 3-7 Reference electrodes developed

The AB experts confirmed that EIS (Electrochemical Impedance Spectroscopy) is very promising technology. As nowadays it is mostly used for laboratory equipment, once the EIS measurement sensors enter the mass production the costs will probably be the most important aspect to focus on, especially for a BMS application. The additional information given by those sensors might be very useful, but cost is a must for mass production. The AB suggested to think about ways to simplify and make cheaper the system even if it loses accuracy.

BeDimensional is already thinking about the costs of the reference electrode to be developed in SENSIBAT project. However, they mention that to reduce the cost of level 2 sensor, it is necessary to change the geometry of the used separator. In the SENSIBAT project the worst scenario is being tested first, reducing the thickness of the electrode to less than 15 micrometres, while preserving the good resistance to structure the signal. So, size and thickness could be reduced while preserving resistance of electrode.

AB specialists recommended also to determine which are the critical parameters and which parameters can be changed, taking into consideration to look at reducing requirements for cost reduction.

3.6 Module development presentation

After introducing the developed sensing technologies inside lithium-ion pouch cells these will be used for a new objective of the project, which is to develop a 24V battery module with integrated sensors. (Level 1). A complete battery module based on six prototype cells connected in series, with integrated sensors connected to the multicell monitoring integrated circuit (IC) and slave BMS will be developed. In addition, A master BMS connected to the slave BMS and programmed with advanced state estimation algorithms will be also developed.

Finally, Joris de Hoog from Flanders Make also explained that by making use of the data from the internal sensing technologies, robust and advanced state estimation functions will be developed. Commonly used state estimation algorithms will be improved and novel safety concepts will be created.

The AB members expressed that there is a lot of commercial value in algorithms that use the rich and new sensor data. AB clarified that there is a need for improvement in the SoX algorithms to extend operational range by having a higher reliability and for that purpose focus should be placed on incorporating ageing throughout vehicle lifetime to those state estimation algorithms. The AB experts also mentioned that they find very important to have an algorithm that can update itself and finally, they advise to ensure there is a dataset of at least two years before commercialisation, so that people will trust the technology.

Regarding the novel State of Safety algorithm, the AB thinks that it can be used as an additional index for degradation conditions and that this could be very valuable, although currently it is not available on market.

3.7 Exploitation in SENSIBAT

The exploitation methodology used within SENSIBAT was presented to the AB by Harald Kren from Varta. Next to the presentation of the internal exploitation following the developed exploitation plan, the partners informed the AB about the planned joint exploitation. For this purpose, SENSIBAT participates together with the Batteries 2030+ partners in Module 1 of the Horizon Booster service. The internal exploitation strategy is displayed in the following figure:

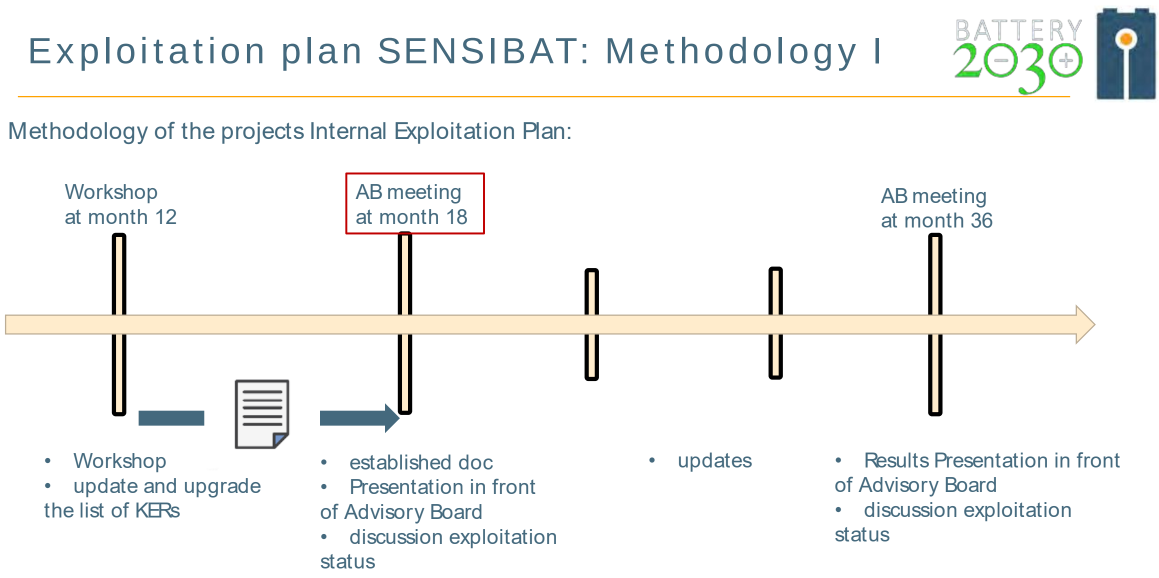


Figure 3-8 Exploitation methodology

According to this plan, the AB was informed about the defined key exploitable results (KER´s) and each of this KERs was described. Exploitation methodology in SENSIBAT assures that research and industrial partners follow the right exploitation path, the project partners will utilize a predefined procedure, allowing to carefully analyse each exploitable result and its marketable value. This procedure is:

1. Initially, all key exploitable results (KER´s) will be identified. At the present day identified KERs are listed in Table 5 1. In the frame of the 1 year General Assembly (GA)-meeting a workshop will be organized by VAR to update and upgrade the list of KERs (check of validity and completeness). In this workshop, the project´s researcher and industry partners will contribute to the KER´s list to achieve a target-oriented exploitation of the project outcomes.

   In the frame of this workshop a lead partner will be aligned to every identified KER. Furthermore, the involved partners will be determined.

2. The dedicated lead partner will then be responsible to complete a template document. The preparation of this template document is in the responsibility of VAR and will incorporate the following key elements of the exploitation process:

   a. KER title
   b. KER description (1/2 to 1 page)
   c. Technical Results (1 to 2 pages, including figures)
   d. Exploitation per partner (2 to 3 pages)
      Nature of exploitation
      Form of Exploitation
      Detailed description of exploitation
   e. Background/Foreground Knowledge Analysis
   f. Risk Analysis (including risk and mitigation strategies)
   g. Joint-ownership management
   h. Intellectual Property management
   i. General conclusion

3. It will be the responsibility of the dedicated lead partner to complete the KER document, supported by the involved partners. VAR will collect these documents and comprise them in one report, the exploitation plan. This document will include the information gathered by the partners on areas, sectors or agents outside the consortium that could be interested in exploiting the results. The report will also provide information by the industrial partners on market needs. With this information the project partners will be able to assess the market potential and barriers. In this context also enablers and constrains for the exploitation can be determined.

4. The exploitation plan will be updated each 6 months by the lead partners.

5. In the frame of the AB meeting at month 18 (D6.4) the exploitation status based on this report will be discussed and necessary measures to promote the exploitation e.g., with industrial partners will be undertaken.

6. Update and further evaluation of changes will be continued to the end of the project and the outcome will be discussed again in the frame of the final presentation at the AB meeting at month 36 (D6.5)

Exploitation is considering also the Key Exploitable Results. An example for the developed documents for each KER was reported shown in according to Fig.7.

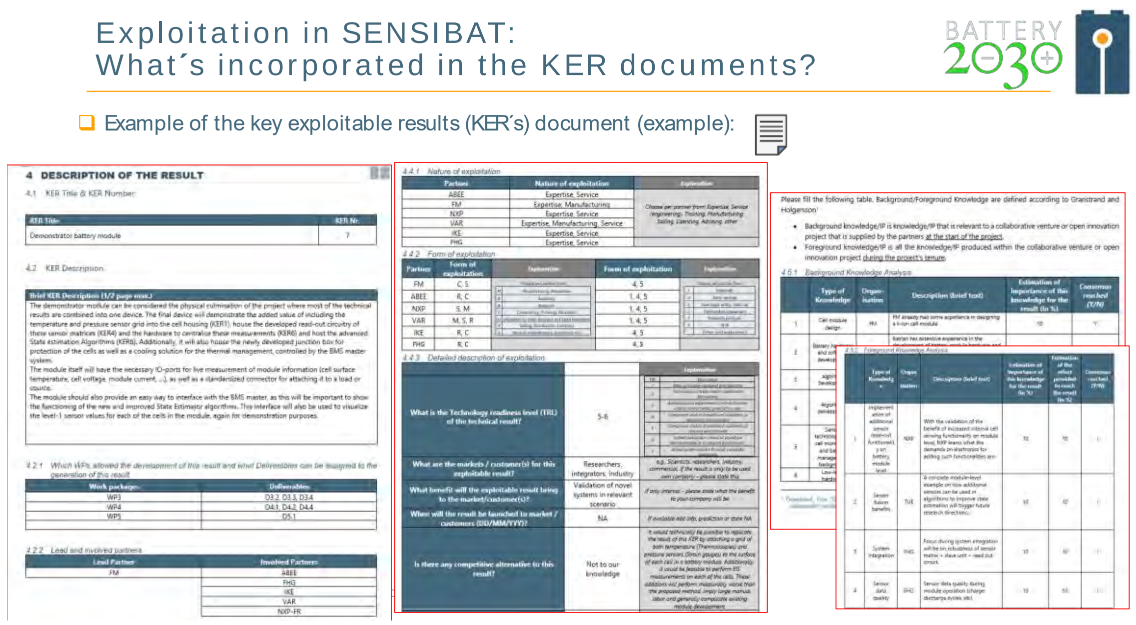


Figure 3-9 Key Exploitable Results

In this context, the project partner also informed the AB about some key findings evaluated by the preparation of the KER documents. For example, it can generally be estimated that:

- The nature of exploitation from SENSIBAT is strongly Research and Consultancy, Training and Education related, followed by Manufacturing and Selling.
- The planned form of exploitation is mainly internally and for further Research programs

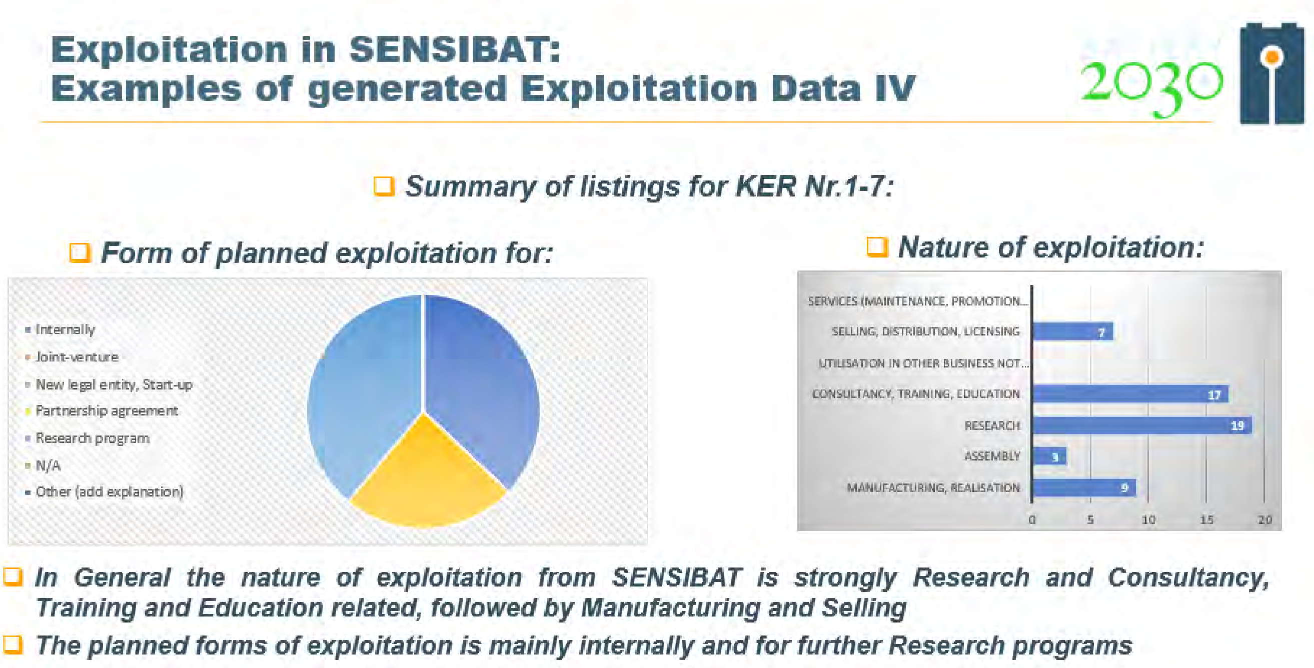


Figure 3-10 Example Overview of generated exploitation data

Finally, some questions were asked to AB to encourage a discussion around the results exploitation:

- As there are two Pathways (Exploitation plan together with Battery 2030+ partners) or individual Exploitation in SENSIBAT, what is your recommendation of Exploitation Strategy to follow (individual or combined)?
- The high amount of Internal and Research related Exploitation forms is understandable as the developed Sensors strongly focus on a single cell format – in other words – the technology of such sensors is established but there is still the need to adopt this technology to a potential costumer´s cell format (TRL increase)
    - o Would you agree on this point?
    - o Can you recommend strategies to tackle this issue? (e.g. apply for a further project based on the technologies achieved and focus on the sensor integration of commercial available cells (e.g. wound cell format like 18650/21700 cells)

The AB reported their experience about the importance of giving presentations of the results at events and using demonstrators. Although, this is partially covered by Battery2030+ initiative with its dissemination and exploitation activities. SENSIBAT partner will participate in important events.

AB experts also observed that the main priority, when results are available, is to start to search for partners that provide SENSIBAT with information on application fields and issues on bilateral basis.

3.8 Education activities

Some education activities are also part of the dissemination aspects of SENSIBAT. On March 7th and 8th 2022, a zeroing course was offered to all Battery2030+ community. More than 240 attendees registered at the event.

The AB replied reporting the importance of Education in the European landscape in particular considering the huge demand of skilled people to work in next future in battery field. Strategy needs to be adapted and flexible to the needs of the new community; what are requirements from community and the application fields.

4 Conclusion

Advisory Board experts generally agreed that the 1st SENSIBAT Advisory Board Workshop had a good success and that they looked forward to following SENSIBAT project developments in the near future.

The positive feedback given by the AB was satisfactorily received by SENSIBAT partners. In addition, project partners found very positive the questions discussed during the workshop.

5 Annex 1 – List of participants

Attendees Partner No.	Name
1 IKE	Inigo Gandiaga
2 BDM	Francesco Bonaccorsco
2 BDM	Hossein Beydaghi
2 BDM	Sebastiano Bellani
3 POL	Silvia Bodoardo
3 POL	Andrea Marchisio
3 POL	Piera Di Prima
4 FhG IISB	Martin Wenger
4 FhG IISB	Michael Jank
4 FhG IISB	Vincent Dreher
5 FM	Joris de Hoog
6 TUE	Feye Hoekstra
8 NXP-FR	Martin Royer
8 NXP-FR	Dominique Defossez
8 NXP-FR	Marie Castignolles
9 ABEE	Danial Karimi
10 VAR	Harald Kren
12 UNR	Maaike van der Kamp
12 UNR	Roos Leupen
AB MSWtech	Wolfgang Mildner
AB LithiumBalance	Enrico Baldasso
AB EMIRI	Philippe Jacques
Battery2030+	Simon Perraud

6 Annex 2 – Presentations of the AB Workshop

BATTERY 2030+

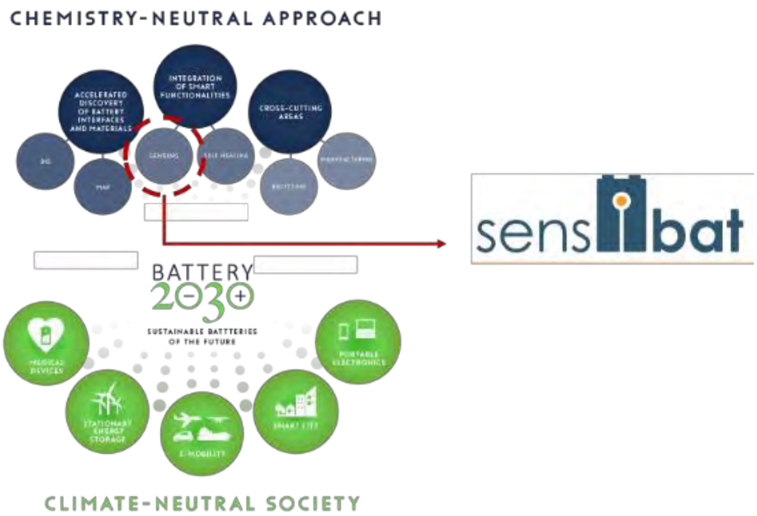
sensibat

SENSIBAT Introduction

SENSIBAT | GA #957273 | Advisory Board | Confidential 24/03/2022 3

Link to Battery 2030

BATTERY 2030+



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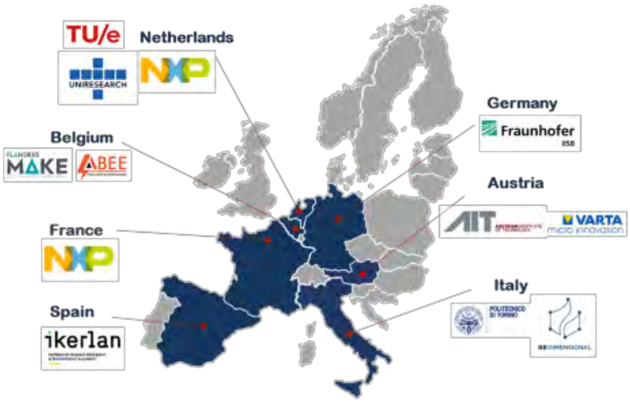
Facts & Figures

- Call H2020-LC-BAT13-2020
- Coordinator Ikerlan S. COOP
- Duration 36 months
- Start date 1 Sep 2020
- Budget/funding 3.3 M€



Consortium
12 partners from **7** countries including key partners from **whole value chain**

Overall objective – aim and vision

Current challenges

- Use of Li-ion battery cells (LIB) comes with safety risk
- Limited range, power and relatively long charging times
- Limited re-use of electric vehicle batteries
- Degradation-mechanisms of LIB not yet fully understood
- Accurate monitoring and control of the battery operation is challenging

Overall objective – aim and vision

SENSIBAT objective

Develop sensing technology that measures in real time the internal battery cell:

- Temperature
- Pressure (gas evolution, mechanical strain)
- Conductivity (ionic and electronic)
- Impedance of different cell parts (e.g. anode, cathode, electrolyte

Data from sensing technology

↓

Improve state estimator functions and include these in Battery Management System

↓

Gain insights into the possible degradation and failure mechanisms

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Overall objective – aim and vision

SENSIBAT targeted impact

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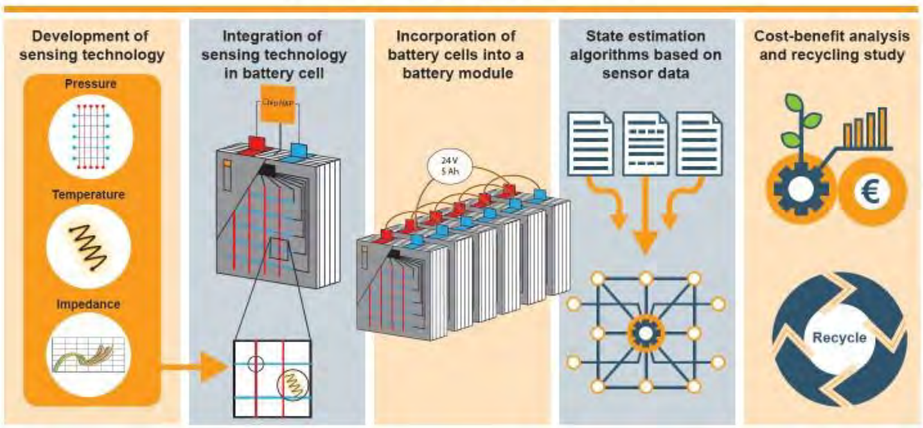
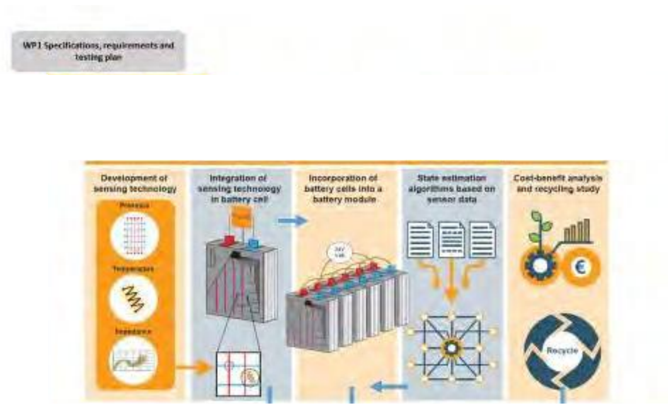
Work Plan



Work Plan

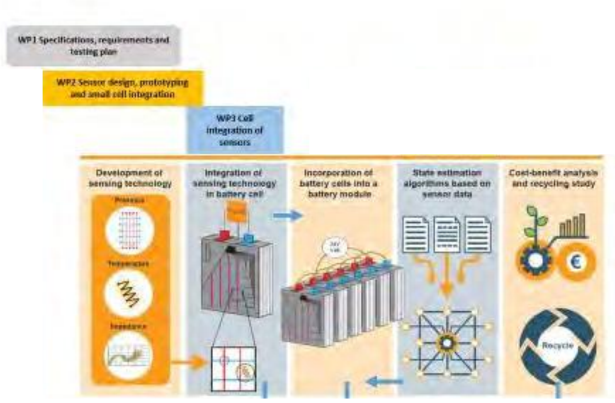


WP1

- Overview of the requirements at sensor, cell and module level
- Test plan taking the defined requirements into account

Work Plan

BATTERY 2030+



WP1
- Overview of the requirements at sensor, cell and module level
- Test plan taking the defined requirements into account

WP2
Develop sensors based on printed auxiliary electrodes (L2 sensor)

WP3
Realise dedicated NMC Li-ion pouch battery cells for:
- Baseline cells (1 Ah and 5 Ah)
- Cells with integrated Level 1 sensor (1 Ah and 5 Ah)
- Cells with Level 2 sensor (1 Ah)

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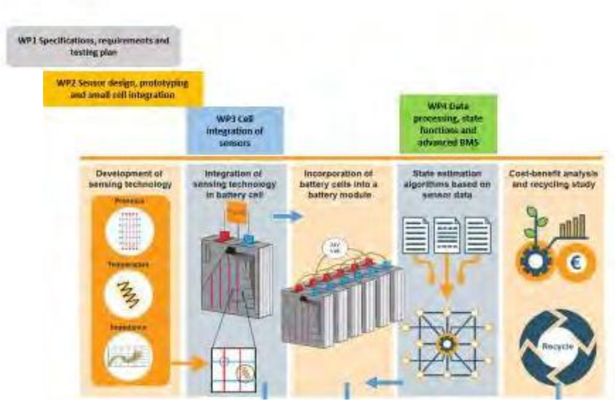
Work Plan

BATTERY 2030+



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WP4
- Advanced module-level state estimators based on L1 sensors
- Advanced cell level state estimation algorithms based on L2 sensors
- BMS-slave supporting the read out of cell-integrated L1 sensors
- BMS-Master and PDMU with L1 SoX algorithms
- BMS-slave-equipped battery module based 5Ah prototype pouch cells with L1 sensors

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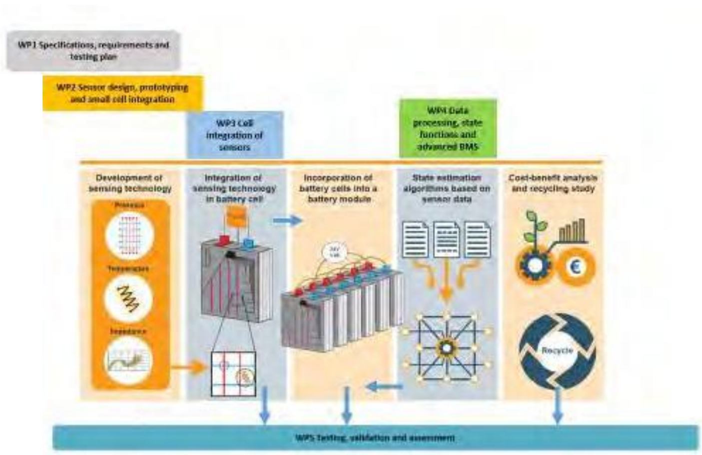
Work Plan



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WP5
- Validation of pouch cells with integrated sensors (L1 and L2)
- Validation of developed module including BMS
- Cost benefit assessment of the batteries including sensors
- Recyclability assessment of the cells (including sensors) and the module
- Validation of assumptions, targets and hypotheses relating to cell and module with respect to performance and safety – quality, reliability, lifetime, identification of defects.

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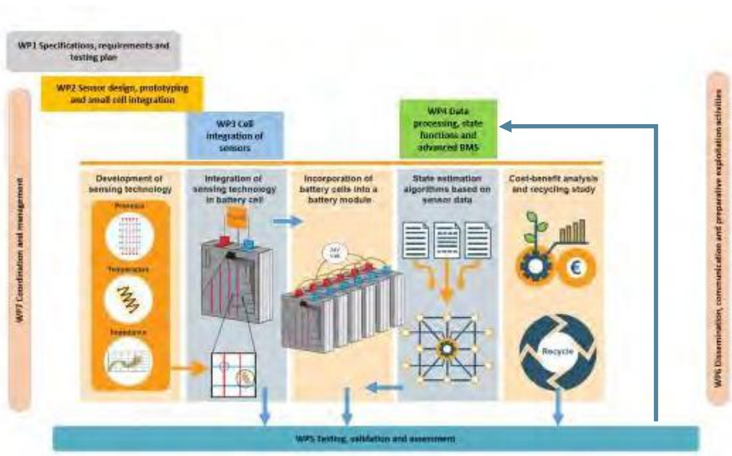
Work Plan



All project results can be found on sensibat-project.eu website in the form of deliverables

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Advisory Board

The purpose of an Advisory Board

The role of an Advisory Board is not to make decisions.

But to provide:

- **Current knowledge**
- **Critical thinking**
- **Analysis**

to increase the confidence of the decision -makers who represent the project

So please think, speak, ask questions …

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Temperature and Pressure sensors (Level 1)

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Background

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Temperature and Pressure Sensors (Level 1)

Goal: A system for aquisition of *in situ* cell data for model development (lab) and state monitoring (life)

Technical Specs.	Cell Requirements	Cost boundaries
• accuracy, reliability • spatial resolution • electronic integration	• mechanical flexibility • cell compatibility: electrolyte, thickness, no topology • feed-through	• system price lab eqt. • large-volume per piece cost model

⇨ All requirements can be met by thin-film systems built on monolithically integrated sensing devices

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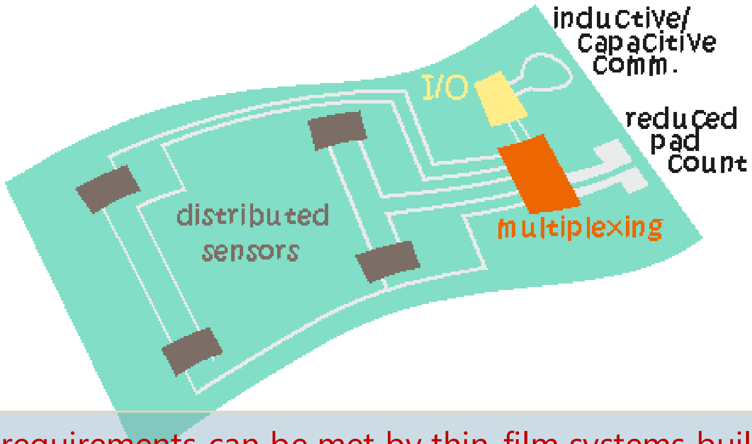
Temperature and Pressure Sensors (Level 1)



⇨ All requirements can be met by thin-film systems built on monolithically integrated sensing devices

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Thin-Film Technology: Print vs Vacuum

Printing Technologies
- Additive manufacturing
- Facile Roll-to-Roll integration
- Availability/maturity of materials?
- Ideal for large volume manufacturing and application

Vacuum Technologies
- Broad range of materials @ high quality available
- High resolution and precision for prototyping or measurement devices accessible
- Ideally suited for prototyping, lab instrumentation, test systems

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Technology

p/T Sensors in SENSIBAT: Temperature Sensors

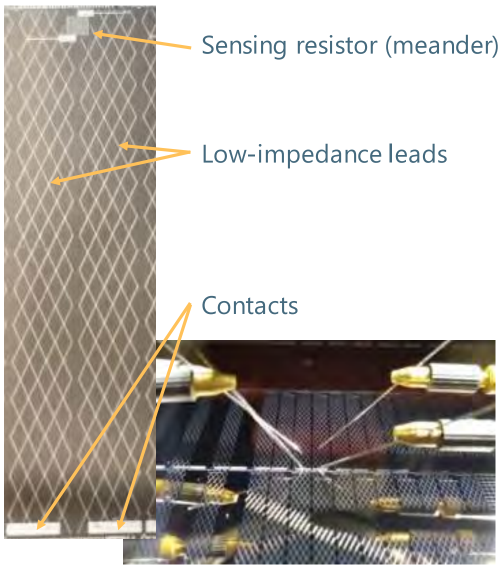
Principles of **resistive temperature sensors**

- Temperature Coefficient of Resistivity (TCR,) defined e.g. by scattering in metals at elevated temperatures

$$R(T) = R_{ref}\left[1 + \alpha \cdot \left(T - T_{ref}\right)\right]$$

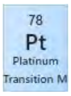
- Typical TCR values

Metal	TCR, a
Platinum	$3.1 \cdot 10^{-3}\ K^{-1}$
Aluminum	$4.0 \cdot 10^{-3}\ K^{-1}$
Cu-Ni alloy (constantan)	$\pm 10^{-5}\ K^{-1}$
Silicon	$-7.5 \cdot 10^{-2}\ K^{-1}$

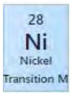


p/T Sensors in SENSIBAT: Temperature Sensor

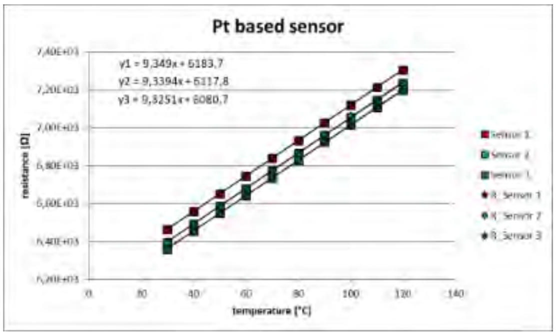
- Materials evaluated as sensing material:
  - Platinum:



    - TCR = 3,8 *10^{-3} $^{1}/_{K}$
    - σ = 9,7 *10^{6} $^{S}/_{m}$
    - High chemical inertness/nobility
  - Nickel:



    - TCR = 5,8 *10^{-3} $^{1}/_{K}$
    - σ = 13,9 *10^{6} $^{S}/_{m}$
    - Good chemical inertness, passivation behaviour, inexpensive



- Aluminum-based metallisation to contact the sensing structure

TCR = temperature coefficient of resistance /σ = conductivity

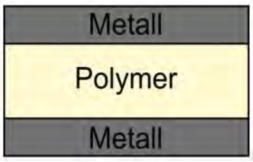
p/T Sensors in SENSIBAT: Pressure Sensors

Principles of **capacitive pressure sensors**

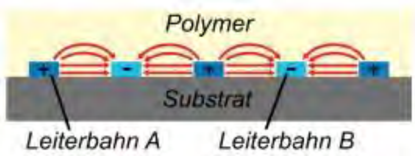
- Capacity value is sensitive to the dielectric function $_r$ between electrodes

$$C = \frac{\varepsilon_0 \varepsilon_r d}{A}$$

Capacitance *C* of parallel plate configuration
$_0$: permittivity of vacuum
$_r$: dielectric function (also: *k*)
d: distance of electrodes
A: area of electrodes



Parallel plate capacitor



Interdigitated finger capacitor (stray capacitances)

- Compression of a polymeric dielectric leads to an increase of capacitance by $_r$↑ (and *d*↓)
- Evaluation / exploitation of different materials and device architectures

p/T Sensors in SENSIBAT: p Test Environment

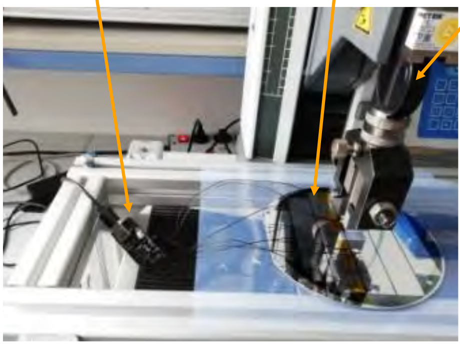
Measurement setup for pressure sensors

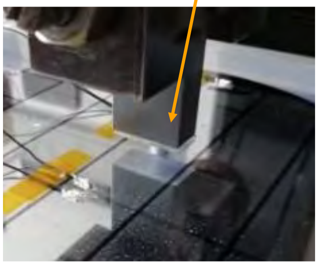
Read-out electronics (µC)

Substrate with pressure sensors (test-layout)

Load cell

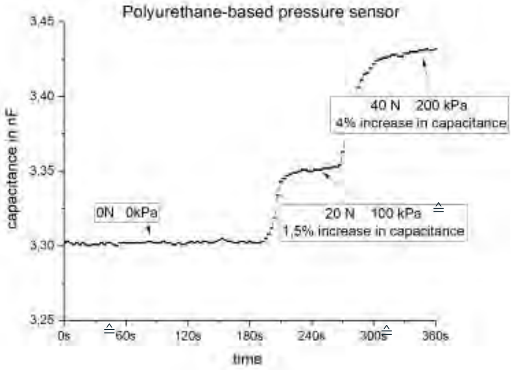
2x1cm stamp





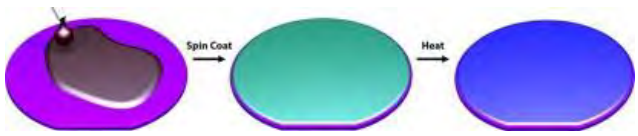
Exemplary results (PU)

Force is applied in 20 N steps and kept for 60 s



p/T Sensors in SENSIBAT: Flex Processing

- Dedicated Coat & Release technique for processing of flexible electronics
  - 150mm silicon wafer as carrier
  - Polyimide as substrate for electronics
- Substrate scheme is compatible to
  - thin-film processing up to 350 °C
  - wet processing (photo + etching)



Status

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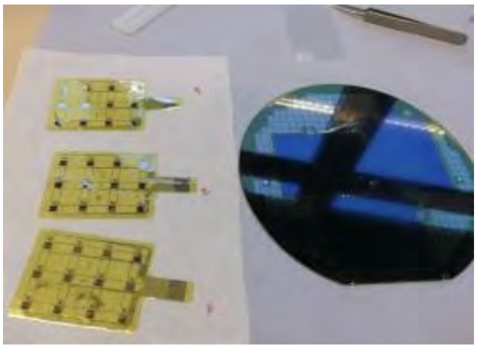
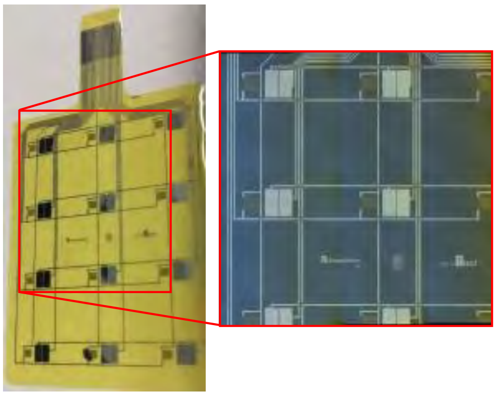
p/T Sensors in SENSIBAT: Release

- 2x12 (p/T) for 1Ah cells: Final matrix size defined by laser cutting
- Matrices are peeled off the carrier





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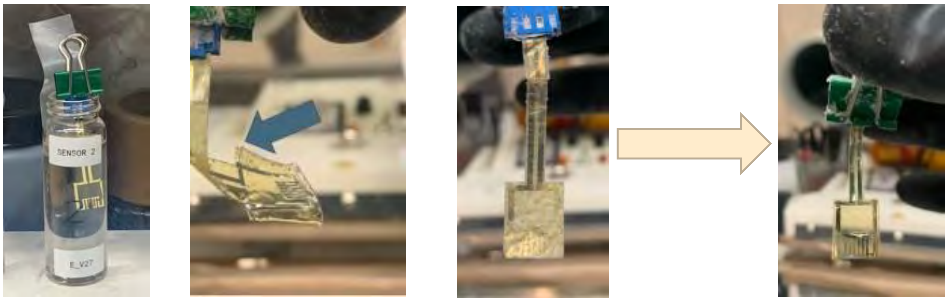
p/T Sensors in SENSIBAT: Encapsulation

- Optimization of parylene encapsulant
  - materials selection, adhesion layers and post-deposition annealing

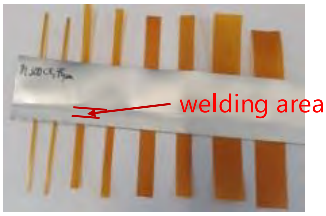


Samples after 1 month dipping in electrolyte @ Varta Innovation: different stages of development

p/T Sensors in SENSIBAT: Feed-through

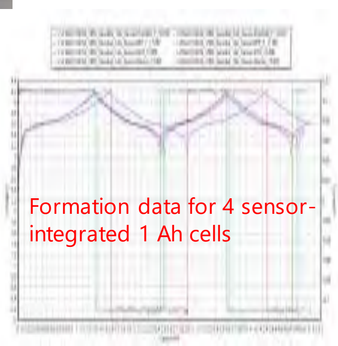
- Engineering and test

from materials sampling



via real integration

until application tests



Q&A, Feedback, Discussion

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Questions from the consortium

High-end, disposable, lab-type product

- Is the application „complete“? What else is needed?
- What should a test system look like? Lab standards?
- „Retail price“, sensor sheet vs read-out system?
- Marketing and commercialization strategies?
- Cost model/commercial partners for mfg (?) and retail?

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Questions from the consortium

Large-volume application

- Print vs vacuum?
- Materials availability for print?
- Cost model vs entrance barrier?
- What is the BMS point-of-view?

sensibat

Impedance sensor (Level 2)

Impedance sensor (Level 2): what is it?

The impedance sensor technology refers to:

- A reference electrode printed on a face of the separator
- A second separator is used above the first one to sandwich the printed reference electrode
- The reference electrode enables:
  - *In-situ* Electrochemical Impedance Spectroscopy (EIS)
  - Reliable *in-operando* measurement of the electrolyte conductivity and its change during the cell operation
  - Accurate monitoring of cathode and anode potential (*e.g.*, control of Li plating at anode and electrolyte decomposition at the cathode in presence of overcharging)

These reference electrodes must be printed onto the cell separator positioned between the active anode and cathode

KEY-REQUIREMENTS OF THE REFERENCE ELECTRODES:

- They should **not interfere** with the operation of the battery
- They should **deliver accurate data** for indications and understanding of degradation mechanisms that may happen at anode, cathode or electrolyte.

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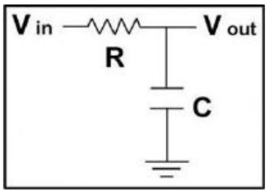
Reference electrodes: preliminary considerations

- **An ideal reference electrode must be non -polarizable**, which means that the corresponding DC resistance must be minimized (since common potentiostats/galvanostats have input current lower than 100pA, the resistance of reference electrode up to 10 kΩ are, in principle, acceptable to avoid relevant voltage losses in DC mode).
- The capacitance of the reference electrode is in series with the resistance of the electrode itself, which means that **the reference electrode behaves as a low -pass RC filter**

Rule of thumb: RC constant of the reference electrode must be maximized to guarantee a wide band operation at frequencies up tens/hundreds of kHz, such as those used in EIS experiments to check the electrolyte conductivity)



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Question n.1

What are traditional reference electrode configurations?

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Question n.2

What are the current limitations of both wire- and mesh-like reference configurations?

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Question n.3 & 4

What are (or could be) the advantages of our printed reference electrodes?

The porous nature of our reference electrode should intrinsically solve the ion blocking effect issues

What are the impedance contribution of our reference electrodes (how modelling them)?

Challenges of industrialization

- High-throughput deposition of our reference electrodes on flexible substrate (*i.e.*, Celgard 2500)
- Extra-cost of our reference electrode-coated separators
- Additional separator (can it affect the pouch cell manufacturing chain?)
- How to perform in-situ reference electrode preconditioning (risk of electrode overcharging)?
- …

Module Development

Objectives of WP4 – Module Development

- Realize a BMS slave for reading out L1 equipped cells
- Develop BMS master for interfacing with Slaves and hosting the BMS software:
  - State tracking (SOC, SOH, SOE, SOP, SOS)
  - Safety monitoring (with PMDU)
  - Auxiliary functions:
    - Cell balancing
    - Thermal strategy
    - …

Module Development - Results

- BMS Slave:
  - Sensor readout circuit concept is finished
  - Multiplexor in SW is being build on development platform
  - HW integration with slave is being breadboarded
- BMS Master:
  - Low- and high-level functionality is defined
  - Hardware selection is done
  - Interface with PMDU is finished and functionally validated
- PMDU:
  - Finished and validated

Q&A, Feedback, Discussion

Discussion points

- Sensibat module serves as a demonstrator of:
  - Usefulness of having L1 sensor -cells
  - Usefulness of new State Estimator algorithms
- What kind of SoX algorithms are currently used in practice?
- Is there a need for improvement?
  - How to validate our models in such a way that companies take notice?
    - We will focus on boundary conditions (100->80% SoC, 20->0%SoC)

Discussion points

- The market demands an SoS (State of Safety) algorithm? What aspects do you think are important in a SoS?

Discussion points

Module will be 24V – 6 cell string

- What application could be used to present findings?
  - Simple DC source/load is efficient but does not inspire companies
  - Simulation of complete drive-cycle (WLTP, others?)
  - Battery pack for electric kart?
  - Battery pack for solar panels?
  - Industrial application (forklift, robot, …)
  - …

Discussion points

Development of the BMS master:

  - Based on Arduino (C) and Raspberry Pi (Python) combo
- Should we aim to release this software somehow?
- What (if any) would be of interest to system integrators

Discussion point

- Module development:
  - Each cell is equipped with 2 sensor arrays
  - Multiplexing sensor-wires for read-out by BMS slave
  - ➔ A lot of additional wiring.
- Potential blocking factor for market penetration:
  - Sensor concepts need to be really worth it.

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Discussion points

Thermal considerations

- We will be able to pinpoint hotspots in the battery housing:
  - How to exploit this information for cooling strategy?
  - Any active cooling techniques that can be applied?

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Discussion points

- Chip shortage:
  - BMS slave software development is done on a NXP PSOC5 development board
  - Standalone PSOC5 chips are not available
  - PSOC6 chips are available, but there is no development board
  - ➔ we are developing the software on a PSOC5 development board, but implementation will be done on the PSOC6 chip.

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Discussion points

- From the module perspective, do you find usable to know the evolution of the internal pressure of cells?
- With solid state batteries do you think it can be a very important issue?
- Should cells be constrained in the battery pack to exploit the pressure sensors in the best way?

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Exploitation and education

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Exploitation

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Exploitation in SENSIBAT

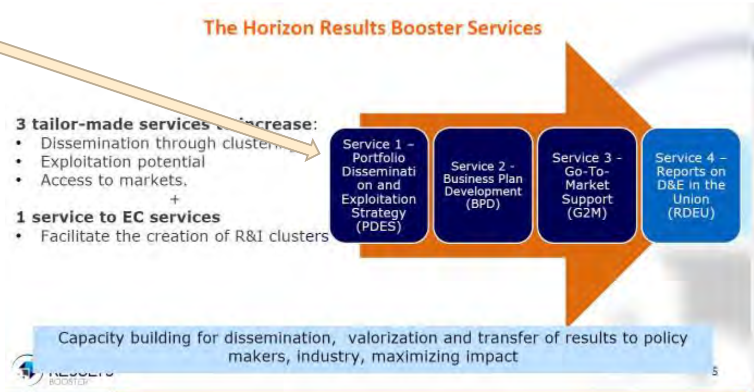
General Objectives:

- ensure the use and the dissemination of knowledge generated during the project by clearly identifying the project outcomes (products, technology and services)
- create a results portfolio (→ Key Exploitable Results (KERs))
- maximise the impact of the project

Exploitation in SENSIBAT

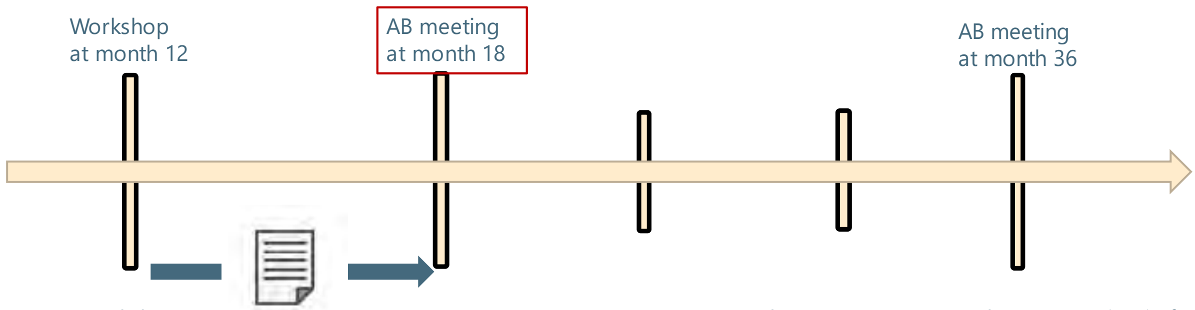
Next to internal, individual Exploitation in SENSIBAT Exploitation activities in SENSIBAT will be further strengthened by joint Exploitation actions in the frame of the Battery 2030+ program:

- Joint apply by all Battery 2030+ projects for the Horizon Results Booster (service 1) tool, offered by the European Commission.
- Service 1= Portfolio Dissemination and Exploitation Strategy and will start with 1st April 2022 (duration 35 days)



Exploitation plan SENSIBAT: Methodology I

Methodology of the projects Internal Exploitation Plan:



- Workshop
- update and upgrade the list of KERs

- established doc
- Presentation in front of Advisory Board
- discussion exploitation status

- updates

- Results Presentation in front of Advisory Board
- discussion exploitation status

Exploitation plan SENSIBAT: Methodology II

❑ Methodology of the projects Internal Exploitation Plan:

predefined procedure allows to analyse each exploitable result and its marketable value:

1. Initially, all key exploitable results (KER's) will be identified (In the frame of the 1 year GA-meeting a workshop by update and upgrade the list of KERs (check of validity and completeness)
   1.1 In the frame of this workshop a lead partner will be aligned to every identified KER. Furthermore, the involved partners will be determined.
2. The dedicated lead partner will then be responsible to complete a template document (provided of VAR). Document will incorporate:
   a. KER title, KER description, Technical Results, Exploitation per partner with Nature, Form and Detailed description of exploitation, Background/Foreground Knowledge Analysis, Risk Analysis, Joint ownership management, Intellectual Property management, General conclusion
3. VAR collected these documents and will comprise them in one report, the exploitation plan.
4. The exploitation plan will be updated each 6 months by the lead partners.
5. In the frame of the AB meeting M18 & M36 the exploitation status based on this report will be reported and discussed

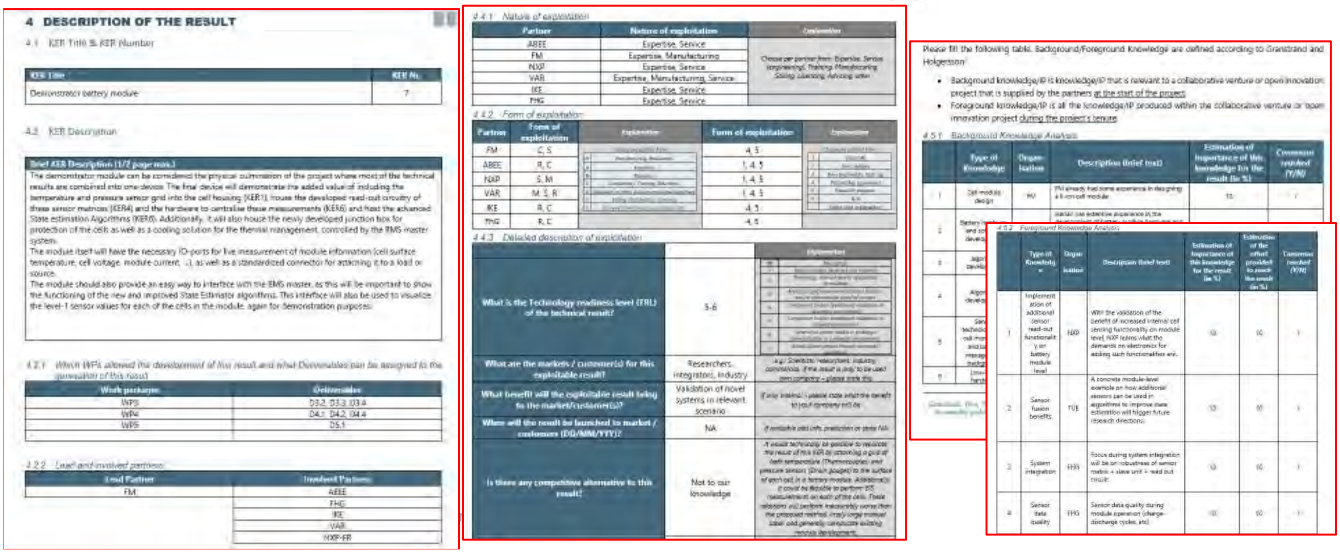
Exploitation in SENSIBAT: Identification of KERs

- Identified Key Exploitable Results (KERs) by the project partners at the present:

Ker No.	KER Titel	Lead partner	Involved partners	Main innovation
1	**Internal temperature and pressure sensor technology**	FHG	ABEE, AIT, VAR	Internal temperature and pressure sensor technology including the knowhow to design, manufacture, connect and integrate the sensor into the cell
2	**Internal auxiliary electrode technology**	BDM	POL, AIT, ABEE, VAR	Internal auxiliary electrode technology including the knowhow to design, manufacture, connect and integrate the electrodes into the cell
3	**In-operando electrical impedance spectroscopy as a tool to analyse internal battery degradation mechanisms/kinetics**	POL	TUE	Electrical impedance spectroscopy technology including the knowhow to model, analyse the results and correlate them to internal battery degradation mechanisms/kinetics
4	**BMS slave development**			BMS-slave development including a multi-cell read-out circuit that reads out the cell-integrated temperature and pressure sensors and communicate with the BMS-master
5	**BMS master development**			BMS-master development including communication with the BMS-slave and improved battery management
6	**Improved SOC, SOH, SOE, SOP state estimation algorithms**	IKE	ABEE, FM, TUE, NXP-NL	Improved state estimation algorithms for the SOC, SOH, SOE, SOP and novel concept for SOS (based on Level I and Level I + II sensor technology)
7	**Demonstrator battery module**	FM	ABEE, FHG, IKE, VAR, NXP-FR	Demonstrator battery module based on the series connection of at least six 5Ah pouch cells with sensors and equipped with BMS and cell and module level state functions

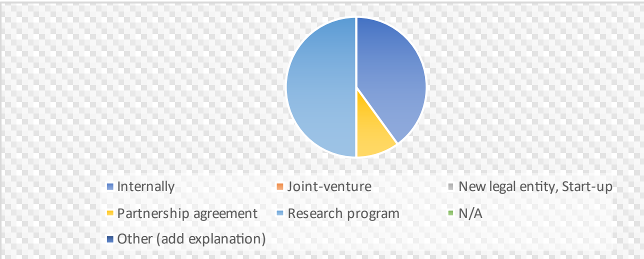
Exploitation in SENSIBAT: What´s incorporated in the KER documents?

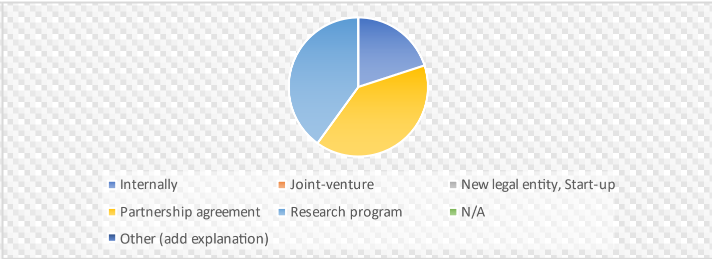
- Example of the key exploitable results (KERs) document (example):



Exploitation in SENSIBAT: Examples of generated Exploitation Data I

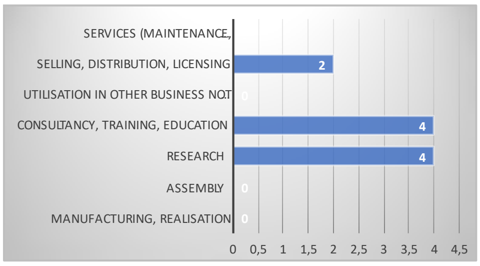
KER Nr.1: Internal temperature and pressure sensor technology Vs: **KER Nr. 7 / Demonstrator battery module**

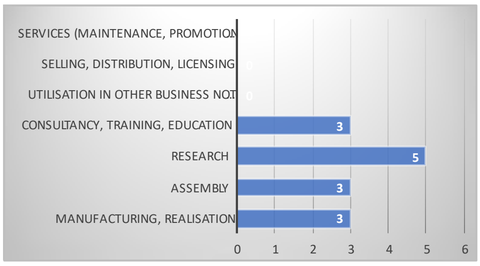




Exploitation in SENSIBAT: Examples of generated Exploitation Data II

KER Nr. 6 / Improved SOC, SOH, SOE, SOP state estimation algorithms Vs: **KER Nr. 2 / Internal auxiliary electrode technology**





Exploitation in SENSIBAT: Examples of generated Exploitation Data III

❑ Risk Analysis (including risk and mitigation strategies):

Example: KER Nr.1: Internal temperature and pressure sensor technology

Highest risks Priority for archiving KER1 are problems of sensor stability (technological) and the importance gain of different cell formats (environmental) which would demand adoption of the sensors

No	Category	Description	Severity	Probability	Risk Grade	Action we may take to prevent the risk or to solve it	Probability of success	Priority
	e.g.: Technological-, Market-Financial-, IP-, Supplier-, Personnel-, Political-, Health & Environmental Risks	*be clear enough in explaining*	*1: Low- 10: high*	*1: Low- 10: high*	*Multiplicate: "Severity" and "Probability" Value*		*1: Low- 10: high*	*Multiplicate: "Risk Grade" and "Probability of success" Value*
R1	*Technological*	Better, smaller, smarter sensors	5	5	25	Adaption improvement of developed sensor device	7	175
R2	*Market*	New cell chemistries (like Solid-State Batteries)	1	5	5	In Principle these chemistries are foreseen to need comparable detection methods for pressure/temperature	9	45
R3	*Technological*	Problems with the sensor stability	10	5	50	Better/improved encapsulation	5	250
R4	*Environmental*	Pouch cells will be replaced by wounded cells	10	5	50	Adaption of sensor layout for wounded cells	5	250

Exploitation in SENSIBAT: Examples of generated Exploitation Data IV

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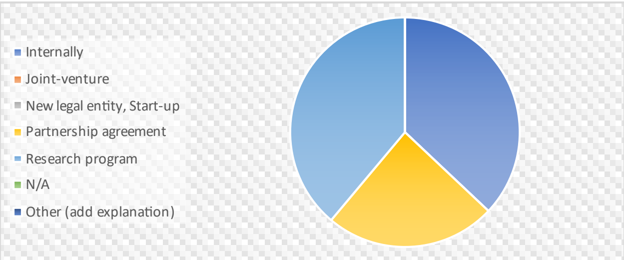

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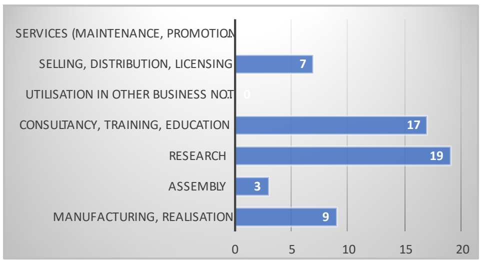

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Q&A, Feedback, Discussion

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Exploitation in SENSIBAT: Questions:

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Education

Education – First activity

Agenda 7 March 2022			
#	**Start-end time**	**Topic**	**Chair**
1	09:00 – 09:15	Welcome	POLITO
2	09:15 – 09:30	BATTERY 2030+ introduction	
3	09:30 -10:00	Li-ion cells introduction; Chemistry, application, ageing, safety	POLITO
4	10:00 – 10:30	Overview of the battery states: i) Cycle states: SOC, SOH, SOE, SOP ii) Life states: SOH, SOS	VARTA JP
5	10:30 – 10:45	Break	
6	10:45 – 12:30	Processes influencing lifetime states: i) SOH - Aging processes on capacity ii) SOS - Aging processes on safety measures	POL

Agenda 8 March 2022			
#	**Start-end time**	**Topic**	**Chair**
1	09:00 – 10:15	Sensors for measuring battery states including the pressure and impedance states	IKERLAN & FRAUNHOFER IISB
2	10:15 – 10:45	How to calculate and measure the battery states	IKERLAN
3	10:45 – 11:00	Break	
4	11:00 – 11:50	Modelling with sensors & implementing of the models in the BMS	POLITO & FLANDERS MAKE
5	11:50 – 12:30	*To be decided*	

For students and researchers
Zeroing course to reach starting level

The zeroing course will take place on the **7th** and **8th of March** from **09:00 - 12:30**

REGISTRATION BEFORE MARCH 3RD :
https://forms.office.com/pages/responsepage.aspx?id=iXGDZS86DkCcJakFsv7IA2CTqPtmhRpCoFg3vyHhHqlUNlRMQ1RaTEtXVDMwU0VOWElNWlNDMVJQSi4u

In connection with Battery2030+
Currently over 180 registrations

Education to society
Torino: Researchers' Night (POLITO) October 2021

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Q&A, Feedback, Discussion

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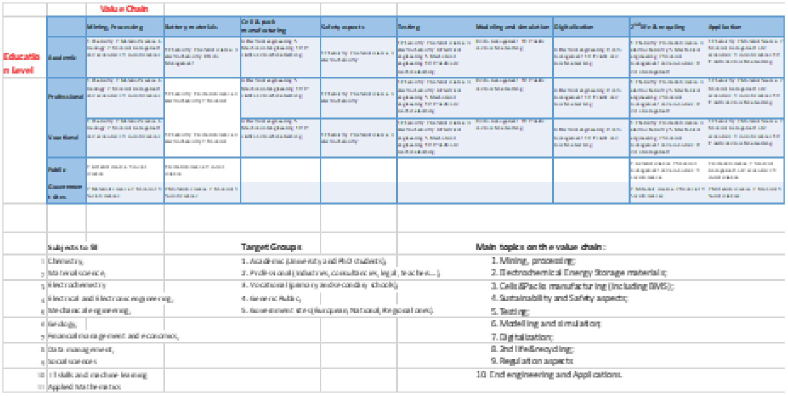
Q&A, Feedback, Discussion

Need to define new curricula topics: how new aspects as the one of sensors in cells can be part of new curricula?

How to engage more new generations in so disruptive activities and give them more visibility?
e.g. Young scientist events



Education level		Mining, Processing	Battery materials	Cell & pack manufacturing	Safety aspects	Testing	Modelling and simulation	Digitalisation	2nd life & recycling	Application
	Academic	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Professional	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Vocational	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Public	[illegible]	[illegible]						[illegible]	[illegible]
	Government sites	[illegible]	[illegible]						[illegible]	[illegible]

Subjects to fill:
1 Chemistry;
2 Material science;
3 Electrochemistry;
4 Electrical and electronic engineering;
5 Mechanical engineering;
6 Geology;
7 Financial management and economics;
8 Data management;
9 Social sciences;
10 IT skills and machine learning;
11 Applied Mathematics

Target Groups:
1. Academic (University and PhD students);
2. Professional (industries, consultancies, legal, teachers...);
3. Vocational (primary and/or secondary schools);
4. Generic Public;
5. Government sites (European, National, Regional ones).

Main topics on the value chain:
1. Mining, processing;
2. Electrochemical Energy Storage materials;
3. Cells&Packs manufacturing (including BMS);
4. Sustainability and Safety aspects;
5. Testing;
6. Modelling and simulation;
7. Digitalization;
8. 2nd life&recycling;
9. Regulation aspects
10. End engineering and Applications.

Disclaimer

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7 Acknowledgement

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Project partners

#	PARTICIPANT SHORT NAME	PARTNER ORGANISATION NAME	COUNTRY
1	IKE	IKERLAN S. COOP.	Spain
2	BDM	BEDIMENSIONAL SPA	Italy
3	POL	POLITECNICO DI TORINO	Italy
4	FHG	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	Germany
5	FM	FLANDERS MAKE VZW	Belgium
6	TUE	TECHNISCHE UNIVERSITEIT EINDHOVEN	The Netherlands
7	NXP NL	NXP SEMICONDUCTORS NETHERLANDS BV	The Netherlands
8	NXP FR	NXP SEMICONDUCTORS FRANCE SAS	France
9	ABEE	AVESTA BATTERY & ENERGY ENGINEERING	Belgium
10	VAR	VARTA INNOVATION	Germany
11	AIT	AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH	Austria
12	UNR	UNIRESEARCH BV	The Netherlands

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