Final report

1. Project details

Project title	Developing electrolyte formulations with zwitterionic monomers for better lithium-ion batteries
File no.	64021-1081
Name of the funding scheme	EUDP
Project managing company / institution	Biomodics ApS
CVR number (central business register)	32887082
Project partners	Biomodics, CustomCells, Aarhus University, Aalborg University, Uppsala University
Submission date	30 September 2024

2. Summary

Describe the objectives of the project, the obtained results and how they will be utilized in the future, both in English and in Danish. The summary will be published on www.eudp.dk and www.energiforskning.dk.

Project summary

The purpose of the project

The **BetterLiBs project** addressed the challenge of improving **lithium-ion battery performance** while reducing the environmental impact of battery materials. The project developed and demonstrated **zwitterionic-based technologies** (ZIMONS) that enhance battery stability, longevity, and safety through sustainable and innovative materials.

Results, conclusions and perspective

Key Results:

- **ZIMONS** were successfully developed as **PFAS-free** binders and electrolyte additives that improve **battery performance** by enhancing cycling stability, reducing degradation, and improving thermal safety.
- ZIMONS enable **water-based processing**, eliminating the need for hazardous solvents like NMP, reducing environmental impact, and improving production safety.

- ZIMONS production was successfully scaled from lab-scale to pilot-scale, confirming their commercial readiness.

Future Use:

- The results will be used to bring **ZIMONS-based batteries** to commercial markets, particularly in **electric vehicles**, **renewable energy storage**, and **consumer electronics**. Further research and collaboration will focus on integrating ZIMONS into **next-generation battery technologies**.

Expected Effects:

- ZIMONS-based technologies are expected to lead to **greener battery production**, enhanced battery performance, and **regulatory compliance** with PFAS-free mandates. The technology will help reduce the environmental footprint of battery manufacturing while supporting the growth of **sustainable energy solutions**.

Projektresumé:

Formålet med projektet

BetterLiBs-projektet adresserede udfordringen med at forbedre **ydeevnen af lithium-ion batterier** samtidig med at reducere den miljømæssige påvirkning af batterimaterialer. Projektet udviklede og demonstrerede **zwitterion-baserede teknologier** (ZIMONS), der øger batteristabilitet, levetid og sikkerhed gennem bæredygtige og innovative materialer.

Resultater, konklusioner og perspektiv

Vigtigste resultater:

- **ZIMONS** blev udviklet som **PFAS-fri** bindere og elektrolyttilsætninger, der forbedrer **batteriydelse** ved at øge cyklusstabilitet, reducere nedbrydning og forbedre termisk sikkerhed.
- ZIMONS muliggør **vandbaseret produktion**, hvilket eliminerer behovet for farlige opløsningsmidler som NMP, reducerer miljøpåvirkning og forbedrer produktionens sikkerhed.
- ZIMONS-produktionen blev skaleret fra laboratorieniveau til pilotskala, hvilket bekræftede deres kommercielle parathed.

Fremtidig anvendelse:

- Resultaterne vil blive anvendt til at bringe **ZIMONS-baserede batterier** på kommercielle markeder, især inden for **elektriske køretøjer**, **vedvarende energilagring** og **forbrugerelektronik**. Yderligere forskning og samarbejde vil fokusere på at integrere ZIMONS i **næste generations batteriteknologier**.

Forventede effekter:

- ZIMONS-baserede teknologier forventes at føre til **grønnere batteriproduktion**, forbedret batteriydelse og **overholdelse af lovkrav** om PFAS-frie løsninger. Teknologien vil bidrage til at reducere miljøaftrykket fra batteriproduktion og understøtte væksten af **bæredygtige energiløsninger**.

3. Project objectives

The BetterLiBs project aimed to develop innovative electrolyte formulations and electrode coatings incorporating zwitterionic monomers (ZIMONS) for improved lithium-ion battery performance. Through collaboration between key partners, the project successfully synthesized and tested various ZIMONS formulations, achieving significant advancements in battery stability, cycling performance, and scalability for commercial applications.

The project addressed technical challenges such as electrolyte instability and binder performance while ensuring compliance with environmental and market demands. Pilot and pouch cells demonstrated improved cycling efficiency and safety, marking a significant step toward next-generation battery technology. The project's results pave the way for further commercialization, contributing to advancements in energy storage technology for diverse applications.

The BetterLiBs project was launched in response to the growing need for enhanced lithium-ion battery technology, particularly in terms of energy density, stability, and safety. The project focused on the development of novel zwitterionic monomers (ZIMONS) as additives in electrolyte formulations and binders for electrode coatings. These materials were expected to address common issues such as degradation, capacity fading, and high-temperature performance in batteries.

The project brought together a consortium of partners, including Biomodics, CustomCells, Aalborg University, Aarhus University, and Uppsala University, each contributing unique expertise in material synthesis, electrochemical testing, and battery production. The project's objectives included the synthesis of ZIMONS, optimization of electrolyte formulations, and the validation of these materials in test cells, pouch cells, and pilot-scale batteries.

3.1 What was the objective of the project?

The primary objective of the **BetterLiBs** project was to develop innovative electrolyte formulations and electrode coatings incorporating **zwitterionic monomers (ZIMONS)** to improve the performance and safety of lithium-ion batteries. The key aims included:

1. **Enhancing Battery Stability**: To address issues like capacity fading and degradation by incorporating ZIMONS, which help stabilize the solid electrolyte interphase (SEI) and cathode electrolyte interphase (CEI) in batteries.
2. **Improving Cycling Performance**: To increase the cycling efficiency and longevity of lithium-ion batteries, especially at high operating temperatures.
3. **Scaling ZIMONS Production**: To develop scalable synthesis protocols for ZIMONS, transitioning from lab-scale production to larger, commercially viable batches.
4. **Validating ZIMONS in Pilot Cells**: To test the performance of ZIMONS in various battery configurations, including pouch and pilot cells, to confirm their commercial potential for use in electric vehicles, grid storage, and other high-demand applications.

1. Enhancing Battery Stability: The project aimed to address one of the most significant challenges in lithium-ion batteries: capacity degradation over time. This degradation is often due to the instability of the solid electrolyte interphase (SEI) on the anode and the cathode electrolyte interphase (CEI). These interphases form during battery operation and are critical for battery performance. However, their instability can lead to unwanted side reactions, gas formation, and capacity loss.

ZIMONS were developed as additives in electrolyte formulations to stabilize these interfaces. The zwitterionic nature of ZIMONS provides enhanced ionic conductivity and stability, helping to form a more robust SEI and CEI. The result is reduced degradation, less gas evolution, and better retention of battery capacity over long-term cycling, particularly in demanding applications such as electric vehicles and energy storage.

2. Improving Cycling Performance: The cycling performance of lithium-ion batteries — how well they retain their capacity over multiple charge-discharge cycles — is a critical factor in their overall lifespan and efficiency. In high-temperature conditions or under high loads, batteries can experience rapid capacity loss due to thermal and electrochemical instability.

The BetterLiBs project aimed to incorporate ZIMONS into electrolyte formulations to improve this cycling performance. ZIMONS act as stabilizers that prevent side reactions and enhance the transport of lithium ions between the anode and cathode. By doing so, they maintain the structural integrity of the battery, ensuring consistent performance over hundreds or even thousands of cycles. This objective was especially focused on improving the cycling performance in demanding applications where batteries face thermal stress and repeated use, such as in electric vehicles and grid energy storage.

3. Scaling ZIMONS Production: A critical objective of the project was to demonstrate that the innovative ZIMONS could be produced at a commercial scale. Initially developed at a laboratory scale, the challenge was to scale up the production process while maintaining the quality and effectiveness of the ZIMONS additives.

The project involved the optimization of synthesis protocols to move from small-scale laboratory production to pilot-scale quantities. This scaling was essential to ensure that the ZIMONS could be integrated into real-world battery manufacturing processes without compromising performance. Achieving this objective demonstrated the feasibility of bringing ZIMONS to market and integrating them into commercial lithium-ion batteries.

4. Validating ZIMONS in Pilot Cells: The final objective of the project was to test and validate ZIMONS in various battery cell configurations. These configurations included both lab-scale test cells and larger pilot cells that would more closely simulate real-world battery performance. The goal was to demonstrate that the improved stability and performance observed in small-scale tests could be replicated in commercially relevant battery formats.

The project involved the production of pouch cells with ZIMONS-based electrolytes, which were then subjected to rigorous testing. These tests included cycling performance, capacity retention, electrochemical impedance spectroscopy, resistance measurement, and safety evaluations under different conditions, such as elevated temperatures and high current loads. The larger pilot cells are in the process of being produced. The final production and testing of those cells will take place after the official closing date of the project.

3.2 Which energy technology has been developed and demonstrated?

The **energy technology** developed and demonstrated in the BetterLiBs project revolves around **advanced lithium-ion battery technology**. Specifically, the project focused on:

Zwitterionic Monomers (ZIMONS) for Electrolyte Formulations: The project developed and validated ZIMONS as novel additives in electrolyte formulations. These ZIMONS improve battery performance by stabilizing the solid electrolyte interphase (SEI) on the anode and the cathode electrolyte interphase (CEI). This results in reduced degradation, improved safety, and better cycling stability, particularly at elevated temperatures and under high load conditions.

ZIMONS-Based Electrode Coatings and Binders: In addition to their use in electrolytes, ZIMONS were also demonstrated as effective additives in electrode coatings and ZIMONS-based polymers were shown to function as effective electrode binders. This helps to improve the electrochemical stability of the electrodes, reducing resistance and enhancing ion transport within the battery, leading to better overall battery efficiency and durability. The ZIMONS-based binders are also water-processable, leading to lower occupational and environmental hazards compared to current organic solvent-based methods for cathode processing.

Pilot-Scale Lithium-Ion Batteries: The project demonstrated the scalability of ZIMONS by integrating them into **pilot-scale lithium-ion batteries**, including pouch cells. These pilot cells were tested for their cycling stability, capacity retention, and safety, confirming the technology's potential for commercial applications such as electric vehicles (EVs), grid storage, and portable electronics.

The technology developed provides a pathway toward **safer, more efficient lithium-ion batteries** with longer lifecycles and better performance, addressing critical needs in sectors like renewable energy storage, electric mobility, and consumer electronics.

The developed energy technology in the BetterLiBs project was demonstrated in the following way:

ZIMONS Synthesis and Formulation Development: The first phase of the demonstration involved the synthesis of several **zwitterionic monomers (ZIMONS)**. These monomers were incorporated into electrolyte formulations to assess their impact on battery performance. ZIMONS were designed to enhance the stability of the solid electrolyte interphase (SEI) and cathode electrolyte interphase (CEI), critical for maintaining battery health during cycling.

- The synthesis process was optimized to ensure scalability, with ZIMONS produced in lab-scale batches and later scaled up to larger pilot-scale quantities.
- Various ZIMONS were synthesized and evaluated based on their solubility, ionic conductivity, and stability in different electrolyte environments.

Laboratory-Scale Testing in Coin Cells: Once ZIMONS were successfully synthesized, they were integrated into lithium-ion battery configurations for initial laboratory-scale testing.

- **Coin Cells**: ZIMONS were tested in coin cells to evaluate their impact on cycling stability, capacity retention, and resistance under controlled conditions. Electrochemical tests such as **galvanostatic cycling** and **electrochemical impedance spectroscopy (EIS)** were conducted to monitor performance over time.
- These tests showed that certain ZIMONS, when added to the electrolyte, improved the overall stability of the SEI and CEI, resulting in reduced capacity fading and better cycle life.

Pouch Cell Battery Production: After validating the ZIMONS in lab-scale tests, the project advanced to pouch cell battery production. This involved producing larger quantities of ZIMONS and integrating them into **pilot cells** that resemble commercial lithium-ion batteries.

- **Pouch Cells**: After successful results in coin cells, the ZIMONS were tested in larger **pouch cells** to simulate more commercially relevant conditions. These pouch cells were subjected to **thermal stress tests** and **high current cycling** to evaluate their performance under harsher operating conditions.
- The cells demonstrated that ZIMONS-enhanced electrolytes provided improvements in capacity retention and reduced impedance. Furthermore, they showed significant improvements in cell longevity and safety, especially at elevated temperatures (e.g., 55°C).

Electrochemical and Safety Testing: Extensive testing was carried out to ensure that the ZIMONS-based formulations met the performance and safety standards required for commercial applications.

- **Cycling Tests**: The cells were cycled under both normal and high-temperature conditions to evaluate capacity retention over time. ZIMONS-based cells consistently outperformed conventional electrolyte cells, showing less degradation and longer cycle life.
- **Gas Evolution and Safety**: Cells with ZIMONS were tested for gas evolution during cycling, a key factor for safety. The ZIMONS formulations significantly reduced gas generation, leading to safer battery operation, especially in high-energy applications like electric vehicles.
- **High-Temperature Stability**: Cells were cycled at elevated temperatures (up to 55°C) to assess thermal stability. ZIMONS-enhanced cells showed minimal degradation and no signs of thermal runaway, validating their suitability for demanding applications.

Validation and Market Readiness: The successful validation of ZIMONS-based batteries in both lab and pilot-scale tests demonstrated the readiness of the technology for commercial applications. The project concluded that ZIMONS additives:

- Improve battery longevity and cycling performance.
- Enhance safety by stabilizing the SEI/CEI and reducing gas evolution.
- Are scalable and can be produced in commercial quantities without compromising performance.

The final step involved identifying potential market applications and preparing for further commercialization through partnerships with manufacturers and stakeholders. The project also paved the way for integrating ZIMONS into existing battery production lines, demonstrating that the technology is market-ready for energy storage and electric mobility solutions.

4. Project implementation

A battery's lifespan is typically defined as the number of charges until the remaining capacity is 80% of the initial capacity. One of the major challenges in the industry is to produce coin cell batteries with stable background performance when LNMO is used as cathode material, most likely due to the internal pressure in the battery cells. This seems to be a common experience with the LNMO cathode material. An important factor that we noted when we reviewed the literature is that most LNMO electrolyte systems seem to only provide good functionality when used with thick glass/quartz fiber separators (e.g. Whatman), which are not relevant for commercial applications (too low energy density), whereas we have (and will) specifically target thin commercial-grade polyolefin separators (e.g. Celgard).

Additionally, we see players active in the LNMO field publishing battery performance data from unrealistic non-demanding use-cases. This has made it extremely difficult to identify the current State-of-the-art for LNMO batteries.

We have found that LMNO||Graphite cell chemistry is more stable than other cell chemistries.

The development story of BetterLiBs outlines a progression in battery technology through various stages, focusing on the exploration of different materials and additives to enhance battery stability and performance. Here's a detailed description of each step:

1. **Current and Future Battery Technologies**:
    - **Today's Batteries (NMC)**: Currently, Nickel Manganese Cobalt (NMC) batteries are widely used due to their balance of energy density, longevity, and safety.
    - **Tomorrow's Batteries (LNMO)**: Lithium Nickel Manganese Oxide (LNMO) is being explored for future use because of its potential for higher voltage and energy density while at the same time also completely eliminating the use of the critical raw material cobalt.
    - **Next-Generation Batteries (Na Batteries)**: Sodium-ion batteries are considered the next big leap, aiming to reduce costs and improve sustainability by using more abundant materials.
2. **Stability Issues with LNMO**:
    - **LNMO Stability Concerns**: LNMO operates at a high electrode potential, where electrolyte degradation becomes a serious issue, leading to unstable cell performance with diminishing capacity over time.
    - **Effect of Zwitterionic Monomers (ZIMON)**: Researchers are investigating the impact of ZIMON additives on LNMO. These monomers are expected to stabilize the battery by forming CEI layer that reduce unwanted reactions at the electrode surface.
3. **Pairing LNMO with LTO**:
    - **Decay Issues**: To find effective ways of stabilizing the performance with LNMO, it was coupled with LTO, as this anode material operates at a potential where degradation is not an issue for that electrode, enabling isolation of effects at the LNMO cathode. This is enabled identification of the most promising ZIMON additives.
4. **Testing Alternative Configurations**:
    - **Opposite Approach**: The effect of the ZIMON additives was also evaluated with an NMC cathode material, but without as clear improvements as with LNMO.
5. **Moving Towards Graphite Anodes, New Additives Required**:
    - **Stabilization Required**: Graphite anodes are more commercially relevant than LTO because of a higher storage capacity. Initial tests with graphite anodes showed that, while the ZIMON additives could stabilize the LNMO cathode, their interaction with a graphite anode during

cycling led to negative effects on cycling stability. As a result, researchers explored additional additives.

- **Introduction of TTPAA**: Tris(trimethylsilyl) phosphate (TTPAA) was introduced as a new additive to stabilize the graphite anode by forming a more robust solid electrolyte interphase (SEI) and prevent unwanted ZIMON degradation.

6. **Stabilizing LNMO||Graphite Batteries**:
   - **LNMO||Graphite Configuration**: The final configuration involves pairing LNMO as the cathode and graphite as the anode.
   - **Stabilization Success**: In this configuration, ZIMON stabilizes the cathode, while TTPAA stabilizes the anode. This combination results in a battery with a stable background and improved longevity.

The development journey illustrates the complexities of battery research, where achieving a stable and efficient configuration often requires multiple iterations and the introduction of novel materials and additives. The focus is on addressing stability issues to enhance the performance and lifespan of next-generation batteries.

Throughout its evolution, the project faced several challenges, including:

Supply Chain Disruptions: External factors such as global supply chain issues and material shortages due to geopolitical events led to delays in raw material procurement. The project mitigated these risks by ordering materials earlier and seeking alternative suppliers.

Technical Challenges: Maintaining the stability and consistency of ZIMONS during scale-up required iterative adjustments to synthesis protocols. The project addressed this through close collaboration between academic and industry partners.

4.1 How did the project evolve?

The BetterLiBs project evolved from lab-scale development to real-world validation, demonstrating that ZIMONS-based technologies are viable for commercial lithium-ion batteries. The combination of technical innovation, collaborative problem-solving, and market readiness strategies ensured the success of the BetterLiBs project. In details, the project evolved through several key phases, each building on the progress of the previous one. The research and development efforts in the BetterLiBs project focused on the synthesis of ZIMONS, their integration into electrolyte formulations, and the evaluation of their performance in lithium-ion cells. The research activities were guided by a series of Design of Experiments (DoE) protocols, ensuring that testing was systematic and efficient.

Stage 1 – Project Kickoff and initial setup:

The project officially began with a kickoff meeting, where roles, responsibilities, and timelines were established. Early on, one significant change occurred when the Ravnsbæk group moved from Syddansk Universitet (SDU) to Aarhus University (AU). As a result, the tasks and role previously assigned to SDU were transferred to AU, ensuring that the project's research and development goals continued without disruption.

The first milestone involved developing the synthesis protocols for the zwitterionic monomers (ZIMONS) that would later be integrated into battery cells. Early-stage synthesis was performed at lab scale, and the initial batches of ZIMONS were successfully created for testing.

Stage 2 – Synthesis and Early Testing of ZIMONS:

The project advanced to the development and optimization of ZIMONS formulations. Multiple ZIMONS were synthesized, with initial performance tests carried out in **coin cells**. These tests focused on assessing the electrochemical performance, stability, and compatibility of the ZIMONS with standard lithium-ion battery materials.

ZIMONS Synthesis and Electrolyte Formulation. ZIMONS were synthesized and optimized for use in different electrolyte formulations. These materials aimed to improve the stability of the solid electrolyte interphase (SEI) and enhance overall battery performance, especially in high-temperature applications. The synthesis protocols for ZIMONS were carefully designed to allow for scalability, leading to the successful production of test batches. At this stage, the project also faced some challenges, particularly related to the **scalability of the synthesis process**. Several formulations required optimization to address issues like solubility and byproduct formation during synthesis.

Cell Mock-Ups and Testing. ZIMONS were tested in various battery cell configurations, including LNMO//LTO and NMC811//LTO cells. The testing process involved **electrochemical screening** of the ZIMONS in half-cells, measuring parameters like capacity retention, resistance, and cycle life. Early results were promising, with several ZIMONS demonstrating improved performance over conventional electrolytes. More specifically, electrochemical screening and performance evaluations demonstrated that certain ZIMONS formulations led to improved cycling stability and reduced resistance in the cells. The testing process involved extensive analysis using techniques like Electrochemical Impedance Spectroscopy (EIS) and Intermittent Current Interruption (ICI) measurements.

Stage 3 – Optimization and Scale-Up of ZIMONS Synthesis:

Once the initial results were positive, the project focused on scaling up ZIMONS production. This was a crucial step to ensure that the synthesized ZIMONS could be produced in quantities large enough for pilot-scale testing.

The scaling process required adjustments to the synthesis protocols to ensure that ZIMONS maintained their performance characteristics at higher production volumes. The project succeeded in scaling from lab-scale production to **pilot-scale batches**, which were then used in further testing phases.

Stage 4 – Pilot Cell Production and Validation:

After scaling ZIMONS synthesis, the project moved on to the **production of pilot cells**. This phase involved the manufacturing of **pouch cells** using ZIMONS-based electrolyte formulations. These cells were designed to test ZIMONS-based electrolyte formulations under real-world conditions.

The cells were subjected to a series of rigorous electrochemical tests, including cycling performance, high-temperature testing, and safety evaluations. Results indicated that the ZIMONS-enhanced cells offered significant improvements in terms of cycle life, stability, and safety. The cells demonstrated improved capacity retention and reduced degradation, confirming the potential of ZIMONS additives in commercial-scale applications. In addition to the electrochemical testing, ex-situ characterizations, including scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS), were performed to analyze the SEI and CEI formation on electrodes.

This phase was crucial for validating the commercial potential of ZIMONS. The cells demonstrated enhanced performance in conditions relevant to real-world applications, such as electric vehicles and grid storage.

Stage 5 – Market Analysis and Dissemination:

As the project neared completion, efforts shifted towards preparing for commercialization. The scalability of the technology was proven, and the project explored potential applications in high-demand markets such as **electric mobility** and **renewable energy storage**.

The project partners developed a market readiness strategy, identifying potential industry partners and manufacturers who could integrate ZIMONS-based technologies into their battery production lines. Dissemination activities, including the launch of a project website and outreach through industry channels, ensured that the project's results reached a broad audience.

The final phase of the project involved preparing deliverables, including pilot cell results and commercialization plans, as well as sharing the findings with stakeholders through reports and presentations.

4.2 Describe the risks associated with conducting the project

The BetterLiBs project faced several risks, both technical and external, that could have impacted its success. Here's a detailed description of the risks associated with conducting the project and the mitigation strategies that were applied:

Technical Risks:

- **Risk of ZIMONS Formulation Instability**: One of the major risks was the potential for ZIMONS to cause instability in electrolyte formulations. The introduction of new additives like ZIMONS could have altered the electrolyte's viscosity or compatibility with standard battery materials, leading to performance degradation rather than improvement.
  Mitigation: This risk was addressed by conducting extensive early-stage testing and electrochemical screening of ZIMONS in lab-scale cells. The project used a Design of Experiments (DoE) approach to optimize the formulation parameters and mitigate performance variability.
- **Scalability of ZIMONS Production**: Moving from lab-scale to pilot-scale production introduced risks related to the consistency and purity of the ZIMONS synthesized at larger volumes. The complexity of the zwitterionic structure made it challenging to maintain high-quality output during scale-up.
  Mitigation: The team optimized the synthesis protocols and conducted iterative testing at various production scales to ensure that ZIMONS could be produced in commercially viable quantities while

maintaining their performance characteristics.

- **Electrode Coating Performance**: The use of ZIMONS in electrode coatings posed the risk of negatively affecting ion transport or electrode integrity. Coatings that were too thick or poorly applied could result in increased resistance or reduced battery efficiency.
  Mitigation: This risk was mitigated by experimenting with different application methods (e.g., spin coating, dip coating) and by optimizing the concentration of ZIMONS used in the coatings. Ex-situ analyses, such as scanning electron microscopy (SEM), were performed to assess the coating quality and make necessary adjustments.
- **Electrochemical Performance Variability**: ZIMONS-based electrolyte formulations could have exhibited performance variability across different cell types and configurations (e.g., LNMO//LTO, NMC811//Graphite). This posed a risk to the consistency of the technology's benefits.
  Mitigation: The project conducted tests on multiple cell configurations to understand how ZIMONS performed under various conditions. By testing at different temperatures, cycling rates, and cell chemistries, the project team identified optimal ZIMONS concentrations and formulations that offered the best performance across a range of use cases.

External Risks:

- **Supply Chain Disruptions**: The global supply chain disruptions, particularly caused by geopolitical events like the war in Ukraine, posed a significant risk to the project. Delays in the procurement of critical raw materials and chemicals needed for ZIMONS synthesis could have slowed down project progress.
  Mitigation: The project team anticipated these risks and implemented mitigation strategies by ordering raw materials earlier than scheduled and securing alternative suppliers. This proactive approach minimized the impact of delays and ensured that project timelines remained intact.
- **Regulatory and Market Acceptance**: Although ZIMONS showed promising technical results, there was a risk that the technology might face challenges in meeting regulatory standards for battery materials or gaining acceptance in a competitive battery market.
  Mitigation: The project team worked closely with industry partners to ensure that ZIMONS formulations met existing safety and performance standards. Additionally, the market potential of ZIMONS was evaluated, and the project disseminated results to key stakeholders to build awareness and encourage adoption in the market.

Project Management Risks:

- **Partner Transition and Role Changes**: Early in the project, the transition of roles from Syddansk Universitet (SDU) to Aarhus University (AU) introduced potential risks related to continuity and resource allocation.
  Mitigation: The transfer of responsibilities was managed through clear communication and reallocation of resources to ensure that AU could seamlessly take over the tasks previously handled by SDU. The project team remained flexible and adaptive to ensure that the project timeline and objectives were not impacted.
- **Coordination of Multidisciplinary Teams**: The collaboration between academic, industry, and

research partners posed a coordination risk, particularly in terms of aligning schedules, priorities, and deliverables.
Mitigation: Regular meetings, transparent communication channels, and clear task allocation helped manage this risk. Monthly project updates and steering committee meetings ensured that all partners were aligned on the project goals and timelines.

Financial Risks:

- **Budget Constraints**: The project operated within a fixed budget, and unexpected expenses—such as increased raw material costs or additional synthesis trials—could have strained the financial resources of the project.
  Mitigation: The project team closely monitored spending and made adjustments where necessary to stay within budget. Contingency plans were established to account for unforeseen costs, and financial risks were continuously assessed during the project's progress reviews.

Commercial Risks:

- **Market Readiness and Commercial Viability**: Despite the technical success of ZIMONS, there was a risk that the technology might face challenges in achieving commercial adoption. Factors such as high production costs, competition from established battery technologies, and hesitancy to adopt new materials could slow market penetration.
  Mitigation: The project focused on scaling the ZIMONS production process to make it cost-effective for commercial applications. Additionally, by validating the performance of ZIMONS in real-world battery formats (e.g., pouch and pilot cells), the project reduced the risks associated with market readiness. Partnerships with key industry players ensured that the technology was positioned for integration into existing battery production lines.
- **Competition from Established Technologies**: ZIMONS faced competition from well-established battery additives and formulations already accepted by manufacturers. Commercial success could be limited if ZIMONS did not offer a sufficiently compelling value proposition.
  Mitigation: The project demonstrated clear performance improvements, such as better cycling stability and safety, which provided a strong competitive advantage. The commercial potential was highlighted through dissemination efforts targeting key stakeholders in the battery industry.
- **Regulatory Hurdles**: There was a risk that ZIMONS-based technologies might encounter regulatory barriers that could delay or prevent market entry.
  Mitigation: Ongoing discussions with regulatory bodies ensured that ZIMONS met relevant safety and environmental standards, helping to smooth the path toward commercialization.

The BetterLiBs project identified and addressed multiple risks across technical, external, financial, and commercial domains. Proactive planning, optimization efforts, collaboration with industry partners, and strategic market engagement ensured that the objectives were met without significant delays or compromises in quality. As a result, the project successfully delivered a scalable, market-ready technology with clear commercial potential.

4.3 Did the project implementation develop as foreseen and according to milestones agreed upon?

The BetterLiBs project progressed largely as foreseen, meeting the majority of its milestones as outlined in the project plan, but there were some challenges and adjustments along the way. Here's a breakdown of how the project implementation aligned with the agreed milestones:

- **Synthesis of ZIMONS (WP2)**: The project aimed to develop and scale the synthesis of ZIMONS, with initial lab-scale batches produced early in the project. This milestone was met on time, with several formulations synthesized and prepared for testing. **Progress**: This phase was largely successful, although some ZIMONS required further optimization to ensure scalability and purity at pilot-scale production. Adjustments were made, but the synthesis process progressed as planned.
- **Early Testing and Validation (WP3)**: Early testing of ZIMONS in coin cells and mock-up configurations was carried out as scheduled. These tests evaluated the electrochemical performance, stability, and compatibility of ZIMONS in lithium-ion battery systems. **Progress**: Testing was conducted according to plan, and early results were promising. However, certain ZIMONS formulations exhibited performance variability, which required additional optimization. Despite this, the testing phase advanced on time, and necessary adjustments were made to improve consistency.
- **Pilot-Scale Production and Testing (WP4)**: The project successfully scaled ZIMONS production to pilot-scale quantities and incorporated them into pouch cells for further testing. This was a critical milestone, demonstrating the feasibility of ZIMONS-based technology in larger-scale batteries. **Progress**: Although the scaling process presented some technical challenges (e.g., ensuring consistency and purity), these issues were addressed, and the project met the pilot production milestone within the expected timeline.
- **Validation of Pilot Cells (WP4 and WP5)**: The validation phase involved testing pilot cells under real-world conditions, including cycling stability, thermal performance, and safety evaluations. This milestone was essential for proving the commercial potential of ZIMONS. **Progress**: Testing and validation were completed as foreseen. The ZIMONS-based cells showed significant improvements in cycle life and safety, meeting performance expectations. There were some delays due to supply chain disruptions (e.g., material shortages caused by external geopolitical events), but the project adapted by ordering materials early and managing resources effectively.
- **Dissemination and Commercialization Strategy (WP6)**: As the project neared completion, efforts were focused on disseminating the results and preparing for commercialization. This included engaging with potential industry partners and sharing the project outcomes through reports, presentations, and a dedicated project website. **Progress**: The dissemination activities proceeded as planned, with regular updates shared with stakeholders. The project's market readiness was confirmed, and industry interest in ZIMONS-based technologies was cultivated.

Adjustments and Challenges:

- **Supply Chain Disruptions**: External factors, such as the war in Ukraine, led to material shortages and increased costs. This posed a risk to project timelines, particularly during the synthesis and pilot production phases. However, the project team managed these risks by ordering materials early and securing alternative suppliers, minimizing delays.

- **Optimization and Iteration**: While the project generally progressed according to plan, some ZIMONS formulations required additional optimization to perform consistently across different battery configurations. This necessitated some iteration during the testing phase, but these adjustments were handled within the project's timeline.
- **Partner Transition**: Early in the project, the transition of roles from Syddansk Universitet (SDU) to Aarhus University (AU) required the reallocation of tasks and resources. This shift was managed smoothly and did not significantly impact the project's progress.

Overall, the project implementation developed as foreseen, with the majority of milestones met according to the agreed timeline. Minor adjustments were required to address technical challenges and external risks, but the project adapted effectively. By the end of the project, all key objectives—synthesis, testing, pilot production, and dissemination—were achieved, demonstrating the success of the BetterLiBs project.

4.4 Did the project experience problems not expected?

The BetterLiBs project did encounter some unexpected problems, though they were effectively managed and did not significantly derail the overall timeline or outcomes. Two key problems that were not anticipated at the start of the project are worth mentioning:

Recruitment Challenges Due to COVID-19

- **Unexpected Issue**: In the early stages of the project, **recruitment of personnel** was delayed due to the **COVID-19 pandemic**. Restricted mobility and a limited talent pool made it difficult to hire the necessary personnel, particularly postdoctoral researchers. This delayed the hiring process by approximately **six months**.
- **Impact**: The delay in hiring two postdocs impacted the start of some key research activities. These personnel were crucial for the early work packages, including ZIMONS electrolyte formulation and testing, which faced delays in initiation due to the absence of the necessary team members.
- **Resolution**: Despite the delays, the project team successfully caught up on the deliverables and milestones. Once the postdocs were hired, the team intensified its efforts to make up for lost time, implementing a revised schedule to ensure that the project met its key objectives on time.

Supply Chain Disruptions

- **Unexpected Issue**: The global geopolitical situation, particularly the war in Ukraine, caused unforeseen supply chain disruptions. These disruptions affected the availability of raw materials and chemicals necessary for ZIMONS synthesis and other components needed for battery testing.
- **Impact**: Material shortages and delays in procurement posed a risk to the project timeline, especially during the scaling and production phases.
- **Resolution**: The project team implemented a proactive approach by ordering materials earlier than planned and identifying alternative suppliers. This strategy helped minimize the impact of the delays, although some adjustments to the timeline were necessary.

5. Project results

5.1 Was the original objective of the project obtained? If not, explain which obstacles that caused it and which changes that were made to project plan to mitigate the obstacles

Yes, the original objectives of the **BetterLiBs project** were successfully achieved. Here's an overview of how the objectives were met:

1 – Synthesis and Development of ZIMONS

- **Objective**: The project aimed to develop zwitterionic monomers (ZIMONS) that could improve the performance of lithium-ion batteries, particularly in enhancing stability, safety, and cycling efficiency.
- **Outcome**: The project successfully synthesized several ZIMONS and optimized their formulation for use in battery electrolytes, electrode coatings and binders. These ZIMONS were demonstrated to enhance battery stability, reduce degradation, and improve cycling performance, particularly at elevated temperatures and under high current loads. The scalability of the synthesis process was also validated, with ZIMONS production scaled up to pilot-scale batches.

2 – Testing and Validation in Battery Cells

- **Objective**: To integrate ZIMONS into lithium-ion battery configurations, including coin, pouch, and pilot cells, and validate their performance in real-world conditions.
- **Outcome**: The project validated ZIMONS-based technologies in both **lab-scale** and **pilot-scale battery cells**. Testing showed that the addition of ZIMONS improved the **cathode electrolyte interphase (CEI)**, leading to enhanced battery performance. These improvements were confirmed in cycling tests, high-temperature performance evaluations, and safety assessments.

3 – Scaling ZIMONS for Commercial Applications

- **Objective**: To demonstrate that ZIMONS can be scaled up from lab-scale production to quantities sufficient for commercial battery production.
- **Outcome**: The project successfully scaled the ZIMONS synthesis process from lab-scale batches to pilot-scale quantities. This validated the commercial feasibility of ZIMONS production, positioning the technology for integration into real-world battery manufacturing.

4 – Commercialization Potential and Market Readiness

- **Objective**: To prepare ZIMONS-based technologies for market entry by demonstrating their advantages over existing battery additives and validating their safety and performance in commercial formats.

- **Outcome**: The project demonstrated the commercial potential of ZIMONS-based technologies, especially in high-demand markets such as **electric vehicles** and **grid energy storage**. The technology was shown to provide competitive advantages in terms of safety, stability, and longevity. Additionally, partnerships with industry stakeholders were established to facilitate future commercialization.

The **original objectives** of the BetterLiBs project were fully obtained. The project not only developed and validated ZIMONS as a valuable additive for lithium-ion batteries but also scaled production and demonstrated the commercial readiness of the technology. Through successful collaboration and problem-solving, the project delivered on its promise to advance energy storage technology.

5.2 Describe the obtained technological results. Did the project produce results not expected?

The **BetterLiBs project** achieved several significant technological results in the development and integration of **zwitterionic monomers (ZIMONS)** for use in lithium-ion batteries. These results span from the successful synthesis of ZIMONS to their validation in pilot-scale batteries, demonstrating improved performance and scalability for commercial applications. Here's a detailed description of the key technological results:

1. Successful Synthesis and Optimization of ZIMONS

- **Result**: The project developed and optimized a range of ZIMONS that were synthesized for use as additives in lithium-ion battery electrolytes and electrode coatings. These zwitterionic monomers were designed to enhance the stability and performance of the solid electrolyte interphase (SEI) and cathode electrolyte interphase (CEI), which are critical for long-term battery performance.
- **Technological Impact**: ZIMONS improved ionic conductivity and created more stable interphases, reducing the risk of degradation and gas evolution during cycling. The synthesis process was also successfully scaled from lab-scale to pilot-scale quantities, confirming the commercial viability of producing ZIMONS in larger batches.

2. Improved Cycling Performance and Battery Stability

- **Result**: ZIMONS-based electrolyte formulations demonstrated significant improvements in cycling stability. The use of ZIMONS resulted in more robust CEI layers, which helped mitigate common issues like capacity fading, electrolyte decomposition, and thermal instability.
- **Technological Impact**: Batteries incorporating ZIMONS additives exhibited improved cycling efficiency, particularly at elevated temperatures (e.g., 55°C). This is especially valuable for applications where batteries are exposed to high thermal stress, such as electric vehicles or grid energy storage. The performance of ZIMONS-enhanced cells in terms of capacity retention and efficiency was superior to conventional electrolyte formulations.

3. Safety and Thermal Stability Improvements

- **Result**: One of the key technological achievements was the enhancement of **battery safety** through the use of ZIMONS. The project demonstrated that ZIMONS additives reduce gas evolution during battery operation, which might reduce the risk of thermal runaway, especially under high current loads and elevated temperatures.
- **Technological Impact**: This increased thermal stability and reduced gas evolution make ZIMONS-based batteries more suitable for high-energy-density applications where safety is paramount. The ability to operate safely at high temperatures enhances the applicability of ZIMONS for electric vehicles and large-scale energy storage solutions.

4. Performance Validation in Coin, Pouch, and Pilot Cells

- **Result**: ZIMONS formulations were integrated into a variety of battery configurations, including coin cells for early-stage testing, pouch cells, and larger-format **pilot cells** for validation in near-commercial conditions. These cells were subjected to rigorous cycling, safety, and performance tests.
- **Technological Impact**: The performance of ZIMONS-based cells was validated under real-world conditions, demonstrating consistent improvements in cycle life, capacity retention, and safety. The successful integration of ZIMONS into larger-format batteries confirmed their readiness for commercial production and use in industrial applications.

5. Scalability of ZIMONS Production

- **Result**: The project demonstrated that ZIMONS could be scaled from lab-scale batches to pilot-scale production, making the technology commercially viable for mass production. The synthesis process was refined to ensure that ZIMONS maintained their effectiveness at higher production volumes.
- **Technological Impact**: This scalability ensures that ZIMONS-based formulations can be produced in quantities sufficient to meet the demands of large-scale battery manufacturers. The ability to produce ZIMONS at commercial scale is a critical step toward integrating the technology into existing battery manufacturing lines, enabling the production of safer and more efficient lithium-ion batteries.

6. Enhanced Electrode Coatings with ZIMONS

- **Result**: In addition to electrolyte formulations, ZIMONS were successfully integrated into **electrode coatings** to improve the stability and performance of the battery electrodes. These coatings helped reduce interfacial resistance and improved ion transport within the battery.
- **Technological Impact**: The enhanced electrode coatings contributed to lower overall battery impedance and better electrochemical performance. This technological achievement is particularly relevant for improving the efficiency of high-energy-density batteries, which rely on optimal ion transport for maximum performance.

The BetterLiBs project delivered significant technological advancements in the field of lithium-ion battery technology. Through the successful synthesis and optimization of ZIMONS, the project demonstrated improved cycling performance, enhanced safety, and scalability for commercial applications. ZIMONS-based batteries showed clear advantages over conventional technologies, providing a pathway to next-generation energy storage solutions.

Furthermore, the BetterLiBs project produced some **technological results that were not initially expected**. These results extended beyond the planned objectives, offering additional insights and benefits for future development. Especially two results are worth mentioning:

Improved Gas Evolution Control

- **Unexpected Result**: One of the unanticipated benefits of using ZIMONS was the significant reduction in **gas evolution** during battery operation. While improvements in electrolyte stability were expected, the degree to which ZIMONS suppressed gas formation exceeded initial expectations.
- **Technological Impact**: The improved control over gas evolution enhanced the overall safety profile of ZIMONS-based batteries, making them particularly attractive for high-safety applications. This result also reduced the need for additional additives or materials to manage gas evolution, simplifying the overall battery design.

ZIMONS as a Complete Substitute for PVDF Binders

- **Unexpected Result**: One of the most unexpected and impactful findings of the BetterLiBs project was the ability of ZIMONS to **completely substitute polyvinylidene fluoride (PVDF)**, a widely used binder in lithium-ion battery electrodes. PVDF, a **PFAS (per- and polyfluoroalkyl substances) polymer**, is commonly used as a binder but comes with environmental concerns due to its persistence in the environment and its reliance on hazardous organic solvents like 1-methyl-2-pyrrolidone (NMP).
- **Technological and Environmental Impact**: By using ZIMONS as a binder, the project not only improved the performance of the electrodes — offering better ionic conductivity and structural stability — but also significantly reduced the environmental impact of battery manufacturing. Unlike PVDF, which requires toxic solvents like NMP for processing, ZIMONS allow the use of **water-based processing**, eliminating the need for hazardous chemicals. This change is beneficial for both the environment and worker safety, reducing the release of harmful solvents and PFAS into the environment.

The switch to ZIMONS-based binders has the dual benefit of **enhancing battery performance** while simultaneously promoting **greener, more sustainable manufacturing processes**. This finding adds to the broader industry push for **PFAS-free technologies** and aligns with global efforts to phase out environmentally harmful substances like PFAS.

5.3 Describe the obtained commercial results. Did the project produce results not expected?

The **BetterLiBs project** delivered significant commercial results, confirming the readiness of ZIMONS technology for market entry and its potential to disrupt various segments of the lithium-ion battery industry. Here's a detailed description of the obtained commercial results:

1. Market-Ready ZIMONS-Based Battery Technology

- **Result**: The project successfully validated ZIMONS-based formulations in pilot-scale battery cells, proving that they offer substantial improvements in battery performance, safety, and scalability. The development of ZIMONS as an electrolyte additive and electrode binder not only enhanced battery stability but also demonstrated significant commercial viability.
- **Commercial Impact**: By confirming the scalability of ZIMONS production, the project positioned the technology for integration into commercial battery manufacturing lines. The ability to produce ZIMONS in larger batches (up to kg) ensures that battery manufacturers can adopt this technology without significant changes to existing production processes. The successful performance of ZIMONS in pilot cells lays the foundation for commercial adoption in industries such as electric vehicles, renewable energy storage, and consumer electronics.

2. Potential to Eliminate PFAS Binders in Battery Manufacturing

- **Result**: One of the most commercially valuable outcomes was the demonstration that ZIMONS could fully replace **polyvinylidene fluoride (PVDF)**, a PFAS polymer, as a binder in battery electrodes. This substitution eliminates the need for PFAS-based materials, which are increasingly scrutinized for their environmental impact.
- **Commercial Impact**: The use of ZIMONS as a binder offers a **PFAS-free alternative**, which is highly attractive to battery manufacturers seeking to comply with global regulations aimed at reducing PFAS usage. Furthermore, ZIMONS-based binders can be processed using **water-based processing** rather than processing using hazardous organic solvents like 1-methyl-2-pyrrolidone (NMP). This not only improves worker safety but also reduces the environmental footprint of battery production, providing a clear commercial advantage in a market that is moving toward greener and more sustainable manufacturing practices.

3. Improved Safety and Performance for High-Demand Applications

- **Result**: ZIMONS-based battery formulations demonstrated **enhanced safety** by reducing gas evolution during cycling and improving the thermal stability of lithium-ion batteries. The enhanced performance, particularly at elevated temperatures, makes ZIMONS an ideal solution for high-demand applications like electric vehicles (EVs) and grid energy storage.
- **Commercial Impact**: The ability of ZIMONS to improve both the safety and performance of batteries opens up significant commercial opportunities in markets that require robust, long-lasting energy

storage solutions. EV manufacturers, in particular, stand to benefit from the extended cycle life and improved thermal management offered by ZIMONS, giving the technology a competitive edge over traditional battery additives.

4. Scalability and Cost-Effectiveness of ZIMONS Production

- **Result**: The project demonstrated that ZIMONS can be produced at **pilot-scale quantities** without compromising quality, ensuring that the technology can be scaled for commercial use. The scalability of ZIMONS synthesis was confirmed through the successful production of larger batches for pilot cell testing.
- **Commercial Impact**: The ability to scale production means that ZIMONS-based technologies are ready for mass manufacturing. This scalability, combined with the performance improvements ZIMONS offer, positions the technology as a **cost-effective solution** for battery manufacturers looking to improve the performance and safety of their products without significant changes to their production processes.

5. Positive Industry and Market Reception

- **Result**: The project's dissemination activities, including partnerships with industry stakeholders and presentations at key conferences, generated positive market interest in ZIMONS technology. The results from pilot testing demonstrated that ZIMONS-based formulations could be integrated into existing battery designs, sparking interest from battery manufacturers and potential investors.
- **Commercial Impact**: The positive reception from industry partners confirms that ZIMONS technology is well-positioned for commercial adoption. The project's engagement with key players in the energy storage sector ensured that ZIMONS technology is recognized for its potential to improve battery safety, reduce environmental impact, and extend battery life—all key factors for large-scale adoption in electric vehicles, consumer electronics, and grid energy storage.

6. Pathway to Further Commercialization

- **Result**: With the successful validation of ZIMONS in pilot cells, the project established a clear **pathway for commercialization**. The results indicate that ZIMONS can be seamlessly integrated into existing battery production lines, accelerating the time to market.
- **Commercial Impact**: The successful validation of ZIMONS technology means that the groundwork has been laid for further commercialization efforts. Ongoing collaborations with industry partners will facilitate the transition from pilot-scale production to full-scale commercialization. This positions the BetterLiBs project as a key driver in the adoption of safer, more sustainable battery technologies.

The BetterLiBs project delivered strong commercial results, confirming that ZIMONS-based technologies are ready for market entry. By offering improvements in battery performance, safety, and environmental sustainability, the project positions ZIMONS as a valuable innovation for industries ranging from electric vehicles to renewable energy storage. The scalability of ZIMONS production and the potential to eliminate PFAS from battery manufacturing further solidify the commercial attractiveness of this technology.

Furthermore, the BetterLiBs project produced several **unexpected commercial results** that extended beyond the original goals and added significant value to the potential commercialization of ZIMONS technology.

Commercial Availability of ZIMONS with CAS Numbers

- **Unexpected Result**: Following the successful development and validation of ZIMONS in the BetterLiBs project, the monomers are now **commercially available** on the **ABCR website**, making them accessible to a broader range of researchers and manufacturers. ABCR is a renowned global supplier and distributor of specialty chemicals with more than 400,000 different products in their portfolio. All synthesized ZIMONS have been successfully registered with CAS numbers, confirming their commercial readiness and regulatory compliance.
- **Commercial Impact**: The availability of ZIMONS through ABCR provides an immediate commercial pathway for battery manufacturers, research institutions, and companies interested in integrating ZIMONS-based technologies into their products. The registration of ZIMONS with **CAS numbers** ensures that the materials meet global regulatory standards, further enhancing their appeal in international markets. This unexpected commercial outcome significantly accelerates the adoption of ZIMONS in the broader energy storage sector and positions the technology for rapid market penetration.

Stronger Industry Interest in Sustainability

- **Unexpected Result:** The project encountered unexpectedly strong interest from industry stakeholders in the sustainability aspects of ZIMONS technology, particularly the use of water-based processing and PFAS-free materials. The growing regulatory and environmental pressures to eliminate PFAS from industrial products have led to an **unexpected surge in market demand** for PFAS-free alternatives. ZIMONS, by offering a PFAS-free solution for battery binders, align perfectly with this demand.
- **Commercial Impact:** The emphasis on sustainability in the energy storage market is creating new commercial opportunities for ZIMONS-based technologies. This unanticipated level of interest positions ZIMONS as a solution not only for performance improvements but also for companies looking to enhance their environmental credentials. This shift in market dynamics provides ZIMONS with a broader range of potential applications, particularly in markets with a strong focus on sustainable production. The project's ability to position ZIMONS as a solution to this growing demand has opened new commercial pathways that were not initially foreseen. Battery manufacturers, particularly those in regions with strict PFAS regulations, are likely to adopt ZIMONS-based technologies to comply with upcoming environmental laws. This gives ZIMONS a **competitive edge** in markets where compliance with PFAS-free mandates is becoming increasingly critical.

5.4 Target group and added value for users: Who should the solutions/technologies be sold to (target group)? Describe for each solution/technology if several

The **BetterLiBs project** produced several solutions/technologies that can be sold to different target groups across various industries. Below is a breakdown of the target groups and the added value for each solution:

1. ZIMONS-Based Electrolyte Formulations

Target Group:

- **Battery Manufacturers**: Companies that produce lithium-ion batteries for various applications, including electric vehicles (EVs), consumer electronics, and energy storage systems.
- **Electric Vehicle (EV) Manufacturers**: Automakers and suppliers looking for advanced, high-performance batteries for electric and hybrid vehicles.
- **Renewable Energy Storage Providers**: Companies focused on grid energy storage solutions that require long-lasting, stable battery technologies for renewable energy systems.

Added Value:

- **Enhanced Stability and Performance**: ZIMONS-based electrolyte formulations provide improved cycle life, higher thermal stability, and reduced degradation, making them ideal for applications requiring long-lasting and high-performance batteries.
- **Increased Safety**: The reduction of gas evolution and enhanced thermal management provided by ZIMONS improves safety in high-stress environments like EVs and energy storage systems.
- **Greener Manufacturing**: For manufacturers focused on sustainability, ZIMONS offer a PFAS-free solution, which reduces environmental impact and aligns with global regulatory trends toward greener technologies.

2. ZIMONS as a Complete Replacement for PVDF Binders

Target Group:

- **Battery Manufacturers**: Companies looking to improve the environmental profile of their batteries by eliminating PFAS-based materials (like PVDF) from their production process.
- **Sustainability-Focused Companies**: Industries prioritizing environmentally friendly materials, such as green technology developers, energy companies, and electric vehicle manufacturers.

Added Value:

- **PFAS-Free Production**: ZIMONS provide a sustainable alternative to traditional binders like PVDF, helping manufacturers comply with emerging global regulations that restrict the use of PFAS chemicals. This is a critical value for companies needing to phase out harmful substances from their products.

- **Water-Based Processing**: Unlike PVDF, which requires hazardous solvents like NMP, ZIMONS can be processed using water-based solvents. This simplifies production, reduces costs associated with hazardous solvent handling, and improves worker safety.
- **Improved Battery Performance**: In addition to environmental benefits, ZIMONS-based binders enhance the structural stability of electrodes, resulting in better battery performance over time.

3. ZIMONS for High-Safety and High-Performance Battery Applications

Target Group:

- **Aerospace and Defense**: Industries that require highly reliable, safe, and efficient batteries for critical operations, such as satellites, drones, and military applications.
- **High-Safety Sectors**: Sectors where battery safety is paramount, such as medical devices, aviation, and industrial applications.

Added Value:

- **Improved Safety**: ZIMONS-based technologies reduce thermal runaway risks and improve the thermal stability of batteries, making them suitable for high-safety industries where battery failure could have severe consequences.
- **Extended Battery Life**: The enhanced cycling stability and reduced degradation provided by ZIMONS increase battery longevity, which is especially important in sectors where reliability is critical, such as aerospace and medical technology.

4. Commercially Available ZIMONS for Research and Development

Target Group:

- **Research Institutions**: Universities, laboratories, and research organizations working on next-generation battery technologies.
- **Battery Component Manufacturers**: Companies involved in the development of advanced battery components and materials for future battery technologies.

Added Value:

- **Access to Cutting-Edge Materials**: ZIMONS are now commercially available and registered with CAS numbers, making them readily accessible for researchers and developers looking to explore new battery chemistries.
- **Scalable Production**: With ZIMONS production successfully scaled to pilot-level quantities, manufacturers can explore integrating these advanced materials into their product lines with minimal changes to existing production processes.

5. ZIMONS for Renewable Energy and Grid Storage Solutions

Target Group:

- **Energy Storage Providers**: Companies focused on providing large-scale, stable energy storage solutions for renewable energy grids.
- **Utility Companies**: Electric utilities looking to incorporate energy storage technologies that provide reliable and long-lasting performance.

Added Value:

- **Long-Lasting Performance**: ZIMONS-based batteries provide extended cycle life, which is crucial for energy storage solutions that must support long-term grid stability and smooth out fluctuations in renewable energy supply.
- **Sustainability and Environmental Compliance**: ZIMONS offer a sustainable and environmentally friendly alternative to traditional battery materials, aligning with the renewable energy sector's focus on reducing carbon footprints and promoting sustainable technologies.

The ZIMONS-based technologies developed in the BetterLiBs project can be sold to a wide range of industries, including **battery manufacturers**, **electric vehicle producers**, **aerospace and defense companies**, and **renewable energy providers**. Each solution offers unique added value, such as improved battery safety, enhanced performance, and environmentally sustainable production processes, making ZIMONS a versatile and commercially attractive technology for multiple sectors.

5.5 Where and how have the project results been disseminated? Specify which conferences, journals, etc. where the project has been disseminated

The project team actively presented the results of the BetterLiBs project at several key conferences, exhibitions and workshops to reach industry stakeholders, researchers, and potential collaborators:

- SMART Lighthouse Summer School, Denmark, 2022
- Danish Export Center, Germany, 4-6 October 2022
- EU-Japan partnering Conference, Japan, 11 October 2022
- BioJapan, Japan, 12-14 October 2022
- CEATEC, Japan, 18-21 October 2022
- Nordbatt, Sweden, 26-28 October 2022
- CPhI, Germany, 2 November 2022
- Brainnovation Day, Denmark, 16 November 2022
- MEDICA, Germany, 16 November 2022
- Battery Japan, Japan, 15-17 March 2023
- MRS Spring Meeting & Exhibition, USA, 10–14 April 2023
- Danish Center for Energy Storage (DACES), Battery section member meeting, Denmark, 12 May 2023
- ChemSpec Europe 2023, Switzerland, 24-25 May 2023
- Folkemøde, Denmark, 17 June 2023
- Swiss Battery Days, Switzerland, 18-20 September 2023
- EU-Japan Biotech & Lifescience conference, Japan, October, 10, 2023

- BioJapan 2023, Japan, October 11-13, 2023
- iNano talks, Denmark, 13 October 2023
- Innovation center in Palo Alto, USA, October 17-19, 2023
- MEDICA, Germany, 13 November 2023
- Danish delegation to Korea, November 14-16, 2023
- Workshop with potential Chinese partner and KOLs, China, November 17, 2023
- Visit 4 monomer and polymer production sites in Japan with potential customer, Japan, November 20-24, 2023
- Project presentation for Japanese chemical company about collaboration, online, January, 23, 2024
- Meeting with chemical distributor company in Japan, online, April, 16, 2024
- Danish delegation to Korea, May, 6-10, 2024
- Visiting 5 companies and 3 universities interested in collaboration on ZIMONs, Japan, May 13-16, 2024
- 5th International Conference on Bioinspired and Zwitterionic Materials, Ithaca, NY, USA, July 29-31, 2024
- Nordbatt, Norway, September 24-27, 2024

In addition to academic and conference presentations, the project actively engaged with **industry stakeholders** to promote the commercialization of ZIMONS-based solutions. Outreach activities included:

- **Partnership Development**: The project team conducted direct outreach to **battery manufacturers**, **electric vehicle companies**, and **renewable energy storage providers**. These partnerships were aimed at accelerating the commercialization and adoption of ZIMONS-based technologies in real-world applications.
- **Project Website and Social Media Channels**: A dedicated project website (https://betterlibs.dk/) was launched to share the latest results, publications, and events related to the BetterLiBs project. The website also provided updates on the commercial availability of ZIMONS through ABCR. Social media channels (LinkedIn, Twitter) were used to disseminate project findings and engage with a broader audience.
- **Industry Webinars and Workshops**: The project team organized webinars and workshops to discuss the benefits of ZIMONS with potential partners and industry experts. These sessions focused on the **technical** and **commercial** aspects of ZIMONS, including their performance advantages, environmental benefits, and scalability for mass production.

6. Utilisation of project results

6.1 Describe how the obtained technological results will be utilised in the future and by whom

The technological results from the **BetterLiBs project** will be utilized across several industries, driving advancements in battery technology and offering significant environmental and performance benefits. Below is a detailed description of how these results will be used in the future and by whom:

1. ZIMONS-Based Electrolyte Formulations: ZIMONS-based electrolyte formulations will be integrated into the production lines of **lithium-ion battery manufacturers**. The demonstrated improvements in battery stability, cycling performance, and thermal management make ZIMONS an ideal additive for enhancing the performance of batteries in high-demand applications such as electric vehicles (EVs), grid storage, and consumer electronics. **By Whom**:

- **Electric Vehicle Manufacturers**: EV producers will benefit from ZIMONS-based electrolytes as they seek to extend the range, safety, and lifespan of their batteries. ZIMONS provide the stability needed for high-energy-density batteries, making them especially attractive for next-generation electric vehicles.
- **Battery Manufacturers**: Companies producing lithium-ion batteries will adopt ZIMONS to improve the performance of their products and meet the growing demand for longer-lasting, more reliable energy storage solutions.
- **Energy Storage Providers**: Grid energy storage solutions will integrate ZIMONS-based formulations to increase the longevity and efficiency of energy storage systems, enabling better support for renewable energy sources.

2. ZIMONS as a PFAS-Free Binder for Electrodes: The ability of ZIMONS to replace **PVDF (a PFAS polymer)** in battery electrodes is a significant technological breakthrough with immediate environmental and commercial benefits. ZIMONS-based binders will be used to produce **PFAS-free batteries**, which comply with increasingly stringent global regulations regarding harmful substances. **By Whom**:

- **Sustainability-Focused Battery Manufacturers**: Companies seeking to eliminate PFAS from their production processes will adopt ZIMONS-based binders to produce greener, more sustainable batteries. This includes manufacturers in regions where PFAS use is being phased out due to environmental concerns.
- **Electric Vehicle Companies**: EV manufacturers will benefit from using PFAS-free batteries, which align with their broader sustainability goals and respond to market demand for eco-friendly transportation solutions.
- **Green Technology Developers**: Companies focused on green technology and sustainable production will adopt ZIMONS binders to reduce their environmental footprint and comply with upcoming regulatory changes in the battery industry.

3. ZIMONS for High-Safety Applications: ZIMONS-based technologies will be used in high-safety applications where battery reliability, safety, and thermal stability are critical. The reduction of gas evolution and enhanced thermal management make ZIMONS an ideal solution for industries where battery failure is not an option. **By Whom**:

- **Aerospace and Defense**: Aerospace companies, including satellite and drone manufacturers, will utilize ZIMONS-based batteries for their high-safety standards and extended lifespan under extreme conditions. Defense contractors will also adopt the technology for use in military-grade batteries.

- **Medical Device Manufacturers**: Medical device companies will benefit from ZIMONS-based batteries in applications requiring long-term reliability and safety, such as implantable devices, where battery failure could have serious consequences.

4. Commercial Availability for Researchers and Developers: With the commercial availability of ZIMONS through **ABCR's website** and their registration with **CAS numbers**, researchers and developers will have direct access to these advanced materials. ZIMONS will be used in ongoing **research and development** efforts to further improve battery performance and explore new applications in energy storage. **By Whom**:

- **Research Institutions and Universities**: Academic researchers will explore the further potential of ZIMONS in advanced energy storage applications, expanding their use into new chemistries or configurations beyond lithium-ion batteries.
- **Battery Component Developers**: Companies focused on developing next-generation battery materials will adopt ZIMONS for integration into their proprietary battery designs, pushing the boundaries of performance and safety.

5. ZIMONS for Renewable Energy Storage Solutions: ZIMONS-based battery technologies will play a crucial role in improving the efficiency and reliability of **renewable energy storage systems**. The increased cycle life and stability provided by ZIMONS will enhance the performance of batteries used to store renewable energy, helping to smooth fluctuations in power generation and ensure long-term energy availability. **By Whom**:

- **Utility Companies**: Utility providers and energy companies focused on renewable energy grids will integrate ZIMONS-based batteries into their energy storage infrastructure. The longer lifespan and reduced maintenance requirements of these batteries will enable more reliable grid management and support for intermittent renewable energy sources like wind and solar.
- **Energy Storage System Manufacturers**: Companies producing large-scale energy storage systems will use ZIMONS-based technologies to develop more durable, efficient solutions for the renewable energy sector, reducing the overall cost of storing energy and improving the sustainability of energy grids.

6. PFAS-Free, Water-Based Production for Greener Battery Manufacturing: ZIMONS allow battery manufacturers to switch to **water-based processing** for electrode production, eliminating the need for hazardous solvents like NMP. This technology will contribute to more sustainable and cost-effective production processes across the battery industry. **By Whom**:

- **Battery Manufacturers**: Companies looking to reduce production costs and align with environmental regulations will adopt ZIMONS for water-based manufacturing. This shift will help them reduce the use of harmful solvents and enhance worker safety.
- **Sustainability-Focused Companies**: Companies that prioritize environmentally friendly production processes will adopt ZIMONS to create **eco-friendly batteries**, meeting both regulatory standards and market demand for greener products.

7. Further Maturation of the Technology through Research and Innovation Funding: The **BetterLiBs project consortia** will continue to exploit the technological results by applying for **additional research, development, and innovation funding**. The goal is to further mature the ZIMONS technology and explore new applications, improving its commercial readiness and expanding its impact across industries. **By Whom**:

- **Project Partners**: The consortia, including academic institutions like Aarhus University and industry partners, will collaborate to secure funding for further development. This includes applying for national and international research grants, such as EU Horizon Europe programs, to refine the technology and explore its integration into new battery chemistries and applications.
- **Collaborative R&D Networks**: The project will also engage with broader R&D networks and innovation clusters, leveraging partnerships to drive the continued advancement of ZIMONS-based technologies.
- **Added Value**: Further funding will allow the consortia to optimize ZIMONS for additional battery applications, push the boundaries of performance and safety, and bring the technology even closer to large-scale commercial adoption.

The technological results from the BetterLiBs project will be utilized by a wide range of industries, including **battery manufacturers**, **electric vehicle companies**, **aerospace and defense**, and **energy storage providers**. ZIMONS technology offers multiple commercial benefits, such as improved performance, increased safety, and environmental sustainability, making it a valuable asset for the future of battery technology across high-performance and green energy markets.

6.2 Describe how the obtained commercial results will be utilised in the future and by whom the results will be commercialised

The commercial results obtained from the **BetterLiBs project** have opened up multiple avenues for future utilization and commercialization. These results, which include the development of ZIMONS-based technologies for lithium-ion batteries, will be commercialized by various industry stakeholders. Below is a detailed description of how these results will be utilized and by whom they will be commercialized:

1. ZIMONS-Based Electrolyte Formulations for Enhanced Battery Performance: The ZIMONS-based electrolyte formulations developed in the project will be used to improve the **performance, stability, and safety** of lithium-ion batteries. Battery manufacturers will incorporate ZIMONS into their electrolyte formulations to enhance cycle life, thermal stability, and energy density. **Commercialization by**:

- **Battery Manufacturers**: Large-scale battery producers will commercialize ZIMONS-based electrolytes in their products, targeting sectors like **electric vehicles (EVs)**, **consumer electronics**, and **renewable energy storage**. These manufacturers will market ZIMONS-enhanced batteries as safer and longer-lasting alternatives to conventional lithium-ion batteries.
- **Electric Vehicle (EV) Industry**: Automotive companies developing electric vehicles will integrate ZIMONS-enhanced batteries to increase the range, safety, and efficiency of their vehicles. ZIMONS technology will allow EV manufacturers to meet increasing market demands for higher-performance batteries with improved safety profiles.

- **Renewable Energy Providers**: Companies offering grid energy storage solutions will use ZIMONS-enhanced batteries to improve the efficiency and durability of energy storage systems, enabling longer-lasting and more reliable power solutions for renewable energy integration.

2. ZIMONS as a PFAS-Free Binder for Green Battery Production: The replacement of **PVDF (a PFAS polymer)** with ZIMONS as a binder in battery electrodes will be a key contribution to sustainable battery manufacturing. By eliminating PFAS-based materials and enabling **water-based processing**, ZIMONS will help companies reduce their environmental impact while improving battery performance. **Commercialization by**:

- **Sustainability-Focused Battery Manufacturers**: Manufacturers prioritizing eco-friendly production will adopt ZIMONS binders to create **PFAS-free batteries**. These companies will market the batteries as **green alternatives**, which comply with global regulations aimed at phasing out harmful substances like PFAS.
- **Electric Vehicle and Consumer Electronics Producers**: Companies in the EV and electronics sectors will incorporate ZIMONS-based binders into their products, offering sustainable battery solutions that meet both performance and environmental requirements. The elimination of harmful solvents and PFAS will enhance the market appeal of these products.

3. Commercial Availability of ZIMONS for Research and Development: ZIMONS are now commercially available through **ABCR's website** and have been registered with **CAS numbers**, making them accessible to research institutions, battery component manufacturers, and developers. These materials will be used to further explore the applications of ZIMONS in energy storage and beyond. **Commercialization by**:

- **Research Institutions and Universities**: Academic and research organizations will continue to explore the potential of ZIMONS in developing next-generation battery technologies. Their work will be essential for driving innovation and exploring new chemistries beyond lithium-ion.
- **Battery Component Manufacturers**: Companies focused on advanced battery components will commercialize ZIMONS by integrating them into their product offerings. These manufacturers will leverage the unique properties of ZIMONS to develop high-performance battery materials for a range of industries.

4. Commercialization of ZIMONS in High-Safety Applications: ZIMONS-based battery technologies will be used in **high-safety industries**, where the stability, safety, and reliability of energy storage systems are critical. The reduced gas evolution and improved thermal stability of ZIMONS-based batteries make them ideal for applications requiring strict safety standards. **Commercialization by**:

- **Aerospace and Defense**: Companies operating in the aerospace and defense sectors will adopt ZIMONS-based batteries for use in high-reliability applications like satellites, drones, and military-grade equipment. These batteries will be marketed for their extended lifespan and improved safety under extreme conditions.
- **Medical Device Manufacturers**: Medical technology companies will utilize ZIMONS-based batteries in critical devices such as implantable technologies and life-supporting equipment. The commercial

appeal of these batteries lies in their safety and longevity, which are essential for medical applications.

5. Utilization of ZIMONS-Based Batteries in Renewable Energy Storage: ZIMONS-based technologies will be applied to large-scale energy storage systems that support the **renewable energy sector**. The enhanced stability and extended cycle life provided by ZIMONS will make these batteries ideal for long-term energy storage in solar and wind power grids. **Commercialization by**:

- **Utility Companies**: Utility providers offering renewable energy solutions will integrate ZIMONS-enhanced batteries into their energy storage infrastructure. These companies will market the technology as a reliable and long-term solution for storing renewable energy.
- **Energy Storage System Manufacturers**: Companies that develop energy storage systems for grid management and renewable energy integration will commercialize ZIMONS-based batteries as part of their product lines, emphasizing the long-term reliability and sustainability of the technology.

6. Further Commercialization through Research and Innovation Funding: The BetterLiBs project consortia will continue to commercialize the results by **applying for additional research, development, and innovation funding**. This funding will be used to further mature ZIMONS technology, explore new applications, and refine the scalability of the materials. **Commercialization by**:

- **Project Consortia and Partners**: The project partners, including academic institutions like Aarhus University and industry stakeholders, will lead the commercialization efforts. The consortia will pursue additional research grants and development initiatives to improve the technology and expand its market reach.
- **Collaborative Industry Networks**: The consortia will work with collaborative research and innovation networks to accelerate the commercialization process and identify new markets for ZIMONS-based technologies.

The commercial results from the BetterLiBs project will be utilized by **battery manufacturers**, **electric vehicle companies**, **research institutions**, and **high-safety industries**. ZIMONS-based technologies offer clear advantages in terms of performance, safety, and environmental sustainability, making them attractive for a wide range of commercial applications. The project consortia will continue to advance the commercialization of ZIMONS by pursuing further research funding and innovation partnerships to bring the technology to even broader markets.

6.2.1 Did the project so far lead to increased turnover, exports, employment and additional private investments? Do the project partners expect that the project results in increased turnover, exports, employment and additional private investments?

The **BetterLiBs project** has not yet directly led to increased turnover, exports, employment, or additional private investments. However, the project partners are confident that the results obtained will lead to significant commercial and economic benefits in the near future. Below is an overview of the expected impact:

1. Increased Turnover and Export Potential

- **Current Status**: The project has not yet resulted in a measurable increase in turnover or exports, as the commercialization phase is still underway.
- **Future Expectations**: The project partners expect that the commercialization of **ZIMONS through ABCR** and ongoing engagement with **commercial stakeholders** will lead to increased turnover and export potential in the near future. ZIMONS-based technologies offer clear advantages for **battery manufacturers** and **green technology developers**, particularly in high-demand markets like electric vehicles, renewable energy storage, and consumer electronics. As these markets continue to grow, the demand for ZIMONS-enhanced batteries is expected to drive both turnover and exports.

2. Employment Growth

- **Current Status**: The project has not yet directly contributed to increased employment, but the groundwork has been laid for future expansion in this area.
- **Future Expectations**: As the commercialization of ZIMONS-based technologies progresses, the project partners expect that additional personnel will be required to support production, distribution, and further development. This includes roles in **manufacturing**, **sales**, **research**, and **technical support**. The growth of ZIMONS-based solutions in the battery industry could lead to employment opportunities both at the partner companies and throughout the supply chain.

3. Private Investments and Patents

- **Current Status**: The project partners are currently in the process of filing **two patents** based on the results obtained during the project. These patents will protect the novel applications of ZIMONS in battery technologies and provide a strong foundation for attracting further private investments.
- **Future Expectations**: The project partners anticipate that securing these patents will increase the attractiveness of ZIMONS-based technologies to investors. The patented innovations will create new opportunities for **private investments**, particularly from companies in the **energy storage** and **electric vehicle sectors** looking for competitive advantages in battery performance, safety, and sustainability.

4. Commercial Availability Through ABCR

- **Future Expectations**: Having ZIMONS commercially available through ABCR opens up immediate pathways for adoption and sales across various industries. The availability of ZIMONS, combined with the ongoing efforts to engage commercial stakeholders, is expected to contribute to increased turnover and export potential. As **research institutions** and **battery manufacturers** begin to integrate

ZIMONS into their development pipelines, the demand for these materials is expected to grow, driving revenue and market expansion.

While the project has not yet resulted in immediate increases in turnover, export, employment, or private investment, the foundations for future growth have been established. The commercialization of ZIMONS, coupled with the filing of new patents and ongoing engagement with industry stakeholders, is expected to lead to increased economic benefits in the near future. The project partners are optimistic that the success of ZIMONS-based technologies will generate substantial commercial and financial impact as the technology reaches broader markets.

6.3 Describe the competitive situation in the market you expect to enter

The **BetterLiBs project** aims to enter the competitive and rapidly growing lithium-ion battery market. This market is characterized by significant innovation, increasing demand for high-performance batteries, and an evolving regulatory landscape that favors environmentally sustainable technologies. Below is a detailed analysis of the competitive situation:

1. Established Competitors in the Battery Additives Market

- **Existing Technologies**: The market for battery additives is highly competitive, with well-established players providing additives such as **silicon anode enhancers**, **solid electrolytes**, and **electrolyte stabilizers**. Some competitors are already offering solutions designed to improve the cycle life, energy density, and safety of lithium-ion batteries.
- **Key Competitors**: Major chemical companies and specialized battery materials manufacturers dominate the space. Firms such as **BASF**, **3M**, and **Asahi Kasei** produce advanced battery additives that are widely used by battery manufacturers. These established players have strong R&D capabilities and extensive relationships with battery producers.
- **Competitive Advantage of ZIMONS**: The key differentiator for **ZIMONS** lies in their dual functionality as both electrolyte additives and binders, offering not only performance improvements but also environmental benefits. The ability of ZIMONS to provide **PFAS-free solutions** and enable **water-based processing** sets them apart from traditional additives like **PVDF binders**, which rely on hazardous solvents. This unique combination of performance and sustainability gives ZIMONS a competitive edge in markets that prioritize **green technology**.

2. Growing Demand for Sustainable and PFAS-Free Technologies

- **Market Trend**: As global regulations become more stringent regarding the use of hazardous materials, there is a growing shift towards **PFAS-free** and **sustainable battery solutions**. Environmental regulations, especially in regions like Europe and North America, are pushing battery manufacturers to reduce their reliance on harmful chemicals such as PVDF (a PFAS polymer).

- **Competitive Advantage of ZIMONS**: ZIMONS are uniquely positioned to capitalize on this trend, as they provide a **PFAS-free alternative** that improves battery performance without relying on harmful chemicals. This positions ZIMONS as an attractive solution for **electric vehicle manufacturers**, **consumer electronics companies**, and **energy storage providers** that are looking to comply with emerging environmental regulations.
- **Competitors**: While there are some competitors exploring PFAS-free alternatives, the commercial availability and scalability of ZIMONS give them a significant advantage. Many battery manufacturers are still in the early stages of developing PFAS-free solutions, giving ZIMONS a head start in this emerging market.

3. Competitive Landscape in Electric Vehicle and Energy Storage Markets

- **Electric Vehicle (EV) Market**: The EV market is one of the largest growth drivers for the lithium-ion battery industry, with increasing demand for high-energy-density, long-life batteries. Major players like **Tesla**, **LG Chem**, **Panasonic**, **CATL** and **BYD** dominate the market, focusing heavily on battery innovation and cost reduction.
- **Energy Storage Market**: The energy storage market, particularly for **grid storage** and **renewable energy integration**, is growing rapidly as renewable energy sources like wind and solar become more prevalent. Companies like **Siemens**, **Fluence**, and **Tesla Energy** are key players in this space.
- **Competitive Advantage of ZIMONS**: ZIMONS provide a strong competitive advantage in both the EV and energy storage markets due to their ability to improve **battery cycle life**, **thermal stability**, and **safety** — all critical factors for large-scale applications. Additionally, the **sustainability** of ZIMONS will appeal to companies in both markets that prioritize green technologies and look to reduce their environmental footprint.
- **Challenges**: The challenge for ZIMONS-based technologies will be to demonstrate **cost competitiveness** in a market where price sensitivity is high, especially in the EV sector. However, the ability to reduce **production costs** through water-based processing and eliminate hazardous solvents provides an opportunity for long-term cost savings.

4. Technological Barriers and Adoption Rates

- **Technological Barriers**: One of the challenges in entering the battery additives market is the high barrier to entry due to the need for extensive validation and integration with existing battery manufacturing processes. Battery manufacturers are cautious about adopting new materials that could disrupt their production lines or require significant retooling.
- **Adoption Rates**: Despite these barriers, the rapid innovation in the battery industry, driven by the need for higher-performing, safer, and more sustainable batteries, means that new technologies like ZIMONS have a clear pathway to adoption. The key will be to prove the scalability and long-term benefits of ZIMONS through continued testing and industry partnerships.

5. Strategic Positioning and Market Opportunities

- **Positioning**: ZIMONS will be positioned as a **high-performance, sustainable alternative** to conventional battery additives. The focus will be on marketing ZIMONS to battery manufacturers that need to comply with environmental regulations while also improving the performance and safety of their batteries.
- **Market Opportunities**: The **electric vehicle** and **grid energy storage** markets offer the largest opportunities for ZIMONS. Additionally, **consumer electronics** and **medical devices** represent emerging markets where ZIMONS' ability to extend battery life and improve safety will be highly valued.
- **Patents and Intellectual Property**: The project partners are in the process of filing **two patents** based on the results of the BetterLiBs project. These patents will provide protection for the novel applications of ZIMONS and give the project partners a competitive edge in the market by securing their intellectual property.

Competitive Outlook for ZIMONS-Based Technologies: The **BetterLiBs project** enters a highly competitive market dominated by established players, but ZIMONS-based technologies offer a unique combination of **performance enhancements** and **environmental sustainability** that set them apart. The ability to eliminate PFAS, enable water-based production, and improve battery safety and efficiency positions ZIMONS as a highly attractive solution for manufacturers in the **electric vehicle**, **energy storage**, and **consumer electronics** markets. The challenge will be to demonstrate cost-effectiveness and scalability, but the project's patents and early market positioning provide a strong foundation for success.

6.3.1 Are there competing solutions on the market? Specify who the main competitors are and describe their solutions

The **BetterLiBs project** operates in a competitive market where several companies are developing advanced materials to enhance the performance, safety, and sustainability of lithium-ion batteries. Below is an overview of the main competitors and their solutions:

BASF

- **Competing Solutions**: BASF is a major player in the battery materials market, offering advanced cathode active materials (CAMs) and electrolyte additives. BASF focuses on improving energy density, cycle life, and thermal stability in lithium-ion batteries, with a particular emphasis on **nickel-rich cathode materials**.
- **Solution Overview**: BASF's cathode materials, such as **NCM (nickel-cobalt-manganese)**, are widely used in **electric vehicles (EVs)** due to their high energy density. They also offer **electrolyte stabilizers** that enhance the longevity and safety of batteries under high-voltage conditions.
- **Comparison to ZIMONS**: While BASF's products focus on improving energy density through cathode materials, **ZIMONS** offer a distinct advantage in their dual role as **electrolyte additives** and **binders**. ZIMONS provide not only performance improvements but also **environmental benefits**, such as PFAS-free solutions and water-based processing—areas where BASF's solutions may not directly compete.

3M

- **Competing Solutions**: 3M offers a wide range of **fluoropolymer-based binders** for lithium-ion batteries, including **PVDF binders**. These materials are known for their chemical stability and mechanical strength, making them a popular choice for high-performance batteries.
- **Solution Overview**: 3M's **PVDF binders** are commonly used in lithium-ion battery electrodes to provide adhesion and flexibility, ensuring the structural integrity of the electrode. However, PVDF binders require the use of hazardous solvents like **NMP (1-methyl-2-pyrrolidone)** during production, which poses environmental and safety concerns.
- **Comparison to ZIMONS**: **ZIMONS** outperform 3M's PVDF binders in terms of environmental sustainability. ZIMONS enable **water-based processing**, eliminating the need for hazardous solvents, and offer a **PFAS-free** alternative. This makes ZIMONS an attractive solution for manufacturers seeking greener battery production processes, especially in regions with stricter environmental regulations.

Solvay

- **Competing Solutions**: Solvay is another key player in the battery materials market, offering **specialty polymers** and **electrolyte additives** that enhance the performance and safety of lithium-ion batteries. Solvay's products include advanced binders and coatings designed to improve battery stability under extreme conditions.
- **Solution Overview**: Solvay's **polymer-based binders** and **solid-state electrolytes** are designed to improve the thermal and chemical stability of lithium-ion batteries. They focus on developing solutions that enable the safe operation of batteries in high-temperature environments, particularly in electric vehicles and renewable energy storage.
- **Comparison to ZIMONS**: While Solvay's products emphasize thermal stability, **ZIMONS** provide additional benefits by offering **dual functionality**—as both electrolyte additives and binders. ZIMONS also promote environmental sustainability by eliminating the need for PFAS-based materials and enabling water-based processing, areas where Solvay's offerings may not provide a direct advantage.

Asahi Kasei

- **Competing Solutions**: Asahi Kasei is a leading supplier of **separator materials** and **battery electrolyte additives**. Their products are widely used in lithium-ion batteries for electric vehicles, consumer electronics, and energy storage systems.
- **Solution Overview**: Asahi Kasei's **Hipore™ battery separators** and **Li-ion electrolyte additives** are designed to improve battery safety by enhancing the thermal stability of the separator and reducing the risk of short circuits. Their electrolyte additives also improve the cycling performance and overall efficiency of the battery.
- **Comparison to ZIMONS**: While Asahi Kasei focuses on **battery separators** and **thermal stability**, **ZIMONS** address a broader range of issues, including electrolyte stability, binder performance, and environmental impact. ZIMONS-based technologies offer a more comprehensive solution, targeting

both performance and sustainability, whereas Asahi Kasei's products focus primarily on safety and efficiency.

LG Chem

- **Competing Solutions**: LG Chem is a major producer of lithium-ion batteries and battery materials, particularly for electric vehicles. LG Chem's solutions include advanced cathode materials, separators, and electrolyte additives designed to enhance battery performance and lifespan.
- **Solution Overview**: LG Chem's battery materials focus on improving the **energy density** and **cycle life** of lithium-ion batteries. Their products are widely used by leading electric vehicle manufacturers and energy storage providers due to their proven performance in high-demand applications.
- **Comparison to ZIMONS**: While LG Chem focuses on **high-performance battery materials**, **ZIMONS** provide a unique advantage by offering **sustainability-focused solutions**. The ability of ZIMONS to provide **PFAS-free** binders and **water-based processing** is a significant differentiator, especially as environmental regulations tighten.

Daikin

- **Competing Solutions**: Daikin is a global leader in the production of **fluoropolymer materials**, including **PVDF binders** used in lithium-ion battery production. Their fluoropolymers are valued for their chemical resistance and stability, making them a popular choice for high-performance battery applications.
- **Solution Overview**: Daikin's **PVDF binders** are widely used in lithium-ion batteries due to their strong adhesion properties and ability to withstand the harsh chemical environment inside the battery. However, like other PVDF-based products, they rely on hazardous solvents for processing, which raises environmental concerns.
- **Comparison to ZIMONS**: **ZIMONS** offer a compelling alternative to Daikin's PVDF binders, providing a **PFAS-free solution** that eliminates the need for toxic solvents. The environmental and safety benefits of ZIMONS, along with their performance as both electrolyte additives and binders, give them a competitive edge over traditional fluoropolymers like those produced by Daikin.

The lithium-ion battery market is highly competitive, with established players such as **BASF**, **3M**, **Solvay**, **Asahi Kasei**, **LG Chem**, and **Daikin** offering advanced materials that enhance battery performance and safety. However, **ZIMONS-based technologies** stand out for their **environmental sustainability**, **dual functionality**, and ability to enable **water-based production**, positioning them as a strong competitor in the push toward **PFAS-free** and **green battery technologies**. While the market is crowded, ZIMONS offer unique advantages that are well-aligned with current regulatory trends and market demand for sustainable, high-performance batteries.

6.4 Describe entry or sales barriers and how these are expected to be overcome

Entering the highly competitive **lithium-ion battery market** presents several challenges, ranging from technological validation to cost pressures and regulatory compliance. Below is an overview of the **entry or sales barriers** the BetterLiBs project may encounter and how these barriers are expected to be overcome:

Technological Validation and Adoption Risk

- **Barrier**: **Battery manufacturers** are often slow to adopt new materials due to the extensive testing and validation required to ensure compatibility with existing production processes. Incorporating a new material like ZIMONS into batteries may require modifications to production lines, and manufacturers are cautious about potential disruptions.
- **Strategy to Overcome**: The project has already demonstrated the scalability and performance of ZIMONS through **pilot-scale testing**, which helps reduce the perceived risk. Ongoing collaboration with industry partners will be key to overcoming this barrier. By partnering with major **battery manufacturers** and providing detailed validation data, the project can accelerate the adoption of ZIMONS-based technologies in commercial battery production. Additionally, securing **patents** for ZIMONS-based innovations will help build confidence in the market by protecting intellectual property and ensuring the uniqueness of the solutions.

Cost Competitiveness

- **Barrier**: In the battery market, especially in sectors like **electric vehicles** and **consumer electronics**, price sensitivity is high. New materials like ZIMONS will face competition from established, cost-effective solutions like **PVDF binders** and conventional electrolyte additives, which have benefited from economies of scale.
- **Strategy to Overcome**: The **water-based processing** enabled by ZIMONS represents a significant opportunity to reduce overall production costs. By eliminating the need for **hazardous solvents** like NMP (1-methyl-2-pyrrolidone), manufacturers can reduce solvent-related costs, including storage, handling, and disposal. These cost savings can offset the initial investment in ZIMONS. Furthermore, as ZIMONS production is scaled up, economies of scale will bring down material costs, making them more competitive with established alternatives. In addition, the environmental benefits of ZIMONS — such as eliminating PFAS — can be marketed as a long-term cost-saving solution in markets that are moving toward more sustainable practices.

Regulatory Compliance and Certification

- **Barrier**: Entering regulated markets, such as electric vehicles or grid energy storage, requires meeting strict **safety** and **performance certifications**. New materials must undergo rigorous testing to ensure compliance with international standards for battery safety, performance, and environmental impact.

- **Strategy to Overcome**: The project will continue working with **regulatory bodies** and **testing facilities** to ensure that ZIMONS meet all necessary safety and performance standards. By conducting comprehensive safety tests and demonstrating compliance with relevant industry standards (such as **UN 38.3** for battery transportation), the project can ensure that ZIMONS are ready for market adoption. Additionally, ZIMONS' ability to help manufacturers comply with **PFAS-free regulations** will position the technology as a forward-thinking solution in markets with stringent environmental standards, such as **Europe** and **North America**.

Market Entrenchment of Established Solutions

- **Barrier**: The lithium-ion battery industry is dominated by well-established companies like **BASF**, **3M**, and **Solvay**, whose materials are already deeply integrated into battery production lines. These established competitors have strong relationships with major battery producers, making it difficult for new entrants to gain market share.
- **Strategy to Overcome**: The unique value proposition of ZIMONS — combining **performance improvements** with **environmental sustainability** — can be leveraged to differentiate the technology from established competitors. ZIMONS' ability to provide a **PFAS-free**, **sustainable** solution positions them as an attractive alternative to conventional materials. The project will focus on **targeting sectors** where sustainability and green manufacturing are key priorities, such as electric vehicles, renewable energy storage, and consumer electronics. By positioning ZIMONS as a solution that aligns with **future regulatory trends** and **environmental goals**, the project can carve out a niche in the market and attract early adopters.

Manufacturing Integration and Scale-Up

- **Barrier**: Scaling up production and integrating ZIMONS into existing battery manufacturing processes presents logistical and technical challenges. Battery manufacturers may be reluctant to adjust their production lines to accommodate a new material without seeing clear performance and cost advantages.
- **Strategy to Overcome**: The project has already demonstrated the scalability of ZIMONS through successful **pilot-scale production**, which proves that ZIMONS can be manufactured in commercially viable quantities. By offering **technical support** and **testing partnerships** with manufacturers, the project can ease the integration of ZIMONS into existing production lines. Collaborative partnerships with **industry leaders** will ensure that any necessary adjustments to manufacturing processes are made with minimal disruption. Additionally, highlighting the **cost-saving potential** from switching to water-based processing will incentivize manufacturers to make the transition.

Intellectual Property and Competitive Differentiation

- **Barrier**: Protecting intellectual property (IP) is critical in a competitive market. Without strong IP protection, competitors could potentially replicate or modify ZIMONS-based technologies, reducing the competitive edge.

- **Strategy to Overcome**: The project partners are in the process of filing **two patents** to protect the novel applications of ZIMONS. These patents will safeguard the intellectual property behind the technology, giving the project partners a competitive advantage. Additionally, the patents will enhance the appeal of ZIMONS to potential investors and partners, further accelerating commercialization efforts.

Overcoming Entry and Sales Barriers: While the lithium-ion battery market presents several **entry barriers**, the **BetterLiBs project** is well-positioned to overcome them through its focus on **technological validation**, **cost competitiveness**, **regulatory compliance**, and **sustainability**. By demonstrating the performance and environmental advantages of ZIMONS-based technologies, the project can differentiate itself from established competitors and gain market share in high-growth sectors like electric vehicles and energy storage. Collaboration with industry leaders, strong patent protection, and ongoing regulatory engagement will be key strategies for ensuring successful market entry.

6.5 How does the project results contribute to realise energy policy objectives?

The **BetterLiBs project** contributes significantly to several key **energy policy objectives**, particularly those related to **sustainability**, **clean energy**, and **decarbonization**. Below is a detailed description of how the project results align with and support the realization of national and international energy policy goals:

Decarbonization and Reduction of Greenhouse Gas Emissions

- **Energy Policy Objective**: Governments and international organizations, such as the **European Union (EU)** and the **United Nations**, have set ambitious targets for reducing **greenhouse gas emissions** in order to mitigate climate change. A key element of this strategy is the transition to **clean energy** sources and the **electrification of transportation**.
- **Project Contribution**: The **ZIMONS-based technologies** developed in the project contribute to decarbonization by enhancing the performance and efficiency of **lithium-ion batteries**, which are a critical component of the **electric vehicle (EV)** and **renewable energy storage** markets. By improving the **cycle life**, **stability**, and **energy density** of batteries, ZIMONS help facilitate the broader adoption of **electric vehicles** and **grid storage systems** for renewable energy, reducing reliance on fossil fuels and contributing to a lower-carbon economy.

Supporting the Transition to Renewable Energy

- **Energy Policy Objective**: A key goal of many energy policies, including the **EU's Green Deal**, is to increase the use of **renewable energy sources** such as solar and wind. However, the intermittent nature of these energy sources creates challenges for grid stability, making **energy storage** a critical component of the transition to renewable energy.
- **Project Contribution**: The results of the BetterLiBs project, particularly the development of **longer-lasting** and **more stable** batteries using ZIMONS, support the integration of renewable energy

sources into the grid. **ZIMONS-enhanced batteries** improve the efficiency and durability of energy storage systems, ensuring that renewable energy can be stored and delivered when needed, even during periods of low production. This makes **renewable energy** more reliable and accelerates the transition to a sustainable energy grid.

Promoting Energy Efficiency

- **Energy Policy Objective**: Increasing **energy efficiency** is a central policy goal for many countries, aiming to reduce energy consumption while maximizing output. Energy-efficient technologies are essential for reducing overall demand and minimizing the environmental impact of energy production and consumption.
- **Project Contribution**: **ZIMONS-based batteries** improve energy efficiency by enhancing **battery performance** and **reducing energy loss** during charging and discharging cycles. The **stability** and **longer cycle life** provided by ZIMONS reduce the need for frequent battery replacements, lowering the overall energy required for battery production and reducing waste. By extending battery life and improving energy retention, the project contributes directly to improving energy efficiency in sectors like electric vehicles and energy storage.

Reducing Environmental Impact and Promoting Sustainability

- **Energy Policy Objective**: International energy policies increasingly focus on **reducing the environmental impact** of energy technologies, including minimizing the use of harmful chemicals and ensuring that production processes are environmentally sustainable. The phase-out of **PFAS (per- and polyfluoroalkyl substances)** and other harmful chemicals is a key part of this strategy.
- **Project Contribution**: The BetterLiBs project directly supports sustainability goals by developing **PFAS-free** alternatives to traditional battery binders like PVDF. By eliminating PFAS from battery production and enabling **water-based processing**, the project reduces the use of hazardous chemicals and aligns with global efforts to phase out environmentally harmful substances. The use of **ZIMONS** as a sustainable alternative also reduces the environmental footprint of battery production, contributing to cleaner, greener energy solutions.

Enhancing Energy Security

- **Energy Policy Objective**: Energy security is a critical policy objective for many countries, with an emphasis on ensuring a stable and reliable energy supply. Battery technologies play a vital role in stabilizing energy grids and supporting the deployment of **renewable energy** sources that can reduce dependence on imported fossil fuels.
- **Project Contribution**: By improving the performance and reliability of **lithium-ion batteries**, the BetterLiBs project enhances **energy security**. **ZIMONS-enhanced batteries** provide a more reliable energy storage solution for grid applications, helping to stabilize energy supplies and reducing the need for energy imports. This contribution is particularly important for countries that are transitioning away from fossil fuels and toward renewable energy.

Supporting Green Jobs and Economic Growth

- **Energy Policy Objective**: Many energy policies emphasize the importance of creating **green jobs** and promoting **sustainable economic growth**. The transition to a clean energy economy is seen as a key driver of innovation, job creation, and economic resilience.
- **Project Contribution**: The commercialization of ZIMONS-based technologies will create new opportunities for **employment** in battery manufacturing, **research and development**, and **green technology** sectors. As the demand for electric vehicles and renewable energy grows, the market for high-performance, environmentally friendly battery technologies will expand, driving economic growth and supporting the creation of green jobs.

Innovation and Leadership in Energy Technology

- **Energy Policy Objective**: Countries and regions are increasingly focused on becoming **leaders in energy innovation**, with the aim of developing advanced energy technologies that can be exported globally. The development of **next-generation battery technologies** is a key element of this strategy.
- **Project Contribution**: The BetterLiBs project positions its partners as **leaders in battery innovation**, particularly in the development of sustainable, high-performance battery materials. The creation of **patents** for ZIMONS-based technologies further strengthens the project's position in the global market. By promoting innovative battery technologies, the project contributes to national and international goals of becoming leaders in the **clean energy** and **sustainable technology** markets.

Alignment with Energy Policy Objectives: The **BetterLiBs project** makes a significant contribution to key **energy policy objectives**, including **decarbonization**, **renewable energy integration**, **energy efficiency**, and **sustainability**. By developing **ZIMONS-based technologies** that improve battery performance, reduce environmental impact, and enhance energy security, the project supports the transition to a **clean energy economy** and aligns with global goals for a more sustainable future.

6.6 If Ph.D.'s have been part of the project, it must be described how the results from the project are used in teaching and other dissemination activities

Since there were no **Ph.D.'s** involved in the **BetterLiBs project**, there is no direct use of the project results in teaching or related academic dissemination activities. However, the results of the project have been disseminated through **conferences**, **exhibitions**, and **workshops**, contributing to the broader academic and industrial knowledge base in the field of **battery technologies**. These dissemination efforts ensure that the findings are accessible to researchers, industry professionals, and academic institutions, supporting the continued advancement of sustainable and high-performance battery materials.

7. Project conclusion and perspective

7.1 State the conclusions made in the project

The **BetterLiBs project** successfully achieved its primary goals and produced significant technological and commercial outcomes. Below is a summary of the key conclusions made throughout the project:

1. Successful Development and Validation of ZIMONS-Based Technologies

- The project successfully developed and validated **ZIMONS-based electrolyte formulations** and **binders** that enhance the performance, safety, and sustainability of **lithium-ion batteries**.
- **ZIMONS** were proven to improve **cycling stability**, **thermal management**, and **battery longevity**, making them suitable for high-demand applications such as **electric vehicles (EVs)** and **grid energy storage**.
- The technology was validated in **pilot-scale batteries**, confirming its readiness for commercial adoption.

2. Environmental and Regulatory Benefits of PFAS-Free Binders

- The project demonstrated that **ZIMONS** can completely replace **PFAS-based binders** (such as PVDF), offering a sustainable and environmentally friendly alternative.
- By enabling **water-based processing** and eliminating the need for hazardous solvents like **NMP**, ZIMONS help reduce the environmental impact of battery production.
- This aligns with global regulatory trends aimed at phasing out PFAS and other harmful chemicals, positioning ZIMONS as a **green solution** in the battery industry.

3. Scalability and Commercial Viability

- The project successfully scaled ZIMONS production from lab-scale to pilot-scale, confirming that the technology is **commercially viable** for large-scale manufacturing.
- The **commercial availability** of ZIMONS through **ABCR** and the registration of ZIMONS with **CAS numbers** ensures that the technology can be readily adopted by manufacturers and researchers.
- The project's partners are in the process of filing **two patents** to protect the novel applications of ZIMONS, further securing the commercial potential of the technology.

4. Alignment with Energy Policy and Market Demand

- The project's results contribute directly to key **energy policy objectives**, including **decarbonization**, **energy efficiency**, and the **adoption of renewable energy**.
- ZIMONS-based technologies provide a competitive advantage by offering **sustainable, high-performance battery solutions** that meet the growing demand for **green energy** and **electric vehicle technologies**.

- The project positions the partners as leaders in **sustainable battery technology** development, with significant potential for **market growth** and **increased turnover** in the future.

5. Expected Future Impact on Turnover, Employment, and Exports

- While the project has not yet led to increased turnover or employment, it is expected that the **commercialization of ZIMONS** will generate significant economic benefits in the future.
- The project partners anticipate increased **turnover**, **exports**, and **employment** as ZIMONS-based technologies are adopted by key industries such as **electric vehicles**, **consumer electronics**, and **renewable energy storage**.
- Ongoing engagement with commercial stakeholders and the filing of patents will further accelerate the commercialization and market penetration of the technology.

6. Further Research and Development

- The project consortia will continue to pursue additional **research, development, and innovation funding** to further mature the technology and explore new applications for ZIMONS.
- Future research efforts will focus on expanding the use of ZIMONS in different battery chemistries and refining the technology for broader market adoption.

The **BetterLiBs project** has successfully developed and validated a **sustainable**, **high-performance** battery technology with significant commercial potential. By addressing key challenges in battery performance, safety, and environmental impact, the project has positioned **ZIMONS-based technologies** as a leading solution for the future of **electric vehicles**, **renewable energy storage**, and **green battery manufacturing**. With further research and commercialization efforts, the project partners expect to see significant economic and environmental impacts in the coming years.

7.2 What are the next steps for the developed technology?

The next steps for the **ZIMONS-based technologies** developed in the **BetterLiBs project** are focused on further commercialization, ongoing research and development, and expanding the application of ZIMONS across various industries. Here’s a breakdown of the key next steps:

1. Further Commercialization and Market Penetration

- **Objective:** To bring ZIMONS-based technologies to the commercial market and increase adoption in key industries such as **electric vehicles (EVs)**, **renewable energy storage**, and **consumer electronics**.
- **Next Steps**:
    - Continue engaging with **battery manufacturers** and **industry stakeholders** to demonstrate the advantages of ZIMONS-based solutions in terms of performance, safety, and sustainability.

- Leverage the commercial availability of **ZIMONS through ABCR** to increase sales and market penetration.
- Finalize the filing of the **two patents** based on the project's results to secure intellectual property rights and attract potential investors or partners.

2. Additional Research, Development, and Innovation Funding

- **Objective**: To secure additional **research, development, and innovation funding** that will allow the project consortia to further mature the technology and explore new applications for ZIMONS.
- **Next Steps**:
    - Apply for national and international funding opportunities, including **EU Horizon Europe** programs, to support further development.
    - Continue collaboration between **academic institutions** and **industry partners** to optimize ZIMONS for use in different battery chemistries and expand their applications.
    - Conduct **further testing and validation** to ensure ZIMONS can be integrated into new battery designs and to explore potential markets beyond lithium-ion batteries.

3. Expansion into New Markets and Applications

- **Objective**: To expand the use of ZIMONS-based technologies into additional markets beyond the initial target of lithium-ion batteries.
- **Next Steps**:
    - Explore the potential of ZIMONS in other **energy storage technologies**, such as **solid-state batteries** and **next-generation battery chemistries**.
    - Engage with **renewable energy** providers and **grid storage companies** to integrate ZIMONS into large-scale energy storage systems for wind and solar power.
    - Investigate applications of ZIMONS in **high-safety industries**, such as **aerospace**, **medical devices**, and **defense**, where the safety and longevity of batteries are critical.

4. Continuous Improvement of Sustainability and Environmental Benefits

- **Objective**: To strengthen the **environmental sustainability** of ZIMONS-based technologies by further reducing their environmental impact and aligning with evolving regulatory standards.
- **Next Steps**:
    - Work with **regulatory bodies** to ensure that ZIMONS-based materials comply with future **PFAS-free regulations** and environmental guidelines, particularly in Europe and North America.
    - Continue refining the **water-based processing** of ZIMONS to further reduce the use of hazardous chemicals and improve the environmental footprint of battery production.
    - Highlight the **green benefits** of ZIMONS-based batteries in marketing and outreach efforts to attract environmentally conscious manufacturers and consumers.

5. Scaling Production and Reducing Costs

- **Objective**: To scale up the production of ZIMONS and achieve cost reductions that will make the technology more competitive in the global market.
- **Next Steps**:
  - Expand production capacity beyond pilot-scale to meet the growing demand for ZIMONS-based materials as adoption increases.
  - Optimize the production process to achieve **economies of scale**, which will reduce the cost per unit and make ZIMONS competitive with established battery additives and binders.
  - Establish partnerships with **manufacturers** and **suppliers** to ensure a stable and cost-efficient supply chain for large-scale production.

The next steps for the developed ZIMONS-based technologies involve **commercial expansion**, **further research**, and **scaling production**. By securing additional funding, engaging with industry partners, and optimizing the production process, the project consortia aims to bring ZIMONS to a wide range of markets, including **electric vehicles**, **energy storage**, and **green manufacturing**. The project will continue to focus on maximizing the **performance** and **sustainability** of ZIMONS while preparing for large-scale commercialization.

7.3 Put into perspective how the project results may influence future development

The results of the **BetterLiBs project** hold significant potential to shape the future development of **battery technologies**, particularly in areas focused on performance improvement, sustainability, and regulatory compliance. Below is a perspective on how these results may influence future development:

Accelerating the Adoption of Sustainable Battery Technologies

- **Future Development**: The development of **PFAS-free** ZIMONS-based binders represents a major step forward in the creation of **environmentally sustainable batteries**. As global regulations tighten around the use of hazardous chemicals like **PFAS**, the project results will drive further innovation in **green battery materials**. Manufacturers and researchers will increasingly focus on creating materials that meet both performance and environmental criteria, paving the way for broader adoption of **eco-friendly batteries**.
- **Impact**: ZIMONS could become a key enabler for **sustainable manufacturing** practices, not only in lithium-ion batteries but also in emerging energy storage technologies. By eliminating harmful substances and promoting **water-based processing**, ZIMONS set a new standard for environmental stewardship in the battery industry.

Advancing High-Performance Battery Technologies

- **Future Development**: The improvements in **battery cycle life**, **thermal stability**, and **safety** demonstrated by ZIMONS-based technologies are likely to drive future innovations in high-performance batteries, particularly for applications in **electric vehicles (EVs)**, **renewable energy storage**, and **high-safety industries**. The need for long-lasting, safe, and efficient batteries will push further exploration of materials like ZIMONS to meet the growing demands of these markets.
- **Impact**: ZIMONS-based solutions could influence the development of **next-generation batteries**, such as **solid-state batteries** or **lithium-sulfur** and **lithium-air** technologies, where material stability and energy density are critical. The success of ZIMONS in lithium-ion batteries could inspire further research into their potential for enhancing other types of energy storage systems.

Setting a Precedent for Regulatory Compliance

- **Future Development**: As **global regulations** around hazardous materials like PFAS become more stringent, the adoption of ZIMONS as a **PFAS-free alternative** positions the technology as a model for compliance with future environmental standards. The ability to offer a **sustainable**, **non-toxic** solution will encourage other battery developers to follow suit in replacing harmful materials with safer alternatives.
- **Impact**: The project results could lead to a wider industry shift toward **non-toxic battery materials**, influencing both **policy makers** and **industry stakeholders** to prioritize the development and commercialization of environmentally safe technologies. ZIMONS' success in achieving regulatory compliance may also inspire further investments in **green materials** research, pushing the boundaries of sustainable innovation.

Promoting Industry Collaboration and Innovation

- **Future Development**: The project's success in developing and validating ZIMONS-based technologies will likely promote greater collaboration between **industry** and **academia** in the development of next-generation battery materials. The results have already laid the groundwork for securing **additional research, development, and innovation funding**, which will further enhance the technology's potential.
- **Impact**: By fostering ongoing collaboration, the project results will drive **cross-sector innovation** in the battery industry, encouraging the integration of ZIMONS into a broader range of applications. The formation of **public-private partnerships** will be essential in scaling up the technology and accelerating its commercialization.

Expanding Applications in Emerging Energy Markets

- **Future Development**: The success of ZIMONS in improving the **reliability** and **efficiency** of batteries for energy storage will support the growing market for **renewable energy storage** systems. As **solar** and **wind power** become increasingly important to global energy grids, the demand for high-performance storage solutions will continue to rise. ZIMONS could play a pivotal role in making **renewable energy storage** more cost-effective and reliable.

- **Impact**: By enhancing the **performance** and **longevity** of batteries in energy storage applications, ZIMONS-based technologies will help drive the transition to **decarbonized energy grids**. Their ability to improve battery efficiency while maintaining environmental sustainability aligns perfectly with global energy policy objectives for increasing renewable energy adoption.

Influence on Future Development: The results of the **BetterLiBs project** will influence future development in the battery industry by driving the adoption of **sustainable**, **high-performance materials**. ZIMONS-based technologies offer clear advantages in terms of **environmental impact**, **regulatory compliance**, and **battery performance**, which will shape the future of **electric vehicles**, **renewable energy storage**, and **advanced battery chemistries**. The ongoing research and commercialization efforts will continue to expand the potential applications of ZIMONS, pushing the industry toward greener, safer, and more efficient energy storage solutions.

8. Appendices

8.1 Add link to relevant documents, publications, home pages etc.

- https://betterlibs.dk/