This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Battery 2030+

Roadmap structure and process

Roadmap Workshop Oslo June 27th 2024

Philipp Veit

Christian Punckt

Maximilian Fichtner

Karlsruhe Institute of Technology

BATTERY 2030+

BATTERY 2030+

Structure of the initiative

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

LARGE-SCALE RESEARCH INITIATIVE

WP6 Project Management

BATTERY 2030+
SUSTAINABLE BATTERIES OF THE FUTURE

WP1
COORDINATION MONITORING

WP2
ROADMAP NEEDS AND GAPS

WP4
CURRICULA

WP5
COMMUNICATION ENGAGEMENT

WP3
FAIR DATA STANDARDS AND GUIDELINES

BATTERY 2030+ CSA3

SALAMANDER
RENOVATE
phoenix
OPINCHARGE
STREAMS
Revitalise
REUSE
BATTwin
HEALING BAT
OPERA
UltraBat
CICERO
BatCAT Battery Cell Assembly Twin

Structure of the initiative

Project Coordination:
- Kristina Edström (UU) – Project Coordinator
- Simon Perraud (CEA) – Deputy project coordinator

WP-leaders:
- Kristina Edström (UU) – WP1 Coordination
- Maximilian Fichtner (KIT) – WP2 Roadmap
- Simon Clark (SINTEF) – WP3 Best Practices and Standards
- Silvia Bodoardo (POLITO) – WP4 European Curricula
- Thomas Otuszewski (EASE) – WP5 Communication, Dissemination
- Kristina Edström (UU) – WP6 Project Management

Thematic leaders:
- Tejs Vegge (DTU) – Materials acceleration platform & battery interface genome
- Robert Dominko (NIC) – Smart battery functionalities
- Montserrat Casas (CICe) – New battery chemistries → **topic not represented in the current roadmap**
- Frédéric Aguesse (CIDETEC) – Manufacturability
- Marcel Meeus (UU) – Recyclability
- Maitaine Berecibar (VUB) - Battery management system (BMS) → **topic not represented in the current roadmap**

WP2 Maintain and develop roadmaps and identify future research needs

Task 2.1: Mapping of current activities and research/innovation needs in the identified R&I areas
Task leader: UU   Participants: REC, FZJ, CID, NIC, DTU, VUB, WWU, CICe, EMI, CNR, AIT, EMP, BEP

Task 2.2: Research Vision and Research & Innovation Roadmap
Task leader: KIT   Participants: UU, FZJ, CID, NIC, POL, DTU, VUB, WWU, WUT, CICe, EMI, CNR, AIT, ENE, EMP

Task 2.3: Proposition of future R&I actions in collaboration with BEPA
Task leader: CEA   Participants: CID, NIC, CICe

BATTERY 2030+

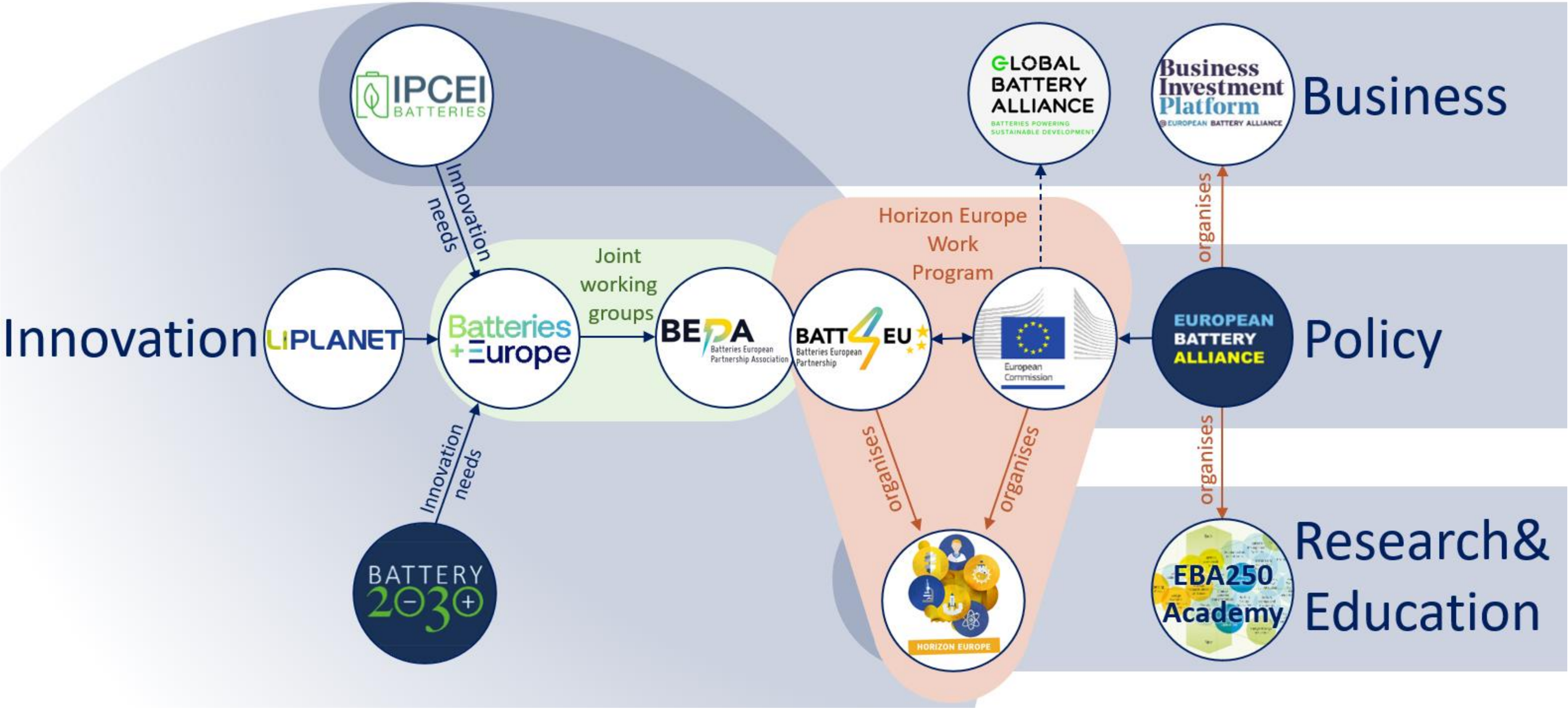
Proposed Timeline for the 2025 Roadmap

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Year	2024							2025											
Month of the year	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12
Month of CSA3	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
M2.1 Roadmap Workshop Oslo (KIT)	X																		
M2.2 Six proposals for R&I actions new calls (CEA)		X													X				
D2.3 Proposition for future R&I actions in Europe (CEA)					X														X
D2.1 National and international R&I programs and needs (UU)															X				
Input from the Writing Groups							X												
1st Draft										X									
2nd Draft													X						
D2.2 Roadmap 4th Edition Writing Period (KIT)																	X		
BEPA & Batteries Europe Activities																			
SRIA 1																			
BEPA Roadmap 2						X													
KPI III									X										
SRIA II										X									
Batt4EU Work Programme																			

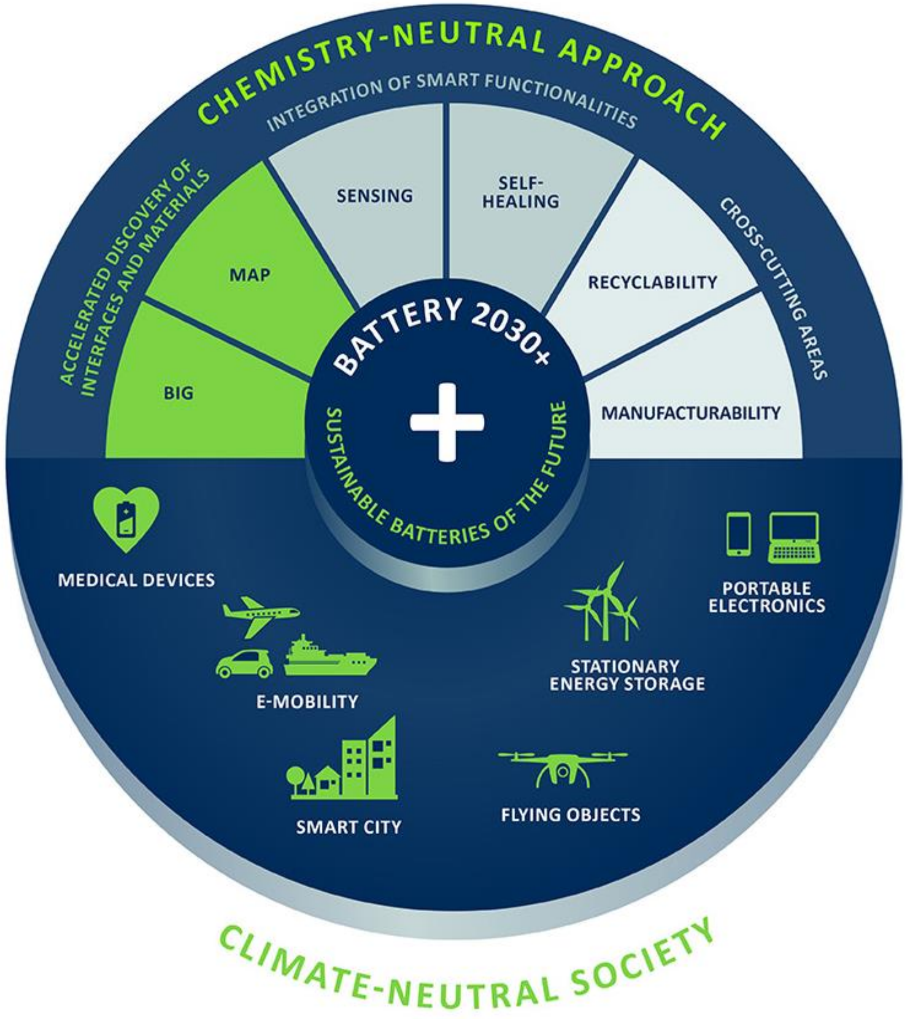
Task 2.3 Proposition of future R&I actions in collaboration with BEPA

→ **Connection of the roadmap with the Horizon Europe Work Program**



The roadmap

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.



CHEMISTRY-NEUTRAL APPROACH:

- Accelerated discovery of interfaces and materials – BIG-MAP
- Smart functionalities – sensing and self-healing
- Cross-cutting areas – manufacturability and recyclability

FUTURE BATTERY CHEMISTRIES

POST-LITHIUM BATTERY CHEMISTRIES
Sodium-ion, multivalent metal-ion, metal-air, redox flow, etc

LITHIUM BATTERY CHEMISTRIES
Generation 3 (advanced lithium-ion)
Generation 4 (all-solid-state lithium-ion or lithium-metal)
Generation 5 (lithium-air, lithium-sulfur)

EU work programme WP2022-2024

Call	Type of Action	Budget (M €)	EU contribution per project (M €)	Indicative no of projects to be funded	Topic	Deadline Application proposal	Project start
2022-D2-01-02	RIA	10.00	Ca 5.00	3	Interface & Electron	6 Sept 2022	**May - Sep 2023/#7**
2022-D2-01-06	RIA	15.00	Ca 5.00	3	Sensing & Self-healing	6 Sept 2022	**Phase 2 Projects**
2022-D2-01-08	CSA	3.00	Ca 3.00	1	CSA	6 Sept 2022	**CSA3**
2023-D2-01-01	RIA	21.00	Ca 7.00	3	Raw materials & material flow	18 April 2023	**Jan – Mar 2024/#8**
2023-D2-01-02	RIA	15.00	Ca 5.00	3	Recycability	18 April 2023	**Phase 3 Projects**
2023-D2-01-03	RIA	14.00	Ca 7.00	2	Digital Twins	18 April 2023	
2023-D2-02-02	RIA	10.00	Ca 5.00	2	Enhanced Safety Li Gen 3	5 Sept 2023	**May-Aug 2024/#2** **Phase 4 Projects**
2024-D2-01-01	RIA	21.00	Ca 7.00	3	End-of-Life (EoL) battery recycling	18 April 2024	**Jan - Mar 2025/ #5**
2024-D2-01-03	RIA	5.00	Ca 5.00	1	Circularity of EU battery value chain	18 April 2024	**Phase 5 Projects**
2024-D2-01-05	RIA	20.00	Ca 20.00	1	BIG & MAP	18 April 2024	
2024-D2-02-02	RIA	15.00	Ca 5.00	3	Post-Li-ion technologies Manufacturing	5 Sept 2024	**May - Aug 2025/#3** **Phase 6 Projects**
TOTAL		**€149M**		**25 projects**			

Outlook WP2025: 2 RIAs (advanced material manufacturing, long-duration), 1 CSA **Exp. Sept 2025** **Sep 2026**

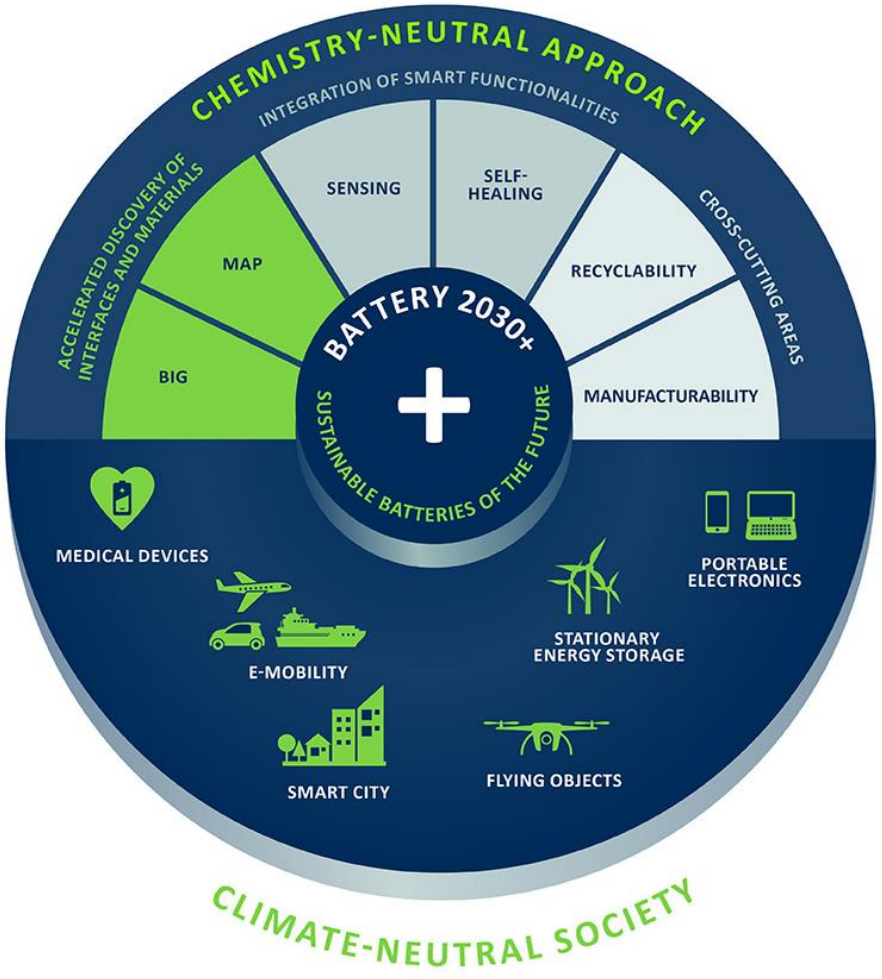
The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

- Materials Acceleration Platform (MAP)
- Battery Interface Genome (BIG)
- Sensing
- Self-Healing
- Recyclability
- Manufacturability

For each thematic area, the roadmap defines

- Current status
- Challenges
- Advances to meet challenges



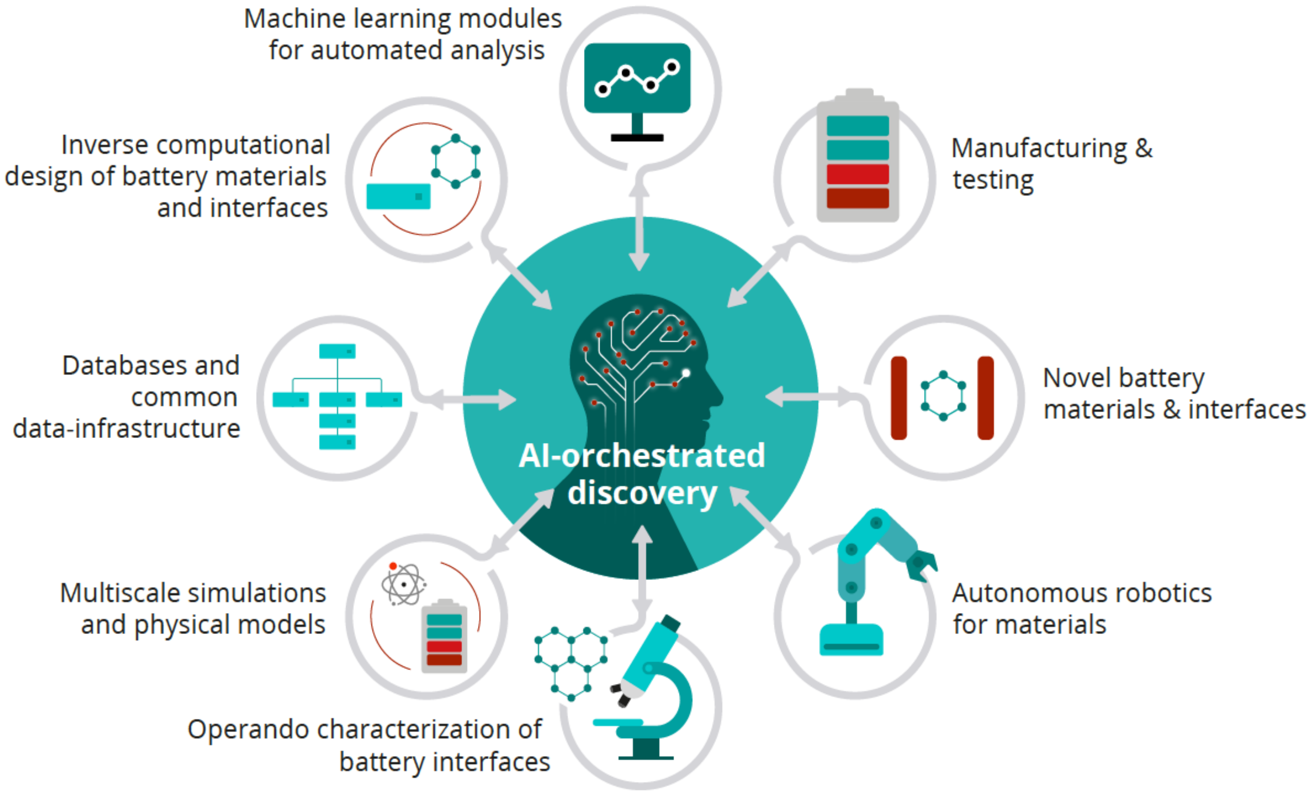
The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Materials Acceleration Platform

Advances needed:

- European strongholds
- Autonomous synthesis and testing
- High throughput & high fidelity
- Scale-bridging and integrated workflows
- AI integration
- Unified protocols
- Inverse design



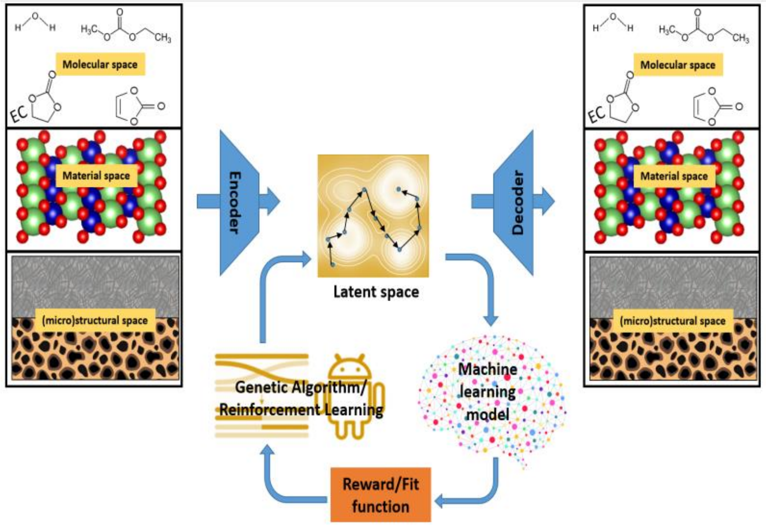
The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Batteries Interface Genome

Advances needed:

- Novel computational and experimental techniques and their combination
- European data infrastructure
- Standardized testing protocols and interoperability
- AI-enhanced multi-scale / multi-feature approaches



VISION: INTEGRATED BIG-MAP APPROACH

The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

BIG-MAP

Was this goal achieved?		
Yes	Partly	No

Research areas	Short term (3 years)	Medium term (6 years)	Long term (10 years)
BIG-MAP	Put in place a pan-European interoperable data infrastructure and user interface for battery materials and interfaces.	Fully implementing BIG in MAP to integrate computational modelling, materials autonomous synthesis, and characterisation.	Demonstrate the integration of manufacturability and recyclability parameters into the materials discovery process.
	Establishing integrated experimental and computational workflows.	Integrate data from embedded sensors into the discovery and prediction process.	Integrate battery cell assembly and device-level testing into BIG-MAP.
	Demonstrating BIG-based hybrid physics- and data-driven models of battery materials.	Develop and apply predictive hybrid models for the spatio–temporal evolution of battery interfaces/interphases to perform inverse materials design.	Implement and validate digital twin for ultra-high-throughput testing on the cell level.
	Deploy autonomous modules and apps for on-the-fly analysis of data characterisation and testing using AI and simulations.	Demonstrating transferability of the BIG-MAP approach to novel battery chemistries and interfaces.	Establish and demonstrate full autonomy and chemistry neutrality in the BIG-MAP.
	Developing multi-modal high-throughput/high-fidelity interface characterisation approaches.	Integrating novel experimental and computational techniques targeting the time and length scales of electron localization, mobility, and transfer reactions.	Demonstrate a 5–10-fold improvement in the materials discovery cycle and interface performance.

BATTERY 2030+

The roadmap – Thematic areas

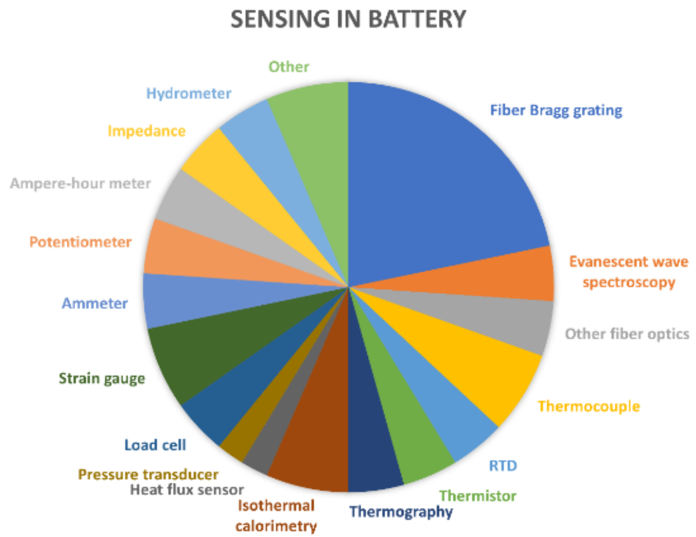
This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

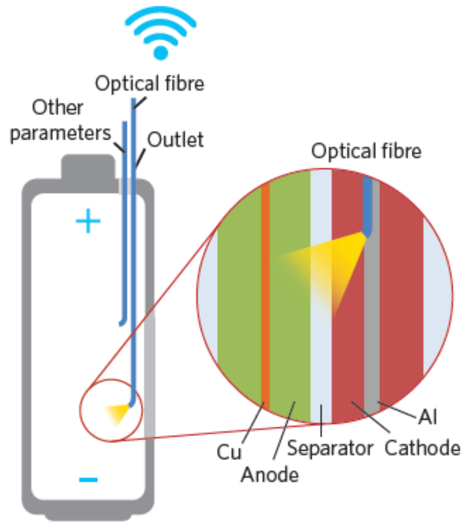
Sensing

Advances needed:

- **Sensor development**
  - Novel approaches
  - Protection/coating

  Transmission of information into/out of the cells
- **Hierarchic approach from component to full pack**
- **Safety – size – scalability – data management**
- **Consider system design trade-offs**
- **Clear demonstration of benefits (life/performance)**
- **Build necessary manufacturing/recycling expertise**





BATTERY 2030+

The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Evaluation Sensing Goals – Example INSTABAT

Research areas	Goals achieved in the last 3 years	Short term (3 years)	Medium term (6 years)	Long term (10 years)
Sensing	Apply non-invasive multi-sensing approaches transparent to the battery chemical environment offering spatial and time resolution.	Miniaturise and integrate the identified (electro)chemically stable sensing technologies with multifunctions at the cell level and in real battery modules, in a cost-effective way compatible with industrial manufacturing processes.	Development of virtual sensors to limiting the number of physical sensors to a minimum	Master sensor communication with an advanced BMS relying on new AI protocols by wireless means to achieve a fully operational smart battery pack.
	Integrating sensors into existing battery components (e.g., separator, current collector, and electrode composite).	Deploy sensors capable of detecting various relevant phenomena (e.g., interface dynamics, electrolyte degradation, dendritic growth, metals dissolution, and materials structure change).	Deliver proof of concept of higher quality, reliability, and lifetime on the cell and module levels.	
	Deploy sensors capable of detecting some of the relevant phenomena (e.g., interface dynamics, electrolyte degradation, dendritic growth, metals dissolution, and materials structure change).		Adaptation of the reliability of the sensor integration	
			Address challenges on integration, measurement and compatibility of sensors related to new cell technologies (e.g., all solid-state batteries)	

Was this goal achieved?		
Yes	Partly	No

BATTERY 2030+

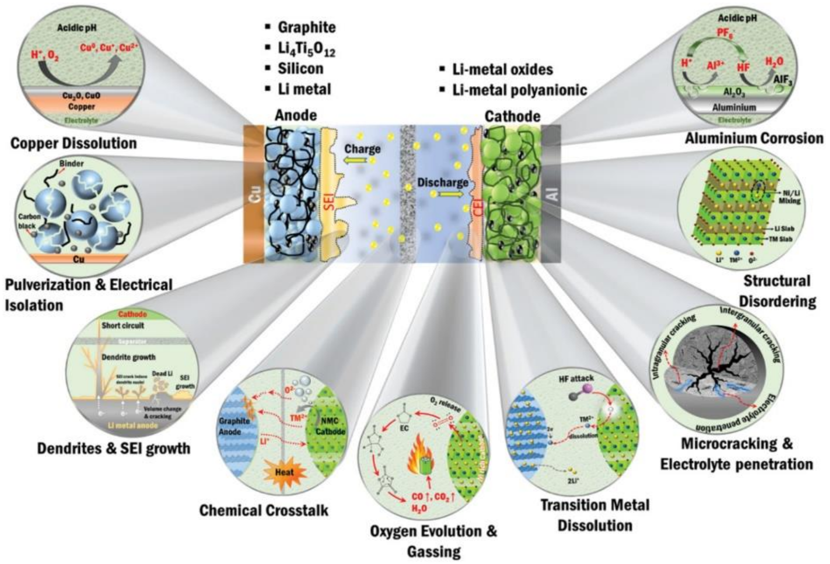
The roadmap – Thematic areas

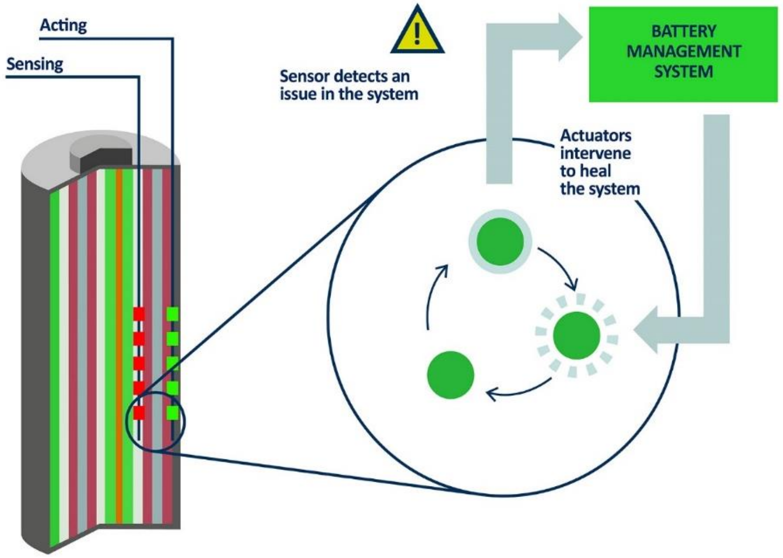
This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Self-healing (→ „smart functionalities")

Advances needed:

- **Functionalized separators / membranes**
  - Polymer membranes w/ in-situ polymerization
  - Bio-sourced membranes with barrier selectivity
- **Self-healing electrodes**





The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Evaluation Self-healing Goals – Example

BAT4EVER
This project is funded by the European Union

Research areas	Short term (3 years)	Medium term (6 years)	Long term (10 years)
Self-healing	Continue developing the research community that includes a wide range of R&D disciplines to develop self-healing functionalities for batteries.	Integration of self-healing functionalities into battery components. Biomimetic membranes developed as a new functionality.	Upscaling of the manufacturing of self-healing batteries is needed in long term, including a cost-benefit estimation.
	Developing autonomous and non-autonomous (on demand) self-healing functionalities for specific battery chemistries, targeting loss of capacity and loss of power.	Feedback loops between cell sensing, BMS, and/or AI modules.	Different cell design concepts and novel designs, including e.g. bi-polar systems, are needed. Manufacturing lines to be adapted on the designs needs.

Was this goal achieved?		
Yes	Partly	No

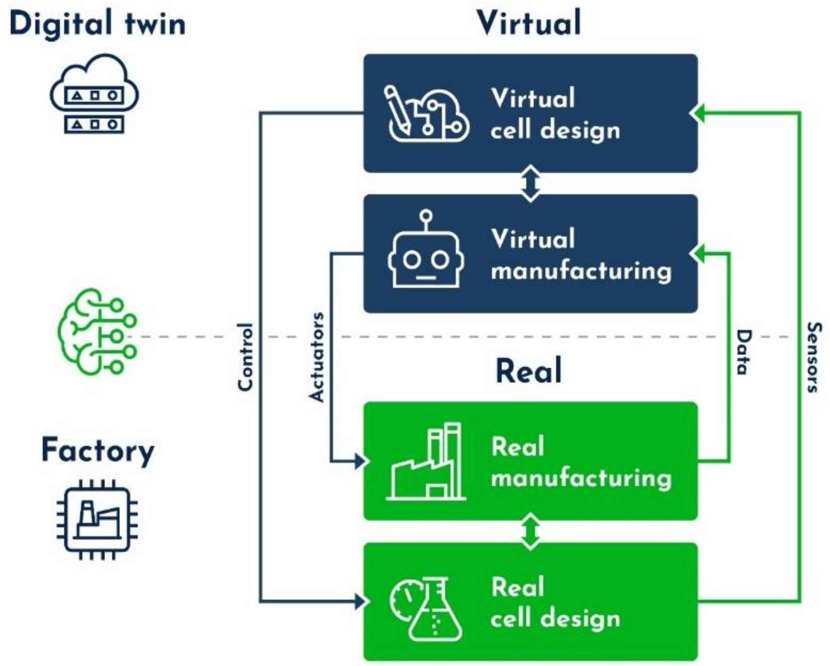
The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Manufacturability

Advances needed:

- Link process parameters variations to cell performance (reduction of scrap etc.)
- Novel, Green(er) manufacturing routes
- Dry coating on the giga scale
- Faster processing and screening (bottom up), smart sensors
- Robust supply chains
- Open source tools for exchange of data that is entirely FAIR
- Digital twins → automatic optimization of cell design and manufacturing



This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

The roadmap – Thematic areas

Manufacturability

Research areas	Short term (3 years)	Medium term (6 years)	Long term (10 years)
Manufacturability	Proof-of-concept (POC) of a digital twin of cell design based on accurate multi-physics multi-scale models and AI data-driven models for LIBs.	Initial POC of a digital twin of cell manufacturing process for LIBs at pilot line level by integrating data-driven aspects (data acquisition, sensorization, communication and interoperability) into the developed models.	Full POC of a manufacturing digital twin for LIBs by integrating the cell design and the manufacturing process sub-loops.
	Improvements towards new greener and more sustainable manufacturing processes for LIBs (3D printing, dry processing) are foreseen.	Developing a methodology that will be adapted to the manufacture process for new battery technologies (SSBs, SIBs, etc.).	POC of a digital twin of novel cell manufacturing routes with closed-loop recycling of optimized LIBs.
	Up-scaling of process models along the LIB cell manufacturing to machine models for optimal designs through pilot validation.	Development of advanced in-line sensors for implementing in manufacturing plants	The new concepts in cell manufacturing are transferred to the industry and academia.
	Improve methodology for scaling up process (from lab to pilot and further)		
	Accellerate and efficient parametrization methods		

BATTERY 2030+

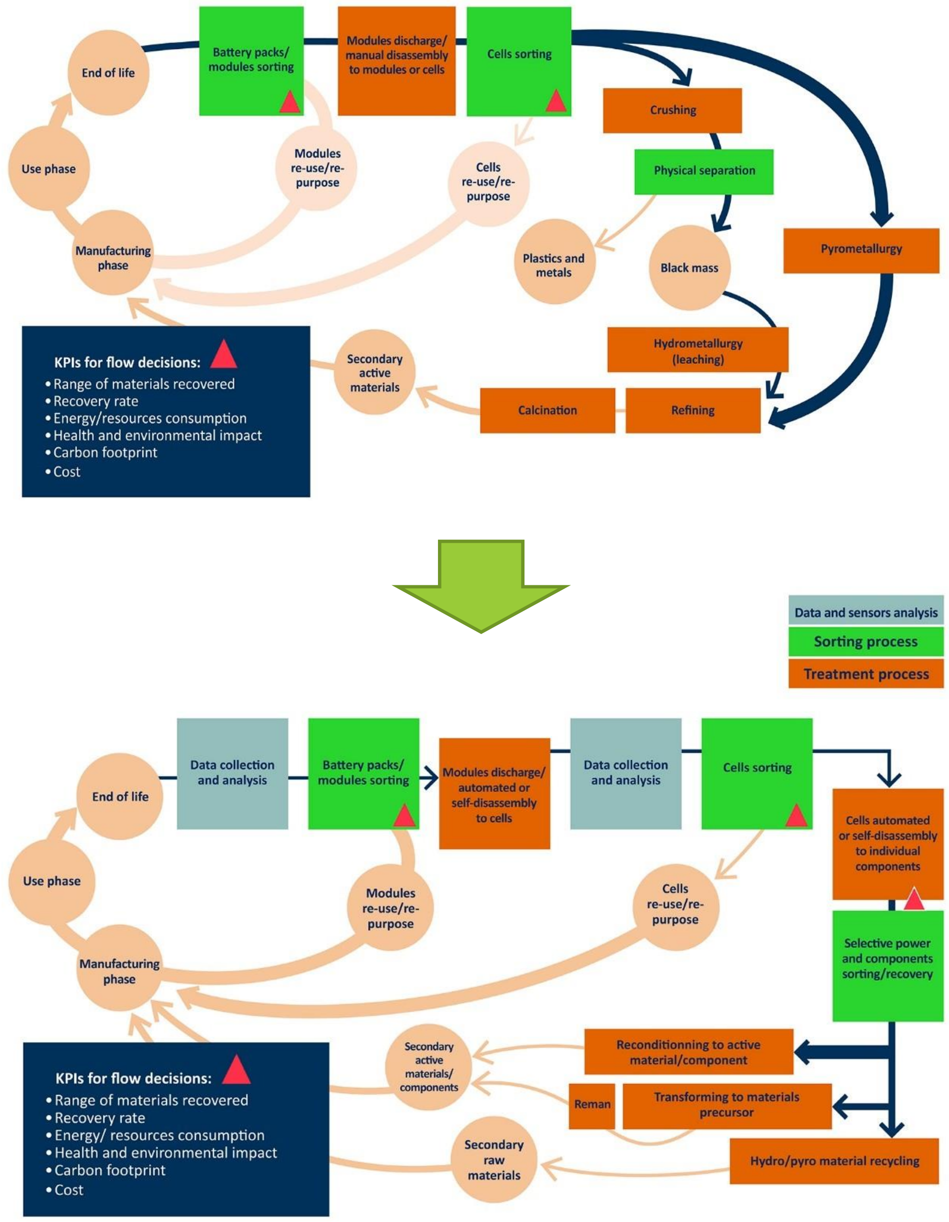
This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

The roadmap – Thematic areas

Recyclability

Advances needed:

- **Ground-breaking new recycling processes!**
  - Data collection and analysis (e.g., from labels, BMS, sensors, battery passport)
  - Modern small-carbon-footprint logistics concepts
  - Automated pack disassembly to the cell level
  - Investigating reuse and repurposing
  - Automated cell disassembly
  - Powder recovery and powder reconditioning
  - Optimized pyro- and hydro-metallurgical processes (ultimate waste): high recovery rate for critical raw materials.
  - More international collaboration



The roadmap – Thematic areas

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Recyclability

Research areas	Short term (3 years)	Medium term (6 years)	Long term (10 years)
Recyclability	Integrated design for sustainability and dismantling.	Demonstrating automated cell disassembly into individual components.	A full system for direct recycling is developed and qualified.
	Demonstration of new technologies for battery packs/modules sorting and re-use/re-purposing.	Sorting and recovery technologies for powders and components and their reconditioning to new active battery-grade materials demonstrated.	Combination of direct recycling with other secondary processes in order to identify optimised solutions aiming at this targets (combination of direct recycling and secondary processes enabling to achieve 98 % recovery)
	Establishing a European system for data collection and analysis.	Significantly improve, relative to current processes, the recovery rate of critical raw materials	
	Developing automated disassembly of battery cells.	Testing of recovered materials in battery applications.	
	By design develop sustainable batteries: integrated design for optimising CRM content, lifetime, sorting, re-purpusing, dismantling, recycling	Develop prediction and modelling tools for the reuse of materials in secondary applications	
	Address how direct recycling can be handled in a chemsitry-neutral way (mix of technologies) by making recyclability an intergral part of battery R&D at an early stage	Integrate battery passport	

BATTERY 2030+

Example: Goals for the 2025 Roadmap

BIG & MAP

BIG-MAP

Was this goal achieved?		
Yes	Partly	No
(green)	(yellow)	(pink)

Research areas	Short term (3 years)	Medium term (6 years)	Long term (10 years)
BIG & MAP	Put in place a pan-European interoperable data infrastructure and user interface for battery materials and interfaces.	Fully implementing BIG in MAP to integrate computational mo[illegible] materials autonomous synthe[illegible]s, and characterisation.	Demonstrate the integration of manufacturability and recyclability parameters into the materials discovery process.
	Establishing integrated exper[illegible] and computational workflows[illegible]	Integrate data from embedded sensors into the discovery and predi[illegible] process.	Integrate battery cell assembly and device-level testing into BIG-MAP.
	Demonstrating BIG-based hybrid physics- and data-driven mo[illegible] battery materials.	Develop and apply predictive hybrid models for the spatio–tempor[illegible]l evolution of battery interfaces/interphases to perform inverse materials design.	Implement and validate digital twin for ultra-high-throughput testing on the cell level.
	Deploy autonomous modules and apps for on-the-fly analysis of dat[illegible] characterisation and testing u[illegible]ng AI and simulations.	Demonstrating transferability of the BIG-MAP approach to novel chemistries and interfaces.	Establish and demonstrate full autonomy and chemistry neutrality in the BIG-MAP.
	Developing multi-modal high-throughput/high-fidelity int[illegible] characterisation approaches.	Integrating novel experimental and computational techniques targeting the time and length scales of electron localization, mobility, and transfer reactions.	Demonstrate a 5–10-fold improvement in the materials discovery cycle and interface performance.

Example: Goals for the 2025 Roadmap

BIG & MAP

Research areas	Short term (2026/2027)	Medium term (2030)	Long term (2035)
BIG & MAP	Integrate data from embedded sensors into the discovery and prediction process.	Fully implementing BIG in MAP to integrate computational modelling, materials autonomous synthesis, and characterisation.	Demonstrate a 5–10-fold improvement in the materials discovery cycle and interface performance
	Develop and apply predictive hybrid models for the spatio–temporal evolution of battery interfaces/interphases to perform inverse materials design.	Demonstrate the integration of manufacturability and recyclability parameters into the materials discovery process.	
	Demonstrating transferability of the BIG-MAP approach to novel battery chemistries and interfaces.	Integrate battery cell assembly and device-level testing into BIG-MAP.	
	Integrating novel experimental and computational techniques targeting the time and length scales of electron localization, mobility, and transfer reactions.	Implement and validate digital twin for ultra-high-throughput testing on the cell level.	
	Developing multi-modal high-throughput/high-fidelity interface characterisation approaches.	Establish and demonstrate full autonomy and chemistry neutrality in the BIG-MAP.	

BATTERY 2030+

This project has recived funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022.

Future of the Roadmap

Challenges:

- **New projects with topics that are already in the roadmap**
- **New projects with topics that are not represented in detail in the roadmap**
- **New thematic areas**

- Roadmap "1.1" March 2020: 83 pages, 157 references
- Roadmap "1.2" Feb 2022: 117 pages, 292 references
- Roadmap "1.3" Aug 2023: 130 pages, 340 references

➢ **Do we want to write Roadmap "1.4" or Roadmap "2.0"?**
  - ➢ World Café Table 6: General Scope of the Roadmap

What do we want to answer today?

1) Which of the current roadmap goals have to be updated?

2) Which objectives of my project could be added to the roadmap goals?

3) What are the expectations of my project from the future roadmap?

4) How does my project want to participate in the roadmap writing?

Before lunch:

4 Breakout Sessions:

- **Discuss short/medium/long-term goals**
- **Which project is working on which goal(s)?**
- **On which goal(s) do we have no project yet?**
- **Form writing groups for the 2025 Roadmap for the different topics**
- **Name one coordinator for each writing group**
- **SWOT analysis for each topic**

10:45 – 11:15	**8) Roadmap structure and process** *(30 min)*	*Philipp Veit*
11:15 – 12:15	**9) Discussion in breakout sessions goals & SWOT** *(60 min)*	***Moderators:***
	9.1) Accelerated discovery of battery interfaces and materials: Battery Interface Genome (BIG) & Materials Acceleration Platform (MAP)	*Ivano Castelli* *Wolfgang Wenzel*
	9.2) Integration of smart functionalities: Sensing & Self-healing	*K. Burak Dermenci*
	9.3) Cross-cutting area: Manufacturability	*Elixabete Ayerbe*
	9.4) Cross-cutting areas: Recyclability	*Marcel Meeus*
12:15 – 12:45	**10) Presentation and discussion of findings from breakout sessions** *(7-8 min each = 30 min)*	*All*
12:45 – 13:00	**11) Discussion:** Expectations for the roadmap *(15 min)*	*All*
13:00 – 14:00	**Lunch**	

BATTERY 2030+

Before lunch:

4 Breakout Sessions:

- **91. BIG & MAP**
- **9.2 Sensing & Self-Healing**
- **9.3 Manufacturability**
- **9.4 Recyclability**

10:45 – 11:15	**8) Roadmap structure and process** *(30 min)*	*Philipp Veit*
11:15 – 12:15	**9) Discussion in breakout sessions goals & SWOT** *(60 min)*	***Moderators:***
	9.1) Accelerated discovery of battery interfaces and materials: Battery Interface Genome (BIG) & Materials Acceleration Platform (MAP)	*Ivano Castelli* *Wolfgang Wenzel*
	9.2) Integration of smart functionalities: Sensing & Self-healing	*K. Burak Dermenci*
	9.3) Cross-cutting area: Manufacturability	*Elixabete Ayerbe*
	9.4) Cross-cutting areas: Recyclability	*Marcel Meeus*
12:15 – 12:45	**10) Presentation and discussion of findings from breakout sessions** *(7-8 min each = 30 min)*	*All*
12:45 – 13:00	**11) Discussion:** Expectations for the roadmap *(15 min)*	*All*
13:00 – 14:00	**Lunch**	

Room on the left
Gyda

9.3

Room on the right
Gunhild

9.1

Big room: Olav

9.4

9.2

Before lunch:

12:15 – 12:45	**10) Presentation and discussion of findings from breakout sessions** *(7-8 min each = 30 min)*	*All*
12:45 – 13:00	**11) Discussion:** Expectations for the roadmap *(15 min)*	*All*
13:00 – 14:00	**Lunch**	

Group Photo and Lunch

12:15 – 12:45	**10) Presentation and discussion of findings from breakout sessions** *(7-8 min each = 30 min)*	*All*
12:45 – 13:00	**11) Discussion:** Expectations for the roadmap *(15 min)*	*All*
13:00 – 14:00	**Lunch**	