SINTEF

An overview of battery research and industry in Norway

by SINTEF

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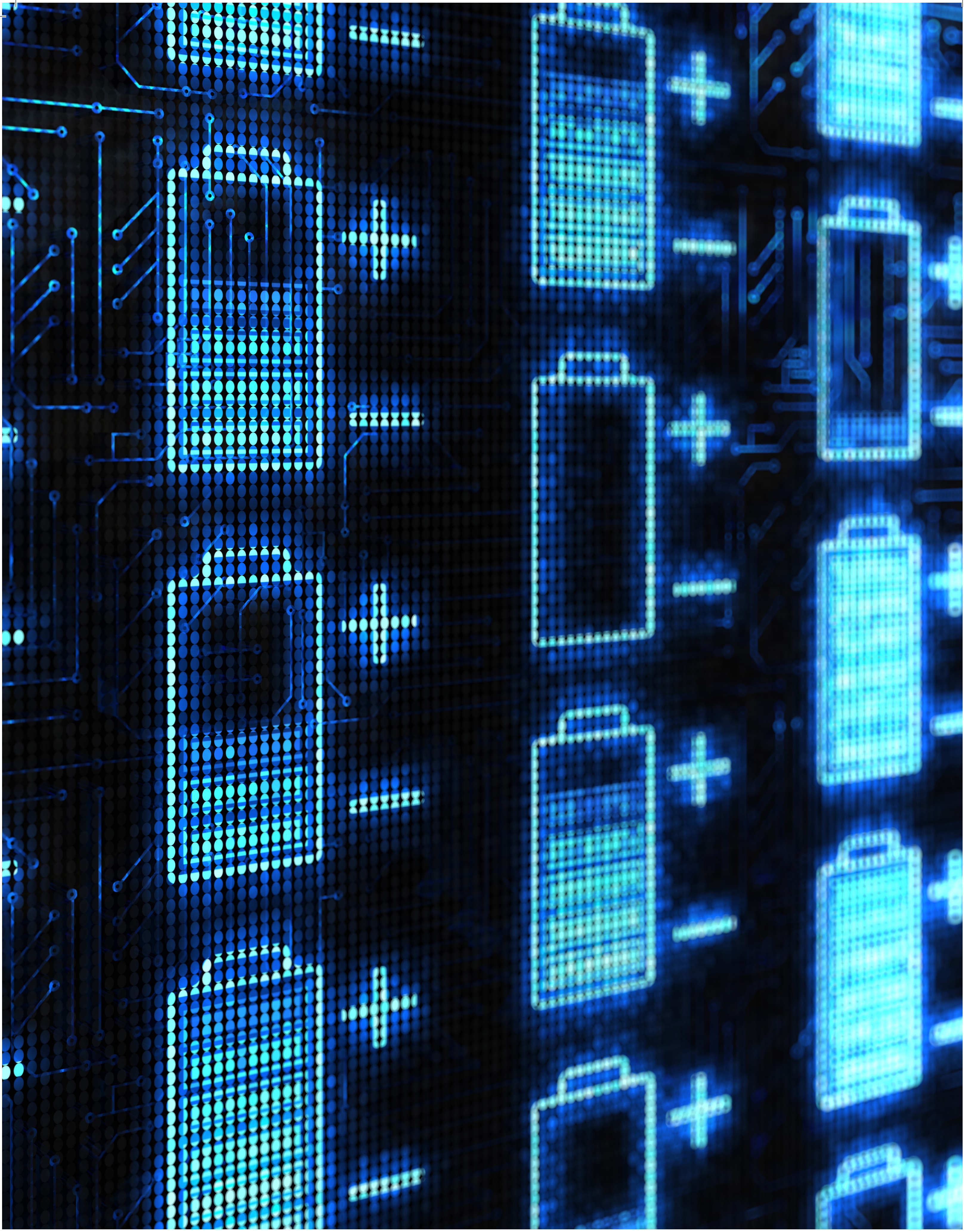


Executive summary

The exponential growth in the electric vehicle (EV) market both in Europe and globally, combined with increased implementation of intermittent renewable energy production as well as electrification of other sectors, are causing a soaring demand for batteries. The global dominance of the Asian stakeholders within Li-ion battery (LIB) cell production, left the European market extremely vulnerable. Seeking to mitigate this situation, we now see a large number of battery cell manufacturing initiatives all across Europe, from Norway and Sweden in the north to Italy and Spain in the south. This also gives rise to growth in other sectors such as mining and materials production, battery pack and system manufacturing, charging infrastructure, recycling, software and hardware development. Additionally, the European Commission has allocated large amounts of funding to battery research, development and innovation (R&D&I), and several partnerships and European collaboration platforms have evolved in the last few years, with focus on battery technology development, battery manufacturing, and implementation of batteries in different areas.

In Norway, several strong research groups have been involved in battery research for more than a decade. And the Norwegian research community is experiencing significantly increased interest from industry and are thus growing in numbers. This report provides an overview (although not exhaustive) of current Norwegian R&D&I efforts along the battery value chain with focus on seven main areas. These are raw materials and recycling, new and emerging technologies, advanced materials, manufacturing technology, battery application for transport and stationary end use, as well as a short introduction to SINTEF's involvement in the European battery community. For each area a brief introduction is provided with an overview of Norwegian stakeholders in this segment, followed by a summary of current research efforts. A brief overview of research infrastructure is also provided, indicating the current capabilities and opportunities within the Norwegian research communities.

Within raw materials and recycling, Norway traditionally holds a strong position globally within minerals and metal production. Although this industry has not been focused on battery materials, we now see that many of the large companies are shifting parts of their focus in that direction. This also gives rise to a very active research community in this field. The areas of new and emerging technologies, and advanced materials are both naturally more dominated by fundamental research, particularly by the universities. It is worth noting that there are also a few growing companies with focus on materials production of advanced materials, and it is an area with potential for growth.

Manufacturing technology and battery application are market areas with strong interest from a large group of stakeholders, particularly application and integration of batteries. Norway has been a spearhead in implementation of hybrid and fully electric ships and vessels, which is also evident on the current stakeholders. However, there is a clear tendency towards increased interest in stationary storage applications in housing, office buildings, as well as industry and in connection with intermittent energy production. And last, but not least, the promise of large LIB giga-factories providing thousands of new jobs gives rise to a whole new market segment in Norway and is an area of significant growth within R&D&I.

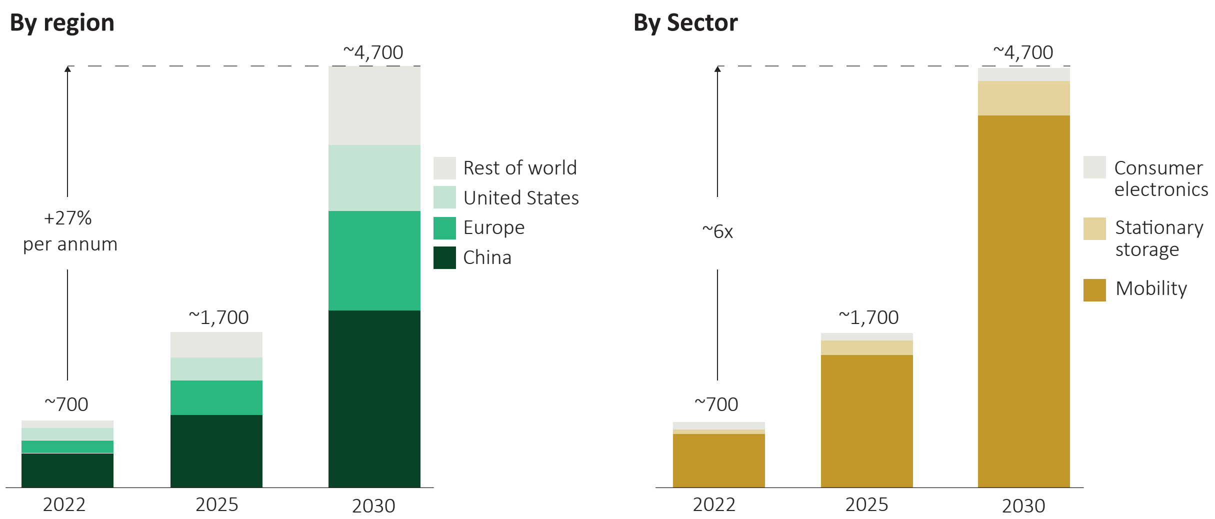
One important factor for both industry and the research community to be successful and blossom in this field, is collaboration with European and global stakeholders. The Norwegian research community has been collaborating with colleagues across Europe and in other parts of the world for decades. This is also evident from the number of European-funded research projects in the current research portfolio. Through the establishment of several industrial clusters, partnerships and organizations, we also now see that Norwegian as well as other European industrial stakeholders realize the great benefits of collaboration across sectors and across countries.

Introduction

The need for batteries is increasing rapidly, driven by the ongoing climate-neutrality targets and clean energy transition. For EU to meet the objectives of EU's Green Deal and REPowerEU on climate neutrality, fossil fuels need to be replaced by renewable energy sources. This growing demand makes the battery market increasingly strategic at a global scale. The European Commission (EC) estimated that to reach its climate neutrality target by 2050, the European Union (EU) would need up to 60 times more lithium and 15 times more cobalt (1). In 2020, the European market potential for batteries was predicted to be worth EUR 600 billion annually from 2025 onwards (2), and the market has evolved even more since then. However, until recently, Asia (mostly China, Japan and South Korea) have dominated the battery cell production with more than 95% of the global Li-ion battery (LIB) cell production, and corresponding IP and knowledge. Another challenge related to battery cell production, is the demand for raw materials and their availability. Currently, materials such as cobalt, nickel, lithium and graphite are sourced and produced in politically unstable and unpredictable regions of the world. Additionally, their extraction often involves the exploitation of both workers' rights and the natural environment.

The EC has identified securing and diversifying supply of critical raw materials as one of the top 10 strategic issues to ensure EU's freedom and operational capacity in the future (3). The dependency of China in particular, can be exemplified by graphite, one of the main components of LIB. In 2018, about 68% of the world's graphite production took place in China (4), with only a few percent production originating from European countries. Graphite specific for battery applications is produced nearly exclusively in China, both natural and artificial, with more than 90% market share (5). The European and global market for electric vehicles (EVs) is thus highly dependent on China, making the European market extremely vulnerable. For mobility applications, McKinsey has predicted that the global LIB cell demand will reach ~4700 GWh by 2023 (6), see Figure 1. In addition to the exponential growth in battery production for the EV market, batteries are also becoming increasingly important for stationary applications. With increasing implementation of intermittent renewable sources (i.e. wind and solar), the need for stationary energy storage is growing rapidly. The stationary battery market in the EU doubled in 2021 from the previous year, with the cumulative installed capacity reaching 4.6 GW / 7.7 GWh, which is around 14 % of global installed capacity (7). The use of utility-scale batteries is predicted by Bloomberg NEF to reach 1000 GWh by 2035 and nearly 3500 GWh by 2050 (8).

In addition to facilitating increased use of intermittent renewable energy sources, storing energy also allows flexibility to adjust demand and supply in the grid, increasing energy efficiency and energy security. Modelling studies show an important relation between increasing renewable energy deployment and flexibility of the energy systems. In addition to providing flexibility, energy storage reduces price fluctuations and lower peak prices. It is a way to electrify different economic sectors like buildings and of course also transportation, but also provides a way for consumers to adapt their energy consumption to prices and their needs. According to the ETC CE report (9) on consumption and the environment in Europe's circular economy, housing is responsible for the largest volume of greenhouse gas (GHG) emissions, contributing to 40 % of total GHG emissions caused by the European households, which is mainly caused by energy consumption for heating, hot water and lighting (9).



[1]Including passenger cars, commercial vehicles, two-to-three wheelerst, off-highway vehicles, and aviation.

↑ ***Figure 1:*** *Global Li-ion battery demand given in GWh. Figure adapted from (6).*

In response to the European and global market trends, the Norwegian Government launched its own battery strategy (Norges batteristrategi) in 2022 (10). This report presents the Norwegian Government's vision for a sustainable battery value chain and identifies 10 actions for the attainment of the Government's goals for the battery value chain. The strategy is focused mainly around industrial development and actions enabling Norway and Norwegian stakeholders to build successful businesses in this market. However, in this fast-growing market, strong research and innovation is key to keep up to speed. Action 10 is to "become a leader in tomorrow's battery solutions and leveraging the opportunities afforded by digital technologies", which means that research, development and innovation (R&D&I) is a pivotal part of succeeding in this market. The R&D&I for battery technology is also stressed in the latest Energi21 strategy, which is the Norwegian national strategy for research and innovation for new climate friendly technology. The last Energi21 strategy was launched in 2022 with a vision of further developing Europe's best energy system (11). The report identifies specifically eight areas of strategic importance for a successful green transition, including hydropower, offshore wind, solar energy, hydrogen, batteries, and CO2 capture and storage. Looking specifically at batteries, a selection of central research and innovation topics were also identified. These include raw materials and materials development and production, efficient battery cell production, efficient battery utilization according to application, safety, reuse and recycling, and digitalization.

Some of these topics have been the focus of Norwegian research groups for more than a decade, while other topics such as reuse of batteries, have come into focus more recently. The main actors in battery research in Norway for the past 15 to 20 years have been SINTEF, NTNU, IFE and UiO. Additionally, RISE Fire Research and FFI have been actively working on battery safety issues for a number of years. Other universities are now also building up research capabilities in the battery area, including Stavanger University (UiS) and Agder University (UiA). UiA is conveniently located next door to Morrow Batteries and benefit from their interest in collaboration with the research and education development. Altogether, the Norwegian research community are actively involved in research along the whole battery value chain. And this report will take a closer look at the main areas and give an overview of the ongoing research as well as the main industry actors involved in the different market segments.

1. Raw materials and recycling

The European Critical Raw Materials Act launched on March 16th, 2023, proposes a comprehensive set of actions to ensure EU's access to secure, diversified, affordable and sustainable supply of critical raw materials (CRMs) (12). CRMs are vital in several strategic sectors such as aerospace, defence sector, the digital industry and the net zero industry. Particularly the latter has been driving the demand for CRMs to produce batteries. Currently, Europe relies heavily on import from countries like China, Congo, Chile, Russia, and Australia, several of which are politically unstable countries with questionable ethical standards for their work force.

Critical raw materials (CRMs) that are used in manufacturing active materials present in LIBs include cobalt (Co), lithium (Li), nickel (Ni), graphite (C), copper (Cu), silicone (Si), and manganese (Mn). These materials are limited resources and some of them are not well distributed in the world (Figure 2). For example, cobalt which is present in most commercial LIBs is a by-product of copper and nickel mines, and it is mostly originated from the Democratic Republic of the Congo, from which 63% of EU's cobalt needs are covered (13). Currently, 60% of lithium mining is dedicated to battery-related purposes and according to McKinsey & company's base-scenario, this percentage will go up to 95% in 2030. It is noteworthy that battery-grade lithium resources are mainly coming from Australia, Chile, and Argentina.

Since battery production requires high-purity materials, refining of raw extracted materials is also of a great importance. A large part of the refining of key materials present in Li-ion chemistry (Co, Li, Ni, and graphite) is located in China. This refining activity is often associated with serious environmental impacts, such as creation of hazardous waste, or contamination of water, soil, and air. Thus, in order to ensure sustainable battery production, the value chain has to move from linear to a circular system by improving re-use, recycling, and integration to secondary raw materials. High degree of circularity will have positive effects on the economy while lowering the overall environmental footprint in addition to preventing shortage of CRMs. The latter will also contribute to decreased price fluctuations of essential materials such as nickel and lithium.

In this report we will screen all projects consisting of raw-materials mining and refining as well as re-use and recycling of LIBs SINTEF, Norwegian industries and Norwegian research institutes.

Norway's position

Minerals and graphite

The current geopolitical game has induced rising concerns regarding security of supplies for crucial minerals that are essential not only for our highly technology dependent everyday life, but also for military defence purposes and the revolution-like, climate saving, green shift that acts upon us. Protectionism, trade barriers and local subsidies is increasingly being used by countries to ensure local value chains at the expense of global trade.

Norway plays an important role to secure European independency as the nation holds substantial amounts of key minerals necessary for sustaining local production and access to advanced technology. As mentioned in the previous section, lithium, nickel, cobalt and manganese are some of the key metals used in the production of EV batteries alongside copper and aluminium. For other battery applications such as stationary storage, other chemistries and minerals are relevant including vanadium and zinc. Today the three largest producers of lithium are Australia, Chile and China with approximately 90% of the global production (14). Norway has no production of lithium, as deposits with economic potential have so far not been discovered (15). However, the Nordic countries (specifically Greenland, Finland, Sweden, and Norway) share a diverse geology formed over a long geological timespan. In central Österbotten in Finland several well-explored lithium deposits have been located in an area of more than 500 km² giving an estimated 15.000 ton of yearly production of battery grade lithium hydroxy mono hydrate (16). The deposits are among the most significant in Europe and is being developed through the Keliber OY project. Nordic Mining ASA is a Norwegian company with their main activity allocated to mining of titanium oxide but held until 2022 an 18.5% share in the project (17).

The deposits of minerals in Norway are far less mapped compared to the neighbouring countries Sweden and Finland. Considerable exploration has been conducted by Geological Survey of Norway (NGU), however, still relatively few samplings using core drilling have been performed which could potentially reveal new areas of interest. As of now, Norway having complementary experience from geoscience and subsea operations from oil and gas exploration, the efforts are being made by the Norwegian government to investigate the potential of deep ocean minerals. Rising concerns for loss of biodiversity and degradation of ecosystems may however put excavation and realization of these resources at a halt indefinitely (18).

In addition to Nordic Mining, the three recently established Norwegian companies Green Minerals, Loke Marine Minerals and Adepth Minerals are seeking to extract valuable minerals for the green shift. In addition to exploration on the Norwegian continental shelf, Green Minerals and Loke Marine Minerals have obtained licenses in the Clarion-Clipperton Zone at the pacific seabed where substantial resources of nickel, cobalt, copper and manganese have been indicated (19).

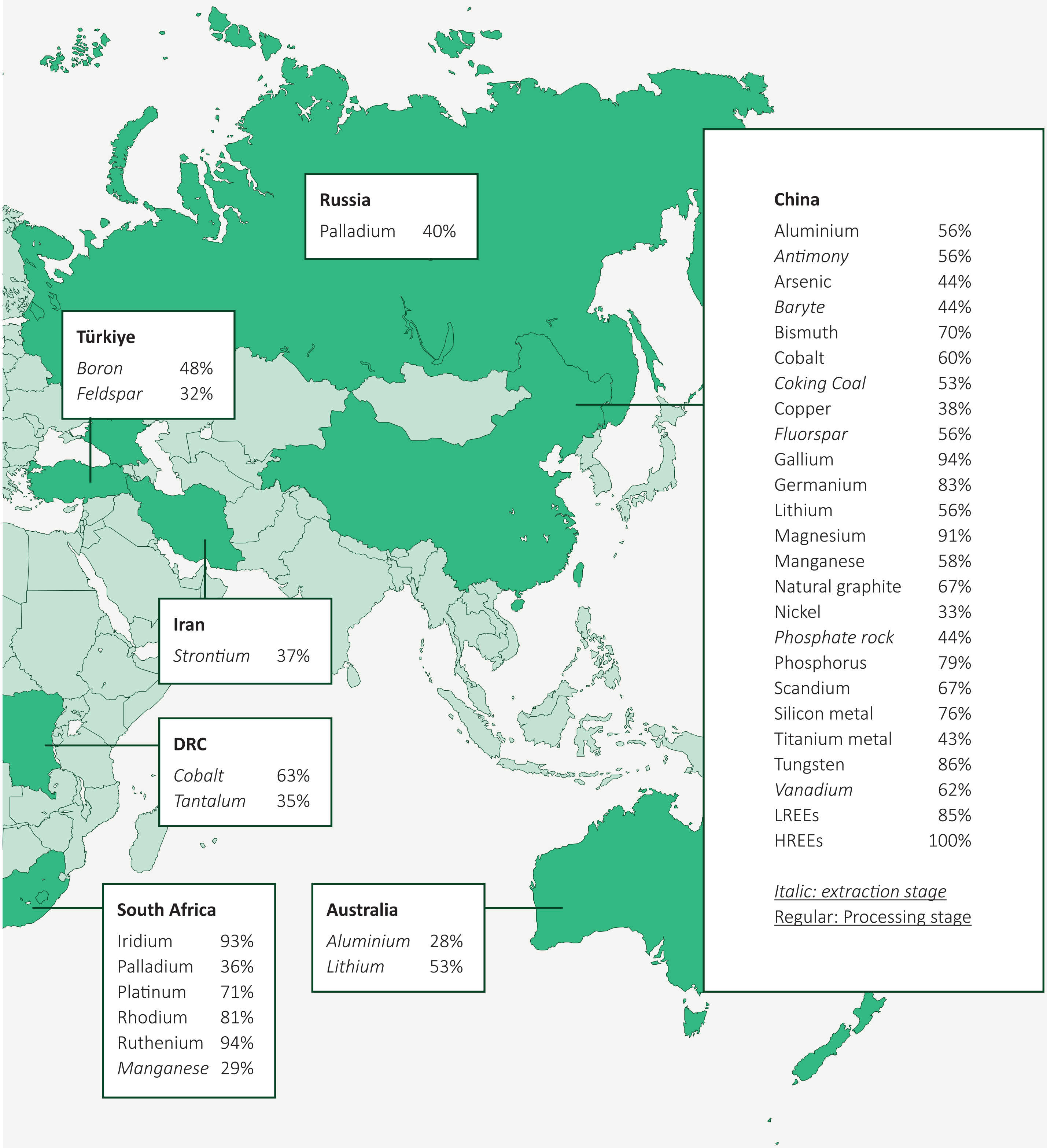
Mining and raw material production in Norway can be dated far back and around 1870 there were 40 mines and 7 smelting plants operational which had a share of ~70% of the global Nickel production. Today there is no mining activity, however the original Kristiansands Nikkelraffineringsverk (now Nikkelverk – a Glencore company) is still producing more than 90.000 tons of nickel pr year, mainly from ores shipped from Canada (20). In addition to nickel, large amounts of cobalt and copper are produced both from raw materials as well as from recycling. As the refinery is offering one of the most sustainable productions in the world, FREYR Battery and Glencore signed in November 2021 a contract for the supply of up to 1,500 metric tons of high grade, sustainably sourced cobalt metal cut cathodes made from partially recycled cobalt produced at Glencore's Nikkelverk facility in Norway (21).

The Norwegian company Hydro is present throughout the aluminium value chain from bauxite mining and aluminium oxide refining (alumina), through primary aluminium production and aluminium extrusion and casting, to aluminium recycling (22). Hydro Bauxite & Alumina includes one of the largest bauxite mines in the world and the largest alumina refinery outside China, both located in Brazil. They extract the bauxite in Paragominas and refine it to obtain alumina at the Alunorte refinery in Barcarena. Hydro has primary metal production facilities in Europe, Canada, Australia, Brazil and Qatar, and recycling facilities throughout Europe and in the U.S. In Norway, Hydro has 5 plants for primary aluminium production. The final aluminium product is one of the key components in LIB and is commonly found as the current collector for the cathode.

Alcoa is an American company with several aluminium production locations globally. Two smelting plants is established in Norway producing aluminium for a variety of applications including batteries (23).

Graphite production is commonly associated with countries like China, India, Brazil, Canada, and Madagascar. However, since 1932 Skaland Graphite situated in northern Norway has been a stable and reliable supplier of high-quality flake graphite products to the global market (24). According to Norwegian Geological Survey (NGU) the Skaland graphite mine is the only current producer in Norway and produces from the world's richest flake graphite deposit with an average grade of 31% graphite carbon (25). As of October 2019, the company was acquisitioned by Mineral Commodities Ltd (MRC), an Australian company whose primary focus is on the development of high-grade mineral deposits within the industrial and battery minerals sector (26). MRC is making significant investments in creating an environmentally sustainable downstream process at Skaland, aiming to become the first European producer of naturally sourced anode material with a low carbon footprint.

↑ ***Figure 2:*** *Countries accounting for largest share of global supply of CRMs. Figure adapted from (13).*



Russia
Palladium 40%
Türkiye
Boron 48%
Feldspar 32%
Iran
Strontium 37%
DRC
Cobalt 63%
Tantalum 35%
South Africa
Iridium 93%
Palladium 36%
Platinum 71%
Rhodium 81%
Ruthenium 94%
Manganese 29%
Australia
Aluminium 28%
Lithium 53%
China
Aluminium 56%
Antimony 56%
Arsenic 44%
Baryte 44%
Bismuth 70%
Cobalt 60%
Coking Coal 53%
Copper 38%
Fluorspar 56%
Gallium 94%
Germanium 83%
Lithium 56%
Magnesium 91%
Manganese 58%
Natural graphite 67%
Nickel 33%
Phosphate rock 44%
Phosphorus 79%
Scandium 67%
Silicon metal 76%
Titanium metal 43%
Tungsten 86%
Vanadium 62%
LREEs 85%
HREEs 100%
Italic: extraction stage
Regular: Processing stage

Norwegian stakeholders on raw materials production

In addition to those mentioned above, there are several companies working with production of raw materials for batteries in Norway.

Borregaard offers sustainable additives based on Norwegian Spruce which improve the capacity, cycle life and safety of Li-ion batteries, as well as reduce the environmental burden of their production and disposal/recycling (27).

Cenate AS is a Norwegian company that develops silicon nano particles for the global LIB industry. The company has a first pilot plant in operation in Askim, Norway, and collaborates closely with SINTEF, IFE, University of Munster and some of the world's leading battery and anode producers (28).

TioTech AS is a Norwegian manufacturer of titania (titanium dioxide) nanomaterials for li-ion battery anodes (29). Their product TitanBTM improves the charging, lifetime, safety and temperature robustness of the battery compared to currently used lithium-titanate based batteries.

The current focus for Elkem is within the areas of graphite for anodes, silicon for tomorrow's anodes and silicone solutions for battery packs and modules and various other applications in electric vehicles (30). The development and production of graphite for LIB is taken over by Vianode, a subsidiary company of Elkem. Vianode offers a range of anode graphite products with supreme performance characteristics and is produced with 90% lower CO2 emissions than today's standard materials. They target producing battery materials for 2 million electric vehicles per year by 2030. Their graphite anodes are based primarily on fossil feedstocks, but their product development is aiming at replacing these by bio-carbon in future production (31).

Bergen Carbon Solutions was established in 2016 and is making CO2 a valuable resource, using renewable energy to turn the excessive greenhouse gas into solid carbon (32). The company has developed a clean process for capturing CO2 and converting it into valuable carbon products such as graphite and nano tubes which could be potential additives or precursors for battery anodes.

Norwegian stakeholders for recycling for raw materials

ReSiTec AS is a technology company based in Kristiansand that specializes in the green shift through processing of critical raw minerals and recycling of valuable materials from the process industry including battery manufacturing. The company provides test equipment, R&D and development services to a wide range of industries and is also a manufacturer of high purity silicon powders recycled from photovoltaics (33).

NORSIK is a company which collects and handles electrical and electronic products, batteries and packaging waste all across Norway (34). Through one of their subsidiary companies Batterigjenvinning, they offer collection and recycling of batteries.

Hydrovolt is a joint venture between the Swedish company Northvolt and Norwegian Hydro on electric vehicle battery recycling (35). In 2022 Hydrovolt commenced commercial recycling operations at its plant in Fredrikstad and has a capacity for 12.000 tons of battery packs pr year. Within Europe the company aims to expand its capacity to 300.000 tons by 2030. From the recycling the fraction termed black mass (a compound containing nickel, manganese, cobalt and lithium) is sent to Northvolt's Revolt Ett recycling plant in Skellefteå, Sweden for a hydro-metallurgical treatment. Northvolt's goal is to use 50% of recycled material in battery production by 2030. Although recycling of black mass from Hydro-volt is currently done in Sweden, there is also now a Norwegian company, Lithium 367, which is dedicated to developing a process that recovers lithium from end-of-life batteries (36). Lithium is currently not recovered from end-of-life LIBs and quickly becoming scarce and very expensive. Thus, recycling of this valuable metal from the black mass will be essential for a circular value chain.

Batteriretur has their headquarters in Fredrikstad, right next door to Hydrovolt, and they collect and recycle all types of batteries from the entire country in Norway, including Svalbard (37). In 2014 Batteriretur Høyenergi AS was established for handling of batteries from electric vehicles (EVs) and maritime sector. Through this company they have also contributed to developing solutions for safe handling, disassembly, reused and recycling of EV batteries.

Glencore is a major recycler of end-of-life electronics, lithium-ion batteries, and other critical metal-containing products. They recycle critical metals like copper, nickel, cobalt, zinc and precious metals (38). In Norway, Nikkelverk, which was also mentioned above as a main producer of nickel, copper and cobalt in Norway, also work with recycling and are one of the largest producers of recycled nickel and cobalt-containing materials (20).

Norwegian stakeholders on second life repurposing

Evyon, established in 2020, provides large scale battery packs for stationary storage based on second life batteries provided from a German car manufacturer. They use a well-proven battery management system together with a cloud monitoring system to ensure a high level of safety for their products. The company has set high goals to become the leading European company within repurposing of batteries within 2025 (39).

Eco Stor is another Norwegian company that specializes in giving second life to batteries from electric vehicles (40). They test the used batteries and make sure their state of health and performance are optimal before they are tailored into a second life energy management system in accordance with the customers' need. Their business model is to reuse the whole battery pack without disassembly. The battery packs are cleaned and thoroughly tested before re-assembling into larger systems. Eco Stor provide solutions for a range of outputs scaling from domestic solar panel PV production to grid balancing and fast frequency balancing. When the batteries no longer fulfil the output requirements, Eco Store remove the battery packs from the system and bring them to recycling facilities where 99% of the precious elements in the batteries are recycled and sold to be used for brand-new batteries.

Chainpro AS was founded in 2019 and is a small company in Trondheim focusing on sustainability and circular economy. They deliver battery packs and systems in addition to solar panels mainly for the domestic market. Their batteries are for a large part based on recertified li-ion EV batteries (41).

The reuse of batteries is also a cornerstone in Hagal´s strategy and technology, pushing large-scale deployment of used EV batteries (42). Together with their cloud-based energy management system (EMS), Hagal offers modular solutions for megawatt sized Battery Energy Storage Systems (BESS). Hagal refers to their production unit as their lifecycle Hub and is located in Hokksund, outside Drammen, in addition to a battery test lab and the headquarters in Oslo.

Another company offering stationary energy storage solutions based on 2nd life batteries in Norway is Eaton. They provide solutions for private homes as well as larger battery systems for office buildings and industrial use (43). There is also Battkomp AS (former Yedlik As) which design and produce LIBs for small mobility applications, replacing end of life batteries with new or used batteries to give applications extended life (44).

Norwegian research and funding potential

Norway's substantial expertise lies in materials refining and process industry, with a particular focus on sectors closely linked to its rich natural resources and energy production capabilities. Regarding Li-ion batteries, the Norwegian research institutes are mostly focused on recycling and re-use of batteries to reduce the environmental footprint of battery manufacturing and disposal while ensuring a sustainable supply of critical raw battery materials in the future to meet the growing demand on Li-ion battery manufacturing in Norway.

The scope of this part is to identify the different recycling and re-use projects across the different research institutes in Norway. The lists below are not exhaustive but include some of the most relevant ongoing or previous project on the topic.

↓ Project Name	↓ Project Description	↓ Participants
BATMAN	BATMAN project funded with 11.75 million NOK by The Research Council of Norway, aims to create a predictive model. This model will address various aspects of the battery value chain, including raw material demand, battery restoration, reuse, recycling, and new energy systems. The primary objective is to support Norwegian companies involved in battery materials production by providing recommendations and regulatory guidance. The aim is to enable the Norwegian industry to establish leadership positions within the global battery market while promoting sustainability.	Eyde cluster, IFE, Norsk Hydro ASA, Elkem, Agder Energi AS, Saint Gobain Ceramic Materials AS. NTNU, UiA, Transport Economics Institute, EIT Raw Materials, British Geological Survey, The Federation of Norwegian Industries, The Cobalt Institute, and The Nickel Institute.
2ND Life	The aim of 2ND LIFE project is to identify and quantify opportunities and challenges for setting up new energy storage solutions based on second-life batteries previously used in electric vehicle. Thus, providing an overview of safety and degradation mechanisms of used batteries while analysing the economic and environmental impact	IFE, FFI, NTNU, UiA, Department of Chemical Engineering at UC London, and The Solar Energy Cluster (SEC).
ELAG	The project aims to develop technologies that enable the automatic discharge and characterization of used electric vehicle batteries	UiA, BTG, Batteriretur, Greenstat, Greenwaves, Hydro, Pixii, and ELKEM.
RHINOCEROS	The aim of the RHINOCEROS project is to develop economically and environmentally viable routes for re-using and recycling end-of-life LIBs from electric vehicles and stationary energy storage. Within the project, these innovative solutions will be tested and demonstrated in industrially relevant environments.	Tecnalia, AccurecJGI HYDROMETAL, UiA, ECO Recycling, ARKEMA, TES, WATT4EVER, Leitat, VITO, KIT, Chalmers, Sapienza U of Rome, PNO Innovation, FORD OTOSAN, LevertonHELM
LIBRES	Project on developing a design basis for a lithium-ion battery recycling pilot plant in Norway including automated disassembly of the EV battery packs/modules/cells.	Batteriretur, Hydro, Glencore Nikkelverk, Keliber OY, UiA, Elkem Technology, IME RWTH Aachen, MIMI Tech, NTNU

↓ Project Name	↓ Project Description	↓ Participants
ReBAT	Sustainable recycling of graphite from lithium-ion batteries investigates the feasibility of fully automating the complete disassembly of individual battery cells-based recycling, and graphite reuse, as alternative to shredding, burning and carbon loss.	UiA
ReLIEVe	Reuse of Lithium Ion-Batteries from Electrical Vehicles for stationary applications is a preliminary study on reusing decommissioned electric vehicle batteries to identify possible stationary applications and effort needed to reuse such batteries.	UiA, Alternativ Energi, Teknova, Batteriretur, Grenland Energy, Illwerke VKW, FH Vorarlberg
Classification of lithium-ion cells for safe reuse	In this project, Hagal will together with IFE develop and implement a scalable methodology to quickly identify promising battery cells that are suitable for repurposing to alternative applications in a safe and cost-effective manner.	IFE, Hagal
Non-destructive evaluation and modelling of degradation mechanisms in Li-ion battery modules	The PhD project focuses on addressing the challenges associated with re-using lithium-ion batteries (LIBs) in second-life applications. With a growing abundance of LIBs reaching end-of-life conditions from the transport and mobility sectors, maximizing the value of critical raw materials present in each battery becomes crucial.	NTNU, Evyon
Seal integrity analysis of maritime battery cells for 2nd life applications	This project focuses on analysing and assessing the seal integrity of Li-ion battery cells for use in second life applications. The project will develop a novel methodology for opening Li-ion cells with-out damaging the seal of the cells. All different common Li-ion geometries will be evaluated. However, the main focus will be on Li-ion pouch cells.	IFE, Corvus

SINTEF's research

SINTEF is dedicating resources to engage in battery projects throughout the value chain, including the critical area of raw materials and recycling. The cost, efficiency, and sustainability of mining, pre-processing, recycling, reuse, and 2nd life, of these materials is a vital aspect of technology for a better society for battery technology. As a result of its active research efforts, SINTEF is currently involved in several ongoing projects related to this important stage in the battery value chain.

TREASoURCE (Territorial and regional demonstration of systemic solutions of key value chains and their replication to deploy circular economy) is an EU project in the Horizon Europe funding programme (45). It is a 4-year project with a total budget of almost 10 M€, consisting of 17 partners from 6 European countries. The project aims to develop and demonstrate systemic circular economy solutions for unused or underutilized plastic-waste, bio-based waste and side streams, and end-of-life electric vehicle batteries in the Nordics and Baltic Sea Region, where the latter is the relevancy for batteries. A part of the TREASoURcE project is to establish Battery Energy Storage Systems (BESS), at three demonstration sites, using old electric vehicle batteries. This will increase the knowledge of reuse and demonstrate 2nd life concepts. Demonstrating this for use inside and outside of Europe is one of the main goals of the project and will support the universal usefulness of battery systems. A significant activity in the project also includes providing an overview of the current regulatory and legislative landscape relevant for batteries, and particularly for implementation of 2nd life batteries in stationary energy storage. Based on the findings from this work a set of recommendations which may accelerate 2nd life battery implementation will be proposed towards the end of the project.

LiCORNE is another EU project, also funded through the Horizon Europe funding programme, is Lithium recovery and battery-grade materials production from European resources, referred to as LiCORNE (46). The 4-year project has a total budget of almost 6.8 M€, and the consortium consists of 15 partners. The project aims to overcome the dependency of material import when it comes to battery technology. Indeed, Europe imports over 50 % of necessary battery materials, i.e., lithium (Li), nickel (Ni), cobalt (Co), and magnesium (Mg). The geopolitical climate, especially in recent years, has highlighted the importance of domestic production, and this project seeks to establish the first Li supply line in Europe. One of the main objectives of this project is to increase Europe's capability to mine, process and refine battery-grade chemicals. The project also includes a cathode manufacturer that will reuse valuable materials such as Li, Co, and Ni, recycled from waste cathode. 8 R&D centres in Europe, included in the project, will review 14 carefully selected technologies able to tackle main issues related to Li processing and recovery.

ICARUS (Innovation eco-efficient processing and refining routes for secondary raw materials from silicon ingot and wafer manufacturing for accelerated utilization in high-end markets) is an EU project coordinated by SINTEF (47). It is a 4-year project with a total budget of almost 12 M€, where a large percentage is funded though the HORIZON 2020 societal challenges programme. Although the focus of the project is on solar energy, battery technology benefits due to the similarities between solar and battery technology. The project seeks to utilize waste materials from manufacturing of silicon ingot and wafer, necessary resources for production of solar panels. Currently, 35% of the material is unused during the silicon processing, and ICARUS will process this waste and reintroduce it into the value chain. The project aims to introduce circular economy to the silicon ingot and wafer manufacturing industry by creating a closed-loop system for waste materials. ICARUS will demonstrate three industrial pilots producing raw materials such as silicon, silica, and graphite, and one pilot will focus on converting silicon waste into commercial commodities suitable for high-end applications, including the production of lithium-ion battery cells.

2. New and emerging technologies

Emerging technologies within batteries and battery manufacturing are rapidly evolving to address the increasing demand for energy storage, the need for higher energy density, longer lifespan, faster charging, and safer battery systems. According to the Batteries Europe Road Map (48) "Emerging technologies" encompasses concepts up to technology readiness level (TRL) 4 and at present there are several ideas and technologies under heavy investigation. In a battery value chain perspective, it is however intuitive to not only associate "emerging technologies" with the chemistry and the hardware of batteries, but also include technologies and processes related to all parts of the value chain, including methods for manufacturing, battery management systems and recycling. A list of different technologies is presented in the following.

Solid-State Batteries

Solid state batteries use solid electrolytes instead of liquid electrolytes, resulting in potentially higher energy density, improved safety, and faster charging (49). They are also less prone to dendrite formation, which can enhance battery lifespan.

Lithium-Sulphur Batteries

Lithium-sulphur batteries offer high energy density due to the use of sulphur as a cathode material (50). They have the potential to provide significantly longer ranges for electric vehicles (EVs) and longer battery life, but challenges related to sulphur's instability and volume expansion need to be addressed.

Metal-Air Batteries

Metal-air batteries have 3-30 times greater theoretical energy density compared to conventional Li-ion batteries, as they use oxygen from the air as a cathode material. However, practical challenges related to stability, efficiency, and cycle life still need to be overcome (51).

Advanced Redox Flow Batteries

Flow batteries use two electrolyte solutions with different oxidation states separated in two tanks. This configuration offers unique advantages in terms of scalability, flexibility, and cycle life (52). Their challenges are related to complexity in managing multiple electrolyte solutions, stability, and toxicity of electrolytes.

Advanced Cathode and Anode Materials

Development of new cathode and anode materials to improve energy density, cycling stability, and charge-discharge rates is a continuous task for researchers. Materials like silicon-based anodes and high-nickel content cathodes are examples of progressive work although challenges are still to be overcome (53).

AI and Machine Learning for Battery Management

Artificial intelligence and machine learning are being integrated into battery management systems to optimize charging, discharging, and battery health monitoring. This improves overall performance, safety, and longevity.

Smart Batteries and IoT Integration

Batteries are becoming more intelligent with the integration of sensors and connectivity, allowing real-time monitoring of performance, temperature, and state of charge. This enhances safety and efficiency.

Battery Recycling and Second-Life Use

As many of the battery technologies are based on critical raw materials, battery recycling becomes essential. Technologies for extracting valuable materials from used batteries or repurposing them for example for stationary energy storage is therefore critical to meet the future energy storage demand (54).

Advanced Manufacturing Techniques

Innovations in battery manufacturing, such as additive manufacturing (3D printing) is emerging as a prospective technology for cost efficiently producing more energy-dense batteries with faster charging rates (55). Planning production through use of digital twins is also being deployed to minimize commissioning time, increase efficiency and reduce scrap, energy and costs (55).

Hybrid Energy Storage Systems

Combining different types of energy storage technologies, such as batteries and supercapacitors (56), can provide complementary advantages in terms of power and energy capabilities.

Quantum Computing for Battery Design

Quantum computing holds potential for simulating and optimizing new materials and chemical processes, accelerating the discovery of novel battery materials and designs (57).

Norway's position

Emerging technologies related to new battery chemistries is mostly under the process of research and is addressed by SINTEF and other Norwegian research institutes and universities. These are described in the following subchapters. Emerging technologies from other stakeholders might be kept secret for intellectual property reasons and hidden from the public. There are however actors in Norway who are engaged in the development of technologies that are close to commercialization or just started production.

nanoCaps is a leading research group for supercapacitors emerged from University of South-Eastern Norway (USN) (58). They base their new products on 15 years of research at USN and have a series of strong patents. They are currently commercializing their technology by developing a first portfolio of unique products with record high sheet capacitance, low series resistance and high energy density and by partnering with GMCC, a world leading Chinese producer of supercapacitors, they are all set to commercialize their product.

Bryte Batteries was founded in 2020 and is today a leading Nordic flow battery company (59). They seek to make flow batteries more efficient and at a lower cost as they believe stationary batteries are the key to enable renewable energy production. Their technology is based on the Vanadium Redox Flow concept, and they advertise their product with long operational lifetime, negligible degradation, and self-discharge, and low levelized cost of storage. Bryte opened their first commercial battery in Trondheim early in 2023 with a total energy storage capacity of 25 kWh. A second larger battery was installed and opened later the same year at Skjetlein videregående skole, and Bryte have plans for more installations in the near future.

Siemens is at the forefront of advanced battery manufacturing. Recently they teamed up to equip FREYRs planned gigafactories with their Industrial Operations Xcelerator portfolio which include Product Lifecycle Management (PLM), Manufacturing Execution Systems (MES), industrial Edge computing, and tools for information- and operational technology (IT/OT) connectivity (60). Siemens states that by leveraging their Industrial Operations Xcelerator portfolio, FREYR will be able to better connect design and manufacturing to scale-up production and further speed up their progress towards the planned gigafactories.

Norway's research and research funding potential

Norwegian research institutes are actively involved in development initiatives with the goal of propelling the progress of battery technologies, this involves research into various emerging materials for Li-ion batteries, primarily centred on anode materials, alongside exploration of novel battery technologies that extend beyond the scope of traditional Li-ion batteries. In recent years, solid state batteries and Na-ion batteries have received increased attention from Norwegian research groups.

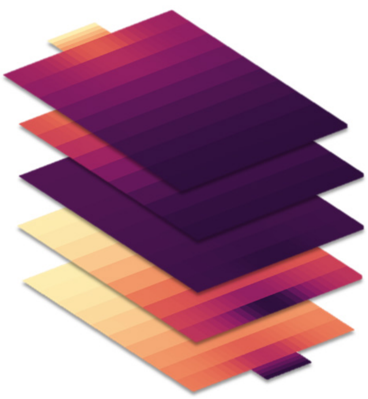
Project Name	Project Description	Participants
SAIL	SAIL project funded by the Norwegian Research Council consists of developing new anode materials for Li-ion batteries. Nanoparticles of silicon nitride are being produced and tested in electrochemical cells to address the difficulties associated with augmenting the silicon content within lithium-ion battery anodes	IFE, UiO, University of Cambridge
Magnesium Batteries	Researcher project delves into the feasibility of utilizing MXenes, a two-dimensional material, as a potential cathode material for rechargeable magnesium (Mg) batteries. The research involves exploring various synthesis techniques and post-synthesis treatments to precisely regulate the intercalation properties of this material. Up to this point, the project has focused on two distinct MXene compositions: V2CTx and Ti3C2Tx."	NTNU
Negative electrode in Li metal batteries	A PhD project working with lithium metal anodes for high energy density batteries. Using both experimental techniques (mainly XPS), and molecular modelling (including DFT and MD simulations), the project aims to investigate the mechanisms of dendrite nucleation and growth on the lithium metal surface.	NTNU
Solid state electrolytes	A PhD project consists of uncovering the fundamental mechanisms governing ionic migration and facilitating the identification and anticipation of novel materials suitable for battery applications using density functional theory (DFT) calculations and methodologies to scrutinize the inherent properties of these materials.	NTNU
OperA	Development of operando techniques and multi-scale modelling to face the zero-excess solid-state battery challenge. Project funded by Horizon EU.	NTNU

↓ Project Name	↓ Project Description	↓ Participants
SOLIMEC	Enhancing the mechanical stability of interfaces in solid-state Li-ion batteries for energy-intensive applications. Funded through the joint call program M-ERA.NET	NTNU, Univ. Autonoma de Madrid, Montan-universität Leoben, Centre for advanced materials application SAS, CSIC, AVL List GmbH
COMBAT	COMposite electrolytes for solid-state BATteries by design. Competence building project (KSP-S) funded by the Norwegian Research Council.	NTNU
ASSESS	Advanced solid-state electric energy storage systems by knowledge-based design, FFG K2-Center	NTNU
SALAMANDER	Smart sensors and self-healing functionalities embedded for battery longevity with manu-facturability and economical recyclability	IFE, UiO, WMG, Frauenhofer ISE, NIC (12 partners)
CoFBAT	Cobalt-free batteries for stationary energy storage. Project funded through Horizon 2020	IFE, Solvay, Varta, CEA, CIC Energigune, Uppsala University, VUB, MIM-ITech, Haldor Topsoe
SIMBA	Na-ion batteries for stationary energy storage. Project funded through Horizon 2020.	IFE, Elkem, TU Darmstadt, KIT, CEA, Uppsala University, Univ. Warwick, Fraunhofer, Johnson Matthey, SAFT
FLUFFY	Fluoride-based Na-ion battery cathodes for stationary energy storage	UiO

↓ Project Name	↓ Project Description	↓ Participants
Upscaling of Super Activated Carbon from laboratory scale (500 g/batch) to prototype scale (5-10 kg/ batch)	This project aims to develop high quality HC for use in different type of battery technologies, and to develop its production process from lab scale to prototype scale using sawdust as starting material. WAI has already a pilot line up and running for production of biocarbon from sawdust, which is an intermediate product for production of HC. WAI and Beyonder together will develop the production process of HC from biocarbon on prototype scale in this project, and plan to commercialize the production of HC.	Beyonder, WAI Environmental Solutions, NTNU
CalSiumbat	Calcium-Silicon alloy-based all-solid-state batteries is a researcher project where the main objective is to achieve a proof of concept for all-solid state Ca-ion batteries (CIB) with energy density higher than 650 Wh/kg. The ambitious part will be develop a new alloy-type of Ca-Si anode (phase 1) and couple it with a solid polymer electrolyte (PEO based) and a barium-free Prussian Blue (PBs) analogue cathode.	UiO
SILICAP	The project's objective is to create Norwegian high-power battery cells that outperform conventional batteries by offering significantly greater power output, lightning-fast charging, and the capability for nearly unlimited charge-discharge cycles. Beyonder has secured three million Norwegian kroner to advance this technology. The core focus is on developing a novel silicon composite for the central components of these batteries, thereby enhancing their energy storage and conductivity in comparison to current materials. Furthermore, these innovative battery cells offer an eco-friendly advantage over existing solutions as they are free from cobalt, addressing environmental concerns related to cobalt's sourcing and waste management.	IFE, Beyonder

SINTEF's research

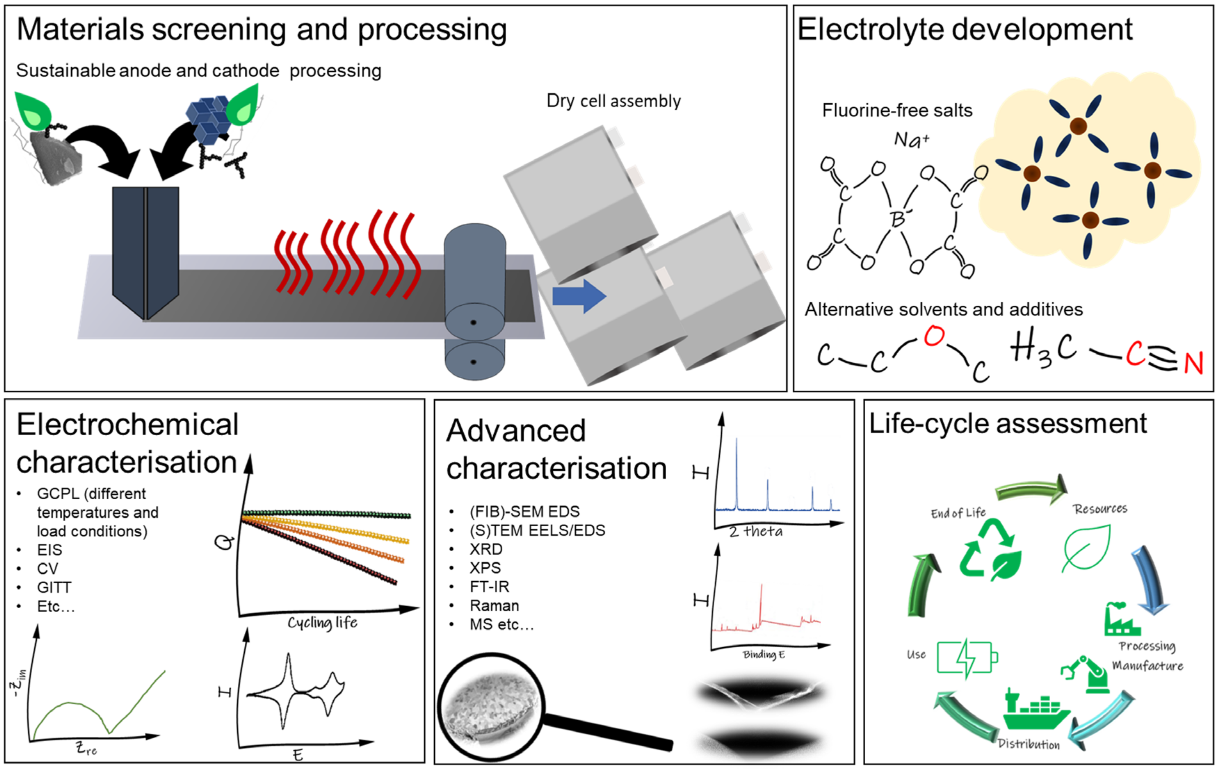
On-going research projects related to new and emerging technologies where SINTEF is either coordinator or partner, are described below. Additionally, it is worth mentioning that SINTEF has developed a multi-scale modelling platform for electrochemical devices called BattMo. BattMo is an electrochemical continuum modelling framework that is designed to allow users to model and simulate a variety of electrochemical systems. Building on a foundation of electrochemical theory and system modelling pioneered by Prof. John Newman and colleagues, BattMo incorporates recent advances and a growing database of materials and component parameters into a versatile platform that is designed to grow with the field. The tool is open source and is available with user-friendly interfaces to be used without in-depth knowledge of coding and simulations. More information about BattMo can be found on the following web site: https://batterymodel.com/.



BIOANODE (Conversion of BIOmass resource from forest industry into hard carbons as greener sodium ion battery anode) is an innovation project involving WAI Environmental Solutions, SINTEF Energy and NTNU. SINTEF Energy focuses on the conversion of forest industry biomass into durable carbon structures for sodium-ion battery anodes (61). NTNU is involved with as a partner contributing with electrochemical characterization of the produced hard carbon materials and evaluating suitability as sodium-ion battery anode. Originating as a pilot study, the project has matured into a three-year effort supported by the Research Council of Norway with a budget of 10 million NOK. At its core, the project aims to repurpose biomass waste from the forest industry into hard carbons. These hard carbons find utility as anode components in sodium-ion batteries, contributing to a more environmentally conscious and sustainable battery manufacturing process. The project's scope encompasses several key research areas, including bioresource selection, pre-treatment processes, biocarbon production, synthesis of hard carbon materials, and comprehensive performance assessment. WAI, the project owners, highlight the project's significance in light of prevalent lithium-ion batteries containing environmentally hazardous elements. They conclude that sodium-ion batteries are better and safer (62).

ZABAT (Next generation rechargeable and sustainable Zinc-Air batteries) is the beneficiary of funding from the M-ERA.NET materials engineering research competition. With a budget of 17.5 million NOK, the project is set to span a duration of three years. The primary thrust of ZABAT revolves around advancing rechargeable Zinc-Air batteries suitable for both industrial applications and households, particularly when integrated with renewable energy sources. The objective is the development of energy storage systems that is not reliant on critical materials such as lithium, natural graphite, and cobalt. A dual performance criterion is set, targeting a minimum energy density of 300 Wh/kg and a cycle life exceeding 2,000 hours. The technology framework is grounded in the utilization of abundant zinc reserves. Beyond its research and development pursuits, ZABAT will also facilitate circular economy principles. The initiative is committed to assessing and enhancing the sustainable and circular attributes of the technology, encompassing evaluations of environmental impact, toxicity, and societal implications associated with its materials and processes.

COFFEE (Cationic Covalent Organic Frameworks as Anion Exchange Membrane for Electrochemical Energy Applications) is another project funded through the M-ERA.NET competition for research in materials engineering is COFFEE (63). With a budget of 9.6 MNOK, the project has a three-year trajectory. The objective of COFFEE resides in the domain of anion exchange membranes, a key component in electrochemical energy systems. Addressing the dual obstacles of low stability in alkaline environments and suboptimal ionic conductivities, the project emphasizes the criticality of the configuration of the



chemical structure of both the polymer backbone and the cationic head group. Central to the COFFEE project's innovation is the proposition of a class of anion exchange membranes, utilizing covalent organic frameworks to elevate the membrane's stability, conductivity, and selective properties. The projected outcome—robust and high-performance anion exchange membranes—holds substantial promise for advancing technologies like zinc-air batteries and anion exchange membrane electrolysers, ushering these technologies closer to commercial feasibility. This, in turn, augments the momentum towards a more widespread embrace of renewable energy solutions. SINTEF's direct role in this project is in the development of molecular building blocks for novel membranes, the fabrication and characterization of the membranes. SINTEF will also perform experiments at the Norwegian Fuel Cell and Hydrogen Centre.

SOLSTICE (Sodium-Zinc Molten Salt Batteries for Low-Cost Stationary Storage) is funded through HOROZON 2020 and is a four-year initiative with a comprehensive budget totalling 7.7 M€ (64). The project is coordinated by Helmholtz-Zentrum Dresden-Rossendorf with SINTEF and NTNU as Norwegian partners. The central ambition of SOLSTICE resides in the evolution of two distinct sodium-zinc molten salt batteries engineered for elevated-temperature operation, with applications tailored towards stationary energy storage. The first battery configuration is based on the ZEBRA technology—a rechargeable molten salt battery architecture predicated on nickel, sodium, and chloride components. By replacing nickel with zinc in the positive electrode, the project seeks to enhance cost-efficiency and diminish reliance on critical materials. The second battery model adopts an all-liquid composition, mirroring the identical chemistry of the prior configuration with the exception of eliminating the ceramic electrolyte. This strategic departure further augments cost reduction strategies. Both battery concepts will be brought to TRL 5 during the project's duration. These prototypes are envisaged to be integrated with self-learning battery management systems for comprehensive demonstration. Upscaling endeavours, system integration, and inclusive public acceptance assessments further characterize the project's scope. The project's overarching narrative converges on the Na-Zn technology framework as an archetype of the most economically viable molten-salt battery. Noteworthy for its holistic sustainability, this technology platform is poised to be positioned for potential commercialization by the year 2030.

HIPERZAB (High Performing Electrically Rechargeable Zinc-Air Batteries for Sustainable Mid-Term Energy Storage) is a project under the HORIZON-EIC umbrella, spanning over four years. The project is coordinated by CIC energiGUNE from Spain, with SINTEF as partner. This concentrated effort is reinforced by a combined financial commitment of 3.9 M€ and involves the collaboration of diverse European partners (65). At its nucleus, the project underscores the prevailing challenges related to metal-air batteries, including restricted storage durations and the operational and maintenance expenses associated with mechanical recharging paradigms. Notwithstanding these hurdles, the technology presents compelling merits: the utilization of economical and abundant active materials, the endowment of impressive gravimetric energy densities, and the promise of enduring stability. HIPERZAB endeavours to carve a ground-breaking path by pioneering the design and validation of an electrically rechargeable zinc-air battery on a laboratory scale. The initiative's hallmark lies in its potential to yield significant advancements in cyclability, storage duration, cost-efficiency, and life cycle attributes, ideally suited for mid-term energy storage over spans of days or weeks. The project's innovation unfolds through the development of three distinctive components:

1. 3D Porous Zn/Biopolymer Composite Anode: This creation holds the potential to redefine anode dynamics.
2. Eco-Friendly Bilayer Gel Electrolyte: Anchored in naturally occurring precursors, this electro lyte innovation addresses environmental considerations.
3. Critical Raw Material-Free Cathode: A cathode structure grounded in high entropy oxides obviates reliance on critical raw materials.

This trinity of novel components converges to establish a revolutionary battery architecture. This design will also incorporate water/air management controls during cycling. Aligned with principles of sustainability, the project integrates life cycle and circular economy perspectives, ensuring the seamless integration of eco-conscious end-of-life strategies within the development trajectory.

SIBERIA (Sodium ion batteries for stationary applications in challenging environment) is a "young talent research project" led by SINTEF. The project, funded through the ENERGIX program, will span a duration of 3.5 years (66). The central objective of SIBERIA revolves around the innovation of cost-effective batteries designed for stationary storage in the challenging climate of the Nordic region. This necessitates the development of batteries with high-performance characteristics even at low temperatures, mitigating efficiency losses that can occur due to active thermal management. A KPI in this context is maintaining battery efficiency under these adverse conditions. The project is also committed to minimizing environmental impacts throughout the entire lifecycle of the batteries. To achieve this, SIBERIA suggests the use of aqueous processing methods and the exclusion of fluorine--based components. A significant focus within the project is on the development of novel electrolytes that employ a blend of various solvent classes and fluorine-free, weakly coordinating sodium salts. Since these specific salts are not readily available commercially, SIBERIA aims to synthesize them within the project. Furthermore, the project involves characterizing the electrochemical performance of these developed electrolytes and their compatibility with iron-based Prussian blue cathodes. Upon conclusion, SIBERIA will carry out a demonstration of

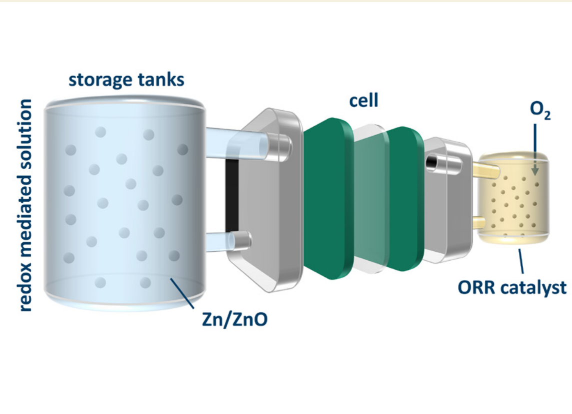


Figure 3: *Illustration of a zinc-air battery (not to scale).*

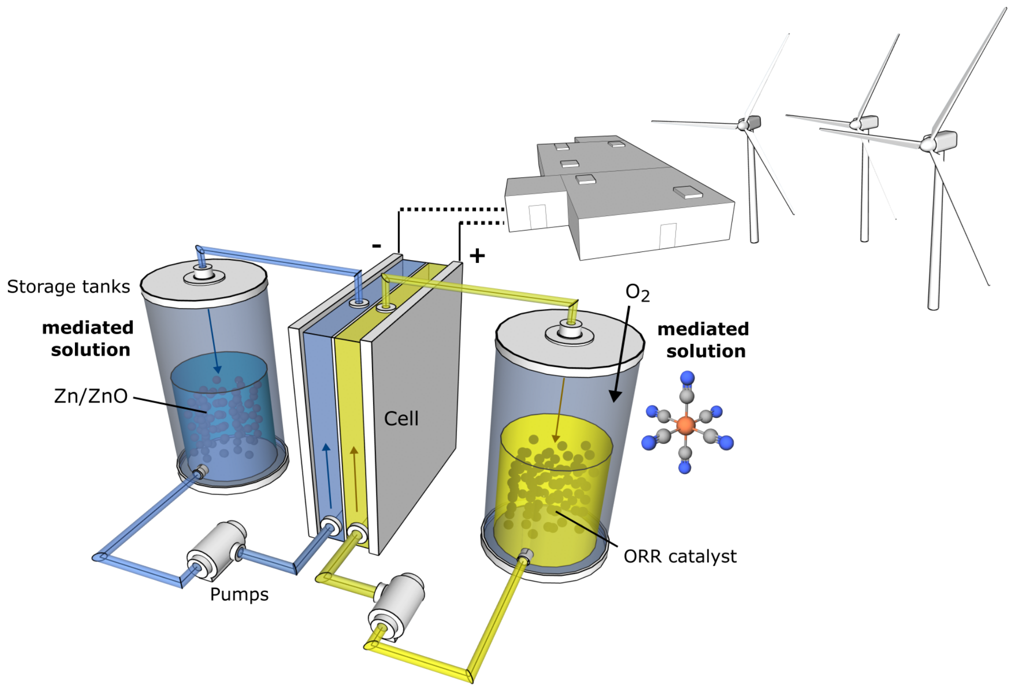


Figure 4: *Illustration of a flow battery connected to grid and renewable energy*

the sodium-ion cells operating under Nordic climate conditions, offering a full characterization of their performance. Additionally, a life cycle analysis will be conducted in parallel throughout the project to assess the environmental and sustainability aspects of these batteries.

ReZinc (Rethinking zinc-air flow batteries for stationary energy storage) is a "young talent research project" led by SINTEF (67). Funded through the ENERGIX program with a budget of 8 MNOK, this collaborative effort also involves Aarhus University and NTNU and is planned to run for four years. Metal-air flow batteries, sometimes regarded as the "Holy Grail" of energy storage, are at the core of ReZinc's research. To harness the full potential of these batteries for long-term energy storage, the project emphasizes the need for innovative strategies that facilitate the reduction of oxides to metal during the charging process and the development of new flow battery designs. ReZinc aims to address several challenges associated with zinc-air batteries and their commercialization, including relatively short discharge durations, high CAPEX, and safety and sustainability concerns. Within the project, the operation and design of metal-air flow batteries will undergo a thorough review, and innovative solutions will be demonstrated at the lab scale, achieving a TRL of 4. The proposed solution involves the creation of a redox-mediated zinc-air flow battery that utilizes ZnO/Zn as a storage vector and incorporates electro-chemical mediators for enhancing the charge transfer process. Furthermore, a disruptive redox-mediated strategy will be employed to improve the charge transfer process, resulting in the development of the first dendrite-free metal-based flow battery. By confining the metal/metal oxide reaction to the negative reservoir and avoiding the electroplating process within the cell, ReZinc aims to achieve long-duration discharging capabilities. This research project represents a significant step toward unlocking the potential of zinc-air flow batteries for stationary energy storage while addressing key challenges related to safety, sustainability, and performance.

ReZilient (Redox-mediated hybrid zinc-air flow batteries for more resilient integrated power systems) is a five-year project funded under HORIZON EUROPE (68). SINTEF coordinates this project, which boasts a total budget of 4 M€ and an impressive consortium of contributors. The project's primary focus is on innovative chemistries and flow system designs, with the aim of providing scalable and long-duration energy storage solutions to address grid resiliency challenges. ReZilient aspires to bridge the gap between short-term electrochemical energy storage and long-term fuel storage by introducing a groundbreaking zinc-air flow battery technology. This technology is designed to operate with a disruptive redox-mediated strategy that significantly enhances the charge transfer process. One of the key innovations is the confinement of the Zn/Zn2+ redox reaction in the negative reservoir, effectively eliminating the electroplating process within the cell. This innovative approach is anticipated to result in several advantages, including improved battery life-time and the ability to discharge energy for extended periods, extending beyond days. This represents a significant advancement compared to current zinc-air batteries. ReZilient's ambitious mission is to contribute to the development of more resilient and sustainable integrated power systems by rethinking energy storage technologies and introducing a new class of zinc-air flow batteries with enhanced performance, longevity, and discharge capabilities.

AMAZE (Advanced Manufacturing of Zn Electrodes for Rechargeable Zn-air Batteries) funded by M-ERA.NET with a budget of 9 MNOK, spans 4 years (69). Its focus is the scalable and economically viable manufacturing of porous Zn electrodes for high-performance Zn-air batteries. AMAZE aims to deliver thick, porous electrodes optimized for maximum Zn utilization, specific energy, and cycling stability. The project intends to validate a full cell zinc-air battery with the best-performing Zn electrode and a non-carbon bi-functional air electrode for at least 250 charge/discharge cycles. It consists of four main activities: (1) Developing 3D calcium zincate structures using low-temperature dry mix technology; (2) Creating high-energy-density 3D Zn structures via additive manufacturing; (3) Crafting carbon-free bi-functional air electrodes using sustainable materials; (4) Conducting environmental and life cycle assessments for future development and upscaling. In summary, the AMAZE project seeks to advance Zn electrode manufacturing for Zn-air batteries with a focus on scalability, economic viability, and performance enhancement.

BIG-MAP (Battery Interface Genome – Materials Acceleration Platform) is an EU project funded under the Horizon 2020 program with a budget of 20 M€. The project is coordinated by DTU (Technical University of Denmark) and boasts a large consortium of 37 partners, including SINTEF. The project spans a duration of four years and has a clear mission: to fundamentally change the way we innovate and develop batteries, thereby accelerating the pace of battery technology advancement. One of the central premises of BIG-MAP is that battery development, historically, has often relied on a trial-and-error approach. While this method has achieved success, it is also expensive and time-consuming. To address these challenges, BIG-MAP seeks to combine several cutting-edge technologies, including an artificial intelligence platform and robotics, to streamline the process. The project aims to create a platform that can synthesize and test new raw materials using vast databases. It will also incorporate multiscale simulation of physical models, providing researchers with tools to model and understand battery processes at atomic scales. This level of detail and understanding can significantly impact battery efficiency, lifetime, and overall performance. By combining these elements, BIG-MAP aims to accelerate the development of sustainable and high-performance batteries. The project sets an ambitious goal, envisioning that this approach could potentially speed up the battery development process by a factor of ten compared to current methods. In essence, BIG-MAP seeks to transform the battery innovation landscape, offering a more efficient and data-driven approach to create the next generation of batteries.

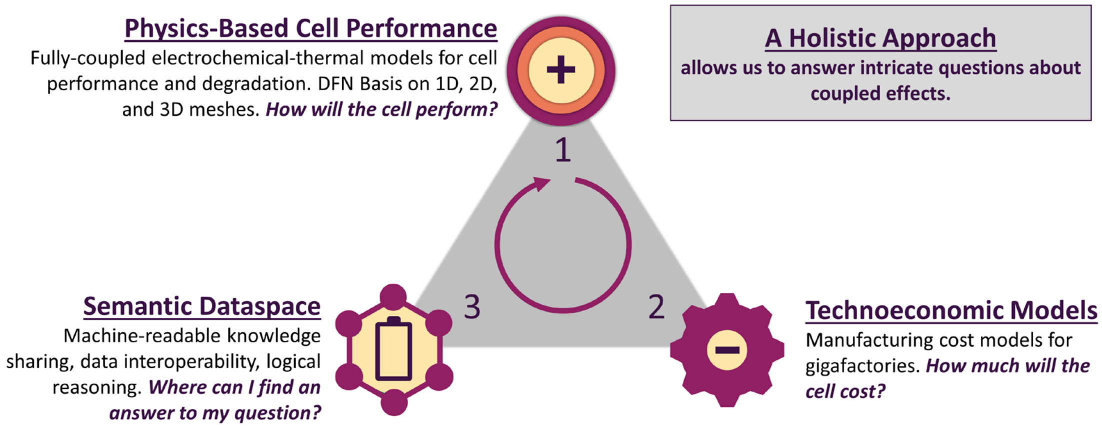


Figure 5: *Battery modelling activities in SINTEF.*

3. Advanced materials

In the category advanced materials there is a certain overlap with topics listed under New and emerging technologies. However, in this section it will be focused on advanced materials for Li-ion batteries. This is an area of research which has received enormous attention globally for the past 30 years. Development of new materials for LIB has led to the improvement in energy density, power density, stability, safety, and cycle life of LIBs from the birth of the first commercial LIB in 1991 (70) until today. Although LIBs are used in many types of portable electronic devices, power tools, medical equipment and other applications, the main driving force for the LIB revolution has been the EV industry, and large parts of the IP related to LIB materials production and cell manufacturing has been owned by Asian stakeholders (China, South Korea, Japan). However, strong research groups have also developed in Europe such as University of Uppsala, Fraunhofer Institute, CNRS, CEA, Empa, Helmholtz-Institute, KIT, TU Delft, and others.

Norway's position

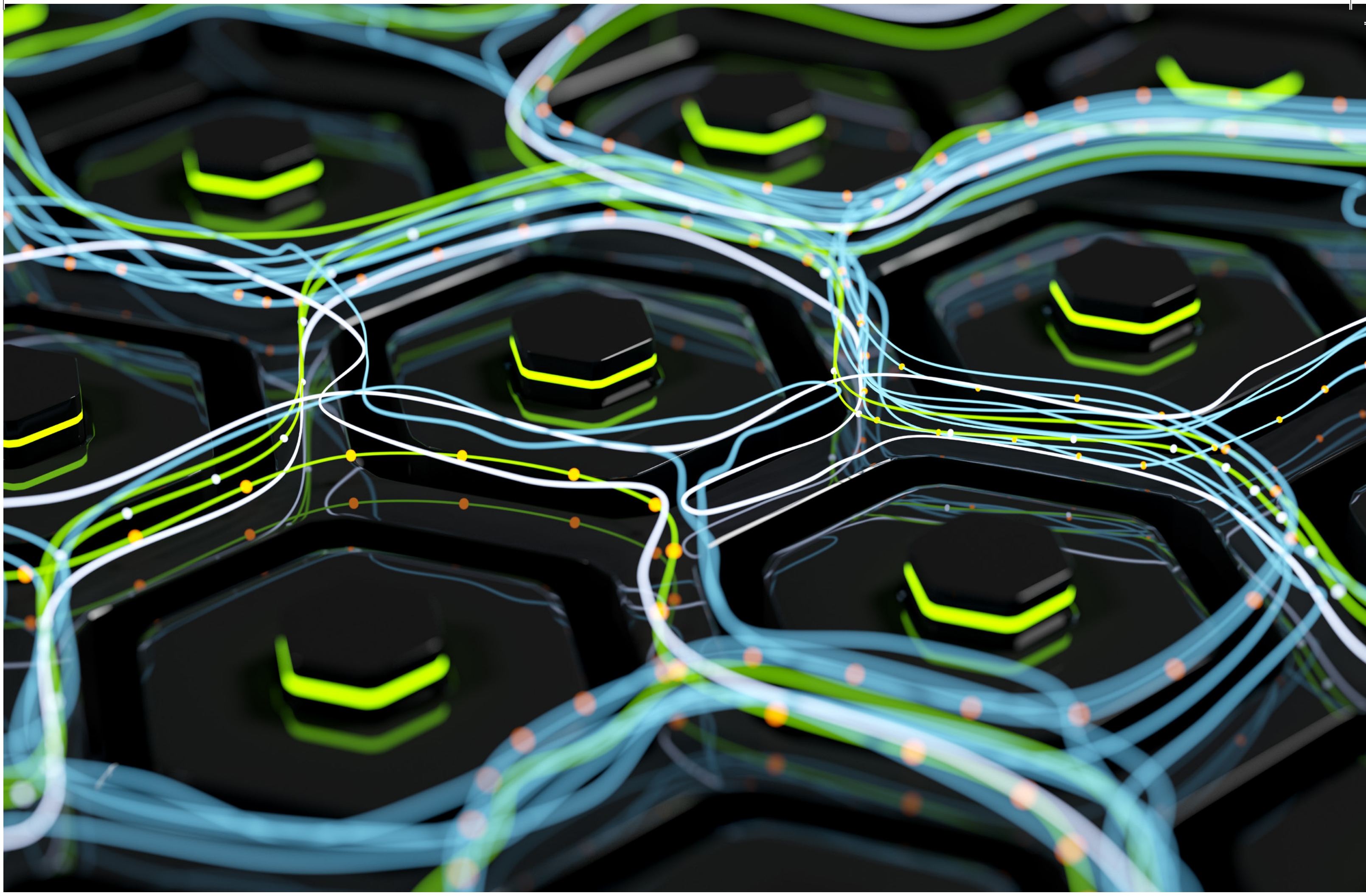
NanoPow AS is a Norwegian company established in Oslo in 2016 providing crystalline silicon nanopowder (71). Their product is based on more than two decades of research and practical expertise resulting in a proprietary low-cost process free from emissions of any toxic or hazardous gases. Their aim is to develop high-capacity batteries together with partners by incorporating silicon nano-powders into the graphite anodes.

Another Norwegian company at the forefront of advancements in lithium-ion battery technology is CealTech which was established in 2012. By leveraging the potential of graphene-based nanomaterials, they are working to enhance the performance and safety of LIB electrodes (72). Their primary focus lies in improving thermal and electrochemical properties, including capacity, fast-charging capabilities, life-cycle longevity, and mitigating safety concerns related to overheating. CealTech is actively engaged in integrating their proprietary Plasma-Enhanced Chemical Vapor Deposition (PE-CVD) graphene as an additive in both cathodes and anodes. In addition, development of novel graphene-enhanced components designed for the next generation of commercial LIBs is also on their agenda.

CerPoTech is a provider of multi-component ceramic oxide powders based on aqueous-based environmentally friendly technology (73). The company is rooted in the expertise from the Department of Material Science and Engineering at the Norwegian University of Science and Technology (NTNU) and started commercial operations in 2007. The oxide powders can be tailored with specific compositions and find application in many materials including battery electrodes.

Planck Technologies is a new start-up company which has its focus areas on chemical and electrochemical systems. They claim to hold expertise and knowledge enabling them to create tailored system solutions using highly efficient materials. They develop technology to optimize materials for higher performance, longer life-cycles and safe and more sustainable energy storage systems (74).

Morrow Batteries is a European company founded in 2020 and located in Arendal in Southern Norway (75). They are building a giga-factory (43 GWh per year by 2030) and plan to start production in early 2024. With the industrial standard cathode material lithium iron phosphate (LFP) Morrow will become one of the



very first battery cell suppliers in Europe. Advancing through lithium nickel manganese cobalt oxide (NMC) they aim to revolutionize the battery industry by bringing the next-generation batteries based on the high-voltage lithium nickel manganese oxide (LNMO) cathode material to the market. With LNMO they are to eliminate the need for cobalt and reduce the required nickel content by up to 60% compared to state-of-the-art NMC. Furthermore, pairing the cathode with their proprietary XNO anode their batteries provide ultralong cycle life, great safety, and fast-charging capabilities.

The recently established Shift Materials is another technology-driven company headquartered in Norway. The company is focusing on LFP cathode material production for the European battery industry (76).

Cenate and TioTech which were also listed as raw materials providers should also be mentioned as companies providing advanced materials. Cenate's silicon nanoparticle technology is aiming for the next generation LIB with improved energy density and longer cycle life. Silicon has been a hot topic in LIB research for some time, but challenges related to materials degradation during use has been hampering widespread implementation in the LIB anode. Cenate now claim to have solved this issue by adding a very thin layer of carbon. These tiny carbon-coated nanoparticles grow into larger (micron-sized) particles which don't crack and pulverize during charging and discharging (77). TioTech's technology claims to be the next-generation anode materials for LIBs. Their TitanBTM aims to replace the current LTO (lithium-titanium-oxide) materials with improved charging, lifetime, safety and temperature robustness of LIBs. Additionally, TitanBTM has higher capacity than LTO and is less resource demanding and more cost-effective as it does not contain lithium (78).

Baldur Coatings AS is a small spin-off company from the University in Oslo (UiO) (79). Their atomic layer deposition (ALD) technology is based on knowledge developed over a 10 to 15 year period at UiO. Since 1995 the research group at UiO has built several ALD reactors for thin film deposition and developed new processes for different compositions, including also coating of powders. Part of their services is to apply thin coatings on powders for i.e. battery electrode applications.

↓ Project Name	↓ Project Description	↓ Participants
High Voltage Cathode Materials for Li-ion Batteries	PhD Project focuses on the development of high-energy cathode materials tailored for Li-ion batteries. Ni-rich layered oxides offer the potential for high energy densities, yet they encounter challenges related to performance and thermal stability. Therefore, the project's objective is to craft modified Ni-rich layered oxides to enhance their stability characteristics.	NTNU
Silicon/Silica electrodes for Li-ion batteries	A PhD project centres on conducting experimental investigations into a variety of electrode materials and electrolyte systems for Li-ion batteries. Notable areas of study encompass understanding the Li-uptake behaviours of biomineralized silica, optimizing binder functionalities for silicon-based anodes, and mitigating aluminium corrosion in high-voltage cathode materials by fine-tuning the use of electrolyte additives	NTNU
SEAMLESS	Screening of Emerging Anode Materials for Li-based Energy Storage Systems is a researcher project aims to create a comprehensive library of nanomaterials based on silicon, designed to propel the evolution of the next generation of Li-ion batteries (LIBs)."	IFE, UIO
MoreIsLess	The objective of this project is to create electrodes for lithium-ion batteries (LIBs) that possess improved ionic and electronic transport characteristics, enabling them to provide increased energy density while maintaining power density.	IFE, NTNU, UIO, University College London (UCL), Freyr, Equinor, Morrow Batteries, Norsk Hydro and Cenate.
CoFBAT	The CoFBAT project's goal is to enhance knowledge in advanced materials, develop and refine new materials and components to extend battery lifetime, reduce costs and enhance safety. This involves combining high-capacity anodes with cobalt-free cathodes and a novel electrolyte.	IFE, The French Alternative Energies and Atomic Energy Commission (CEA)
AGDER Batteri	Agder Batteri investigates an innovation ecosystem designed for accelerating business growth and research in the Norwegian battery sector. This project involves public and private actors dedicated to establishing coordinated development of battery value chains	UIA

Norway's research and research funding potential

Norwegian researchers are deeply engaged in the advancement of cutting-edge materials for batteries, encompassing cathodes, anodes, and electrolytes. Their research is dedicated to enhancing several critical aspects of batteries, including performance, energy density, power output, cycle longevity, cost-effectiveness, and safety, with a strong commitment to sustainability. A special emphasis has been placed on silicon-based anodes due to silicon's potential to substantially boost the energy density of lithium-ion batteries, along with the exploration of innovative techniques to address the associated challenges like material expansion and contraction. Additionally, considerable attention was directed towards the development of cathodes that do not rely on critical raw materials and the creation of novel electrolyte solutions. The main research actors in advanced materials are NTNU, SINTEF, UiO and IFE which have worked on materials development research for the past 15 to 20 years. Other universities (UiS and UiA) are also now increasing their activities in this field.

SINTEF's research

SUMBAT (Sustainable Materials for the Battery Value Chain) is a competence building and collaboration project (KSP) and part of a larger initiative funded through Green Platform, which is co-funded by SIVA, Innovation Norway, and the Research Council of Norway (80). SUMBAT KSP is 1 out of 8 sup-projects in the Green Platform project SUMBAT. SUMBAT KSP has a total budget of 40 million NOK and a duration of 3 years, the project aims to bolster and expand upon Norway's battery expertise throughout the entire value chain. The project fosters collaboration among the key stakeholders in Norwegian battery technology and aims to enhance Norwegian competitiveness in global battery technology. To support research along the entire value chain, the new SINTEF Battery Lab is identified as critical research infrastructure. Although with strong focus on manufacturing and implementation, there is also significant activity on advanced materials in this project. Thus, SUMBAT will fit under several categories and will also be mentioned later in this document.

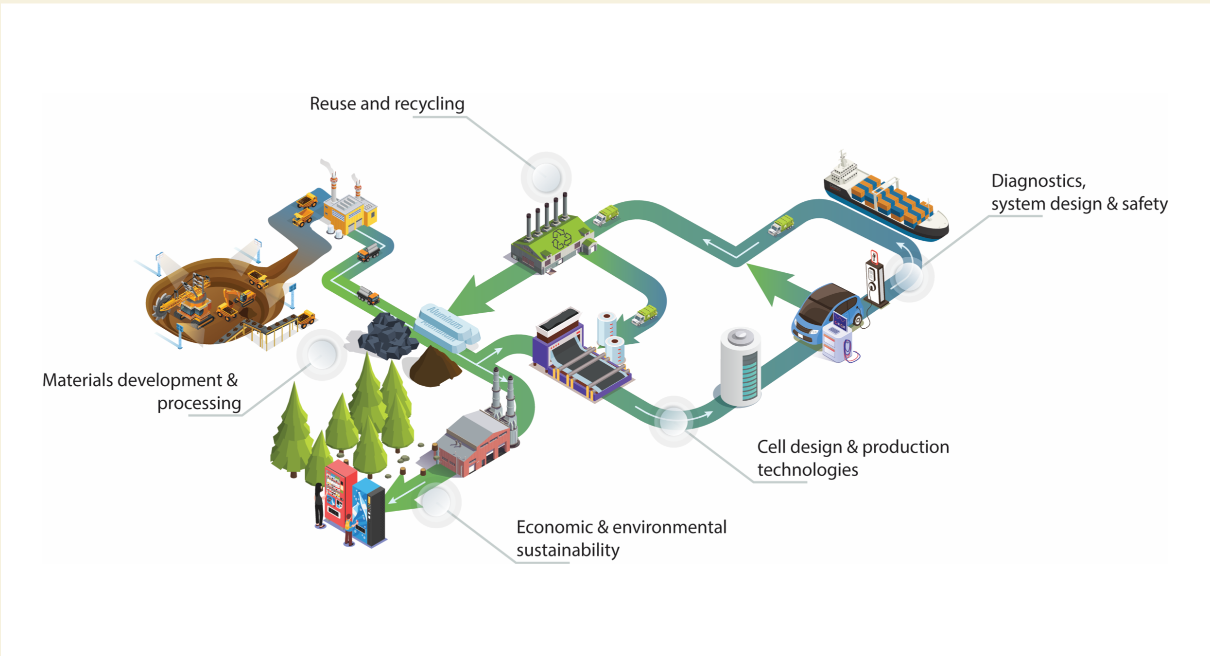


Figure 6: *Figure shows interaction between the SUMBAT KSP project and the innovation projects (SP1-SP6) in the main Green Platform project (figure curtesy of IFE).*

MOGLiS (MOF@rGO-based cathodes for Li-S batteries) is a project funded through M-ERA.NET joint calls with a budget of 9 MNOK (81). The project spans three years, concluding in 2023. MOGLiS addresses challenges associated with graphite electrodes in Li-ion batteries, aiming to harness the potential of lithium-sulphur (Li-S) batteries, which offer theoretical energy densities up to five times that of LIBs. The primary hurdle in commercializing Li-S batteries lies in finding suitable cathode materials capable of immobilizing substantial sulphur loads, exhibiting high conductivity, and preserving mechanical flexibility. To tackle these issues, MOGLiS employs nanotechnology and thin film fabrication techniques. A distinctive nanomaterial design methodology is employed, involving Metal Organic Frameworks integrated with 2-dimensional reduced Graphene Oxide nanosheets to create cathode materials. The project aims to produce flexible and foldable batteries with enhanced capacity, potentially surpassing existing batteries in terms of size, safety, and efficiency.

SMICE-Li (Stabilising conversion anodes with solid molecular ionic composite electrolytes for solid state lithium-ion batteries) is another M-ERA.NET funded project (82). With a budget of 9 MNOK and 3-year duration, the project is set to end in 2024. This project seeks to showcase a novel solid-state battery comprising a conversion anode material, a solid molecular ionic composite electrolyte, and a state-of-the-art high voltage cathode. SMICE-Li will concurrently pioneer novel oxide-based conversion anode materials rooted in complex composition transition metal oxides and innovative solid molecular ionic composite electrolytes. The former holds the promise of increased capacity compared to current graphite anodes while addressing challenges associated with lithium metal electrode manufacturing, such as air sensitivity, thickness control, and excess lithium inventory, along with controlled plating during cycling. The latter strives to combine the safety, voltage, and thermal stability advantages of ionic liquids with the mechanical benefits of solid polymer electrolytes and the high ionic conductivity of liquid electrolytes. A fundamental understanding guides the project's development, with DFT (density functional theory) modelling directing materials synthesis. The ultimate goal of SMICE-Li is to demonstrate a solid-state battery incorporating the conversion anode material, solid molecular ionic composite electrolyte, and high voltage cathode, achieving a specific energy density exceeding 300 Wh/kg and a cycle life surpassing 200 cycles.

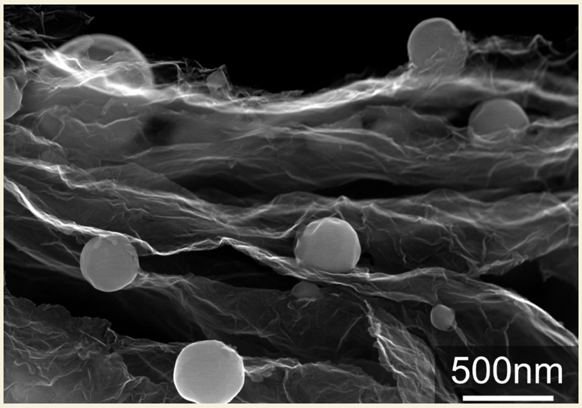


__Figure 7:__ Microscopy image of a diatom frustule taken with a scanning transmission electron microscope.

SUSTBATT (Scalable Sustainable Anodes for Li-ion Batteries by Structural Design) is a collaborative project spanning over 3 years with a budget of 12 MNOK funded through the join-call from M-ERA.NET (83). The project is coordinated by NTNU with SINTEF as the other Norwegian partner. The increasing reliance on renewable energy sources underscores the pivotal role of Li-ion batteries in future energy systems. However, as demand for Li-ion batteries increases in parallel with the cruciality for a climate-neutral energy sector, securing a sustainable supply of raw materials becomes vital. Apart from lithium, graphite plays a fundamental role in Li-ion battery anodes. Yet, graphite presents certain challenges, including limited Li-storage capacity and reliance on synthetic graphite derived from fossil sources or mined through energy-intensive and high-carbon-emission processes. An environmentally friendly alternative to graphite anodes is silicon or silicon oxides (SiO_2), which are abundantly available in the Earth's crust. Silicon oxides occur naturally in various forms, such as diatom frustules. Diatom frustules, or shells, are naturally present in both fresh and sea water and exhibit the capability of consuming CO2 during their growth. They hold significant promise as anode materials for Li-ion batteries. In the SUSTBATT project, Swedish Algae Factory will cultivate diatom frustules, followed by their conversion into usable Li-ion battery materials by magnesiothermic reduction into SiOx with x being between 0 and 2. SINTEF contributes with advanced characterization using TEM, FIB-SEM, and S(T)EM. In addition to lab scale testing of the materials, LiFeSiZE will assess these materials through pilot-scale production.

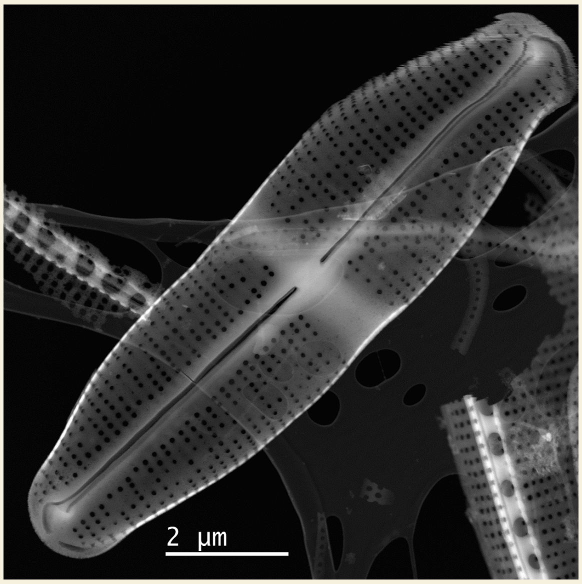


Figure 8: *Microscopy image of a diatom frustule taken with a scanning transmission electron microscope.*

HYDRA (Hybrid power-energy electrodes for next generation lithium-ion batteries) funded through HORIZON 2020, is an EU project with a total budget of 9.4 M€, lasting 4 years (84). The project shares its name with the mythical beast and will develop high-performance and sustainable Li-ion batteries using a multi-headed approach (85). Alongside many acknowledged European partners, SINTEF coordinates the project. HYDRA is dedicated to the advancement of high-performance and sustainable LIBs, prioritizing a holistic perspective. This endeavour encompasses the development of novel high-energy and high-power hybridized electrodes, with a strong emphasis on sustainable materials processing and pilot-scale production. Additionally, HYDRA undertakes the entire battery production value chain, while also conducting comprehensive life cycle assessments on local and global scales to ensure ecological sustainability. The project conducts a thorough evaluation of all facets of battery life cycle, from initial design to second-life applications, consolidating its findings to drive progress in the field.

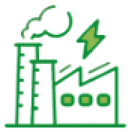
Figure 9: *Photo from HYDRA International Li-ion Battery Workshop organized in Trondheim, summer 2023.*

IntelLiGent (Innovative and sustainable high-voltage Li-ion cells for the next generation (EV) batteries) is another EU-project coordinated by SINTEF (86). The project duration is 4 years, the budget is 6.8 M€, and it is funded through the HORIZON EU (87). The project aims to pave way for the next generation batteries, European generation 3B Li-ion battery (energy density over 350 Wh/kg). IntelLiGent addresses the challenge of accommodating high voltage cathodes and high-capacity composite anodes through a multifaceted approach. This approach encompasses material optimization and advanced electrolytes with enhanced passivating capabilities. Moreover, it integrates self-mitigating and self-healing features into the interactive components of battery cells to extend their lifespan by mitigating parasitic reactions and maintaining electrode structures. The project relies on extensive experiments guided by multiscale modelling, fostering a strong synergy between theory and practice. Notably, IntelLiGent benefits from substantial industry engagement across the value chain, all underpinned by a steadfast commitment to sustainability.

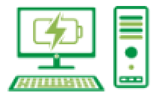
NEXTCELL (Towards the next generation of high performance li-ion battery cells) a project funded through HORIZON EU and coordinated by FEB Europe Gmbh, with SINTEF as partner. The total project funding is around 8 M€ (88). The NEXTCELL project aims to develop a ground-breaking gellified cell concept for high capacity and high-voltage LIBs. The project will address three key parameters which are currently hindering the greater market penetration of LIBs: costs, safety and sustainability. The ultimate goal of the project is to fast-track the commercialisation

Advanced electrolytes and inactive materials

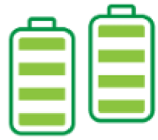
Sustainable electrode materials and processing



Model based design



IntelLiGent Batteries



of the novel cell design and its new components, providing Europe with cutting-edge third generation LIBs while meeting the industry's increasing demands for cost reduction, user-friendliness, and safety.

BronzeTitan (Commercializing bronze titania for safe, fast charging and sustainable Li-ion batteries) focuses on the commercialization of bronze titania for the development of safe, rapid-charging, and sustainable Li-ion batteries. This innovation project is funded through the ENERGIX program (89) with allocated funding from the Norwegian Research Council of 5.7 MNOK and is slated to span a period of 4 years. Within the framework of the BronzeTitan project, researchers aim to investigate a novel production process with specific relevance to lithium-ion batteries. Titania bronze, when utilized in Li-ion batteries, has demonstrated promising attributes encompassing efficient charging, enhanced safety, robust low-temperature performance, and prolonged operational lifespan, as evidenced in academic research. However, a persistent challenge has been the cost-effective synthesis of this material. BronzeTitan endeavours to develop a manufacturing process for titanium dioxide, yielding nanomaterials characterized by the desired atomic structure and associated properties. The project seeks to establish a comprehensive understanding of how particle size and shape influence the characteristics of the battery material. A critical hurdle to overcome is the metastable nature of bronze, which has the propensity to spontaneously transform into a less desirable form known as anatase. Thus, the manufacturing process must be meticulously fine-tuned to minimize the occurrence of anatase titania. Similarly, the dimensions of the particles are instrumental in determining charging rates and the effective capacity of the material. Hence, the project places a strong emphasis on optimizing both the shape and size of nanoparticles, as well as their internal structure. In this collaborative initiative, TioTech will be responsible for delivering particles with varying shapes, sizes, and treatments, while SINTEF will assume the role of conducting testing and validation. Furthermore, the project will explore the processes of scaling up production and validating the resulting products on a larger scale. In summary, the BronzeTitan project is dedicated to harnessing the potential of bronze titania for the advancement of Li-ion battery technology, focusing on cost-effective synthesis, structural optimization, and scalability to usher in safer and more efficient energy storage solutions.

Taser (Titania Anodes for Sustainable, High-Power Batteries) is another innovation project of TioTech AS funded through the ENERGIX program, with allocated funding from the Norwegian Research Council of 7.0 MNOK for 2022-2023. In this project, TioTech will leverage from the company`s extensive know-how about titania nanomaterials and its manufacturing to optimise a production process for a titania anode material suitable for processing in battery cell manufacturing. The material`s corresponding battery chemistry will be developed in collaboration with SINTEF, resulting in a titania drop-in solution for existing battery cell producers.

FME MoZEES (Mobility zero emission energy system) is a centre for environment-friendly energy research, started in 2017 and ending in 2024 (90). The centre is hosted by IFE and includes numerous R&D and industrial partners. The centre aims to design and develop safe, reliable, and cost-efficient zero emission solutions for transport. Four main research areas are pursued in the FME: batteries, hydrogen, systems, and policy and techno-economics. For the relevant battery research area, which is led by NTNU, the centre studies materials and components, increasing performance, capacity and rate capability, new fabrication methods, and lowering the cost of production. One of the priorities of MoZEES is to establish strong research teams that can take advantage of the multi-disciplinary and cross-sectorial capabilities. MoZEES also support R&D performed by the industrial partners, that may influence the international battery value chains.

4. Manufacturing technology

Demand for EV battery production alone is expected to reach 5.3 terawatt hours (TWh) globally in 2035 according to a report by SNE Research, sited in The Korea Times (91). If one is to include all sectors in need of batteries, being heavy machinery, transportation or stationery, the number of battery production plants with GWh capacity would surpass a roughly estimated 400 on a global scale. As mentioned in the previous chapter, Li-ion battery cell manufacturing has been dominated by Asian stake-holders. Thus, knowledge and competence on manu-facturing processes as well as equipment needed for battery cell manufacturing are centred in three main countries, namely China, Japan, and South-Korea. It is only in the last few years that European initiatives on battery cell manufacturing have gained impact, and many of the European manufacturers have chosen to licence technology from Asian companies. A comprehensive list of battery cell manufacturing plants, and planned initiatives was published by Teknisk Ukeblad in September 2023 (92), including also the Norwegian initiatives Freyr, Morrow, Elinor Batteries and Beyonder. In addition to the battery cell manufacturing, European industry is also moving into the equipment and machinery manufacturing market. Upcell, a European Battery Manufacturing Alliance, is a non-for-profit association that aims to create a unique European ecosystem of actors in the equipment and machinery for battery manufacturing industry stronger together, aiming to give Europe a leading position in this field (93). Currently they have gained 76 members and are growing, showing the great interest also for this field in Europe.

Norway's position

Currently there are several initiatives for battery manufacturing in Norway and a few companies are in the initial stages of establishing factories for commercial production. Battery manufacturing can be divided into two categories; cells, and packs and systems, and while the giga factories focus on cell production, there are other companies who mainly put their efforts into the assembling of the cells and adaption of modules to specific applications. Morrow Batteries and Freyr are two companies that are to commence battery production in early 2024 and rapidly expand to GWh levels. Although Freyr has recently announced that the start-up of Giga Arctic in Mo i Rana is now postponed indefinitely. Due to the extremely beneficial conditions provided through the US Inflation Reduction Act (IRA), they have now decided to concentrate their activities in the USA (94). Other initiatives in Norway include Beyonder, HREINN, and Elinor Batteries.

Battery cell manufacturing

Freyr recently completed their customer qualification plant (CQP) in Mo i Rana, which is a demonstration production line offering samples for the customers. Prior to their recent announcement of moving focus to the USA, the original plan in Norway was to expand to a production capacity of 43 GWh pr year by expanding with 8 full scale production lines. In parallel with the Giga Arctic plant in Mo i Rana the company was developing a plan for Giga America (located in Coweta County Georgia). As already mentioned, this has now been changed to fully focus on the plant in the USA. Freyr's technology is licensed from the American company 24M and is based on a semi-dry coating process, avoiding the toxic NMP solvent normally required for electrode production. This gives significant benefits with respect to the cost of production and environmental footprint. Cathode chemistry for their batteries was initially expected to be NMC-based (95). However, Freyr has also entered into a joint venture with Aleees to pursue LFP cathode manufacturing. Thus, it is expected that they will also produce batteries using LFP (96).

Morrow's strategy is to focus on industrial standard production of LFP before maturing into LNMO technology, which is a cobalt-free cathode. For the LNMO materials, Morrow has entered into collaboration with the Danish company Haldor Topsoe, with the aim to establish a pilot facility for LNMO production in the south of Norway (97).

Beyonder, a third major stakeholder in battery manufacturing, exploits the strength of Li-ion batteries and capacitors in a power battery cell by combining the capacitive cathode of a supercapacitor and the battery-type anode of Li-ion battery. This results in high charge and discharge rate capabilities suitable for applications with high power needs. Their cathode is also based on wood derived activated carbon making the production more sustainable (98).

Elinor Batteries is an initiative owned by the Norwegian investment company Valinor (99). They are currently developing plans for a giga-scale battery factory in Orkland, Norway, and is aiming to commence the first production module in 2024. As Freyr, Elinor is planning to build the factory in modules to limit financial and technological risk. Achieving full capacity, the goal is to produce batteries equivalent to 40 GWh pr year. Elinor will in the initial phase target the stationary battery market and are therefore focusing on production of LFP-based batteries.

HREINN is another battery cell initiative in Norway. They plan production on a slightly smaller scale compared to Morrow, Freyr and Elinor, with an annual production capacity between 2.5 and 5 GWh at full capacity (100). HREINN will base their batteries on LFP cathodes.

Production of battery packs and systems

As previously mentioned, in addition to the initiatives on cell production, there are a few companies focusing their effort on assembling cells into battery packs and systems. Siemens Energy opened an advanced robotized and digitalized battery module factory in Trondheim early 2019 basing their production on imported cells (101). The fully automated production is mainly targeting the maritime and offshore market and assembles modules with a total annual capacity equivalent to 300 MWh pr year.

Corvus also has long experience with offering solutions mainly for maritime transportation. Corvus was founded in 2009 in Canada and opened offices and production in Bergen, Norway in 2018 (102). Corvus provides purpose-engineered energy storage solutions often in combination with hydrogen fuel cell systems to secure zero emissions for larger vessels. They currently hold a 90% share of the market for energy storage systems in large commercial hybrid vessels and is world leading in all sectors in the maritime industry.

ZEM Energy (Zero Emission Maritime Solutions) also assembles larger modules mainly for drivelines in maritime applications but also larger container-based solutions ideal for Aquaculture Feed Barges and Construction sites. Their headquarters is located at Høvik in Oslo (103).

SCHIVE The Battery Specialist started promoting Lithium Thionyl Chloride (Li-SOCl2) primary cells already in 1980 and has since been a reliable supplier of a wide range of offshore, subsea, military, and industrial batteries. They engineer, design, build and test batteries for optimum performance for any required application. SCHIVE is also located in Oslo (104).

A potential game changer for Norwegian battery manufacturing appeared when the Inflation Reduction Act (IRA) was adopted into American law in 2022. The IRA was implemented to lower the rising inflation in American economy and by investing and offering subsidies to domestic energy production and promotion of clean energy, they attracted many investors abroad. Investors who previously had stated their intentions to build European battery industry, abruptly put their plans on hold and sought their opportunities in the USA. As a response to the IRA the Norwegian government came up with a 5-point strategy to keep green industry from departing (105). Among these, a 1 billion NOK grant for innovation in battery projects was offered as part of the collective EU response to the IRA. The money is to be allocated to promising projects and upcoming technology that through European collaboration reaches maturity for industrial scale production. The government also aims to offer state loans for green projects as well as increase the capital means from the "grønt Industriløft" which is a road map for the green transition in industry. An evaluation of critical value chains for the green shift is also requested by the government in order to map the consequences of a breakdown in the supply chains. The aim is to get an overview of potential trade partners and collaborators and by doing so assessing the risks and how to mitigate them.

Another bump in the road for Norwegian battery production came with the announcement of 10% VAT on EV batteries sold to the UK, produced outside of the EU. The Brexit deal states that from January 1st, 2027, EV batteries must be produced in the UK or within the EU to avoid additional taxation. Batteries produced in Norway will be considered produced by a third party, meaning outside of the EU. This essentially means that Norwegian-produced batteries in EU-produced EVs sold in the UK, will suffer an additional 10% tax (106). This tax was partially the reason for Panasonic, Hydro and Equinor to drop their plans of a joint battery initiative in Norway (107).

Although there are some political and financial hinders for battery production in Norway, it seems that most of the initiatives are still keeping with their plans for producing LIB cells in Norway. It remains to be seen however, how potential financial barriers and better incentives in other countries will affect the Norwegian battery production in the next few years.

Norway's research and research funding potential

Manufacturing of battery cells and systems are areas that have not been explored much by the Norwegian research community until very recently. It is the exponential growth of battery cell manufacturing initiatives in Europe that has accelerated the activities also on the research front. In addition to the NABLA project described below, which funds Norwegian research infrastructure focused on LIB cell manufacturing, development of manufacturing technology is also included in many newly awarded projects. These are all described in more detail below.

↓ Project Name	↓ Project Description	↓ Participants
Battery Coast	The project at UIA aims to strengthen existing battery research efforts. Its main goals include establishing a battery engineering education, conducting forward-looking battery research in collaboration with local industries, and building an active battery community in southern Norway. The project focuses on enhancing teaching and research capabilities in electrochemistry and cell design optimization.	UIA, Morrow, Vianode, Elkem, Equinor, Glencore Nikkelverk, SKF, EYDE-Cluster

SINTEF’s research

NABLA (Norwegian Advanced Battery Laboratory) is a research infrastructure project that establishes state-of-the-art and beyond laboratories to support Norwegian industry and research organisations. The infrastructure is led by IFE, NTNU, SINTEF, UiA, FFI, and UiO as partners. The purpose is to cover research needs and interests in the field of batteries. As a mean to tackle the needs on a national level, the infrastructure is structured into four main technological areas:

1. *Chemistry,* where the focus is on the development of materials, characterization, and chemistry composition.
2. *Validation*, where the focus is on reproducible validation, flexible validation in close-to-industry conditions.
3. *Manufacturing,* where the focus is on streamlining and alternative cell manufacturing and material processing.
4. *Implementation,* where the focus is on lifetime testing and prediction, extraordinary conditions, and disassembly for recycling.

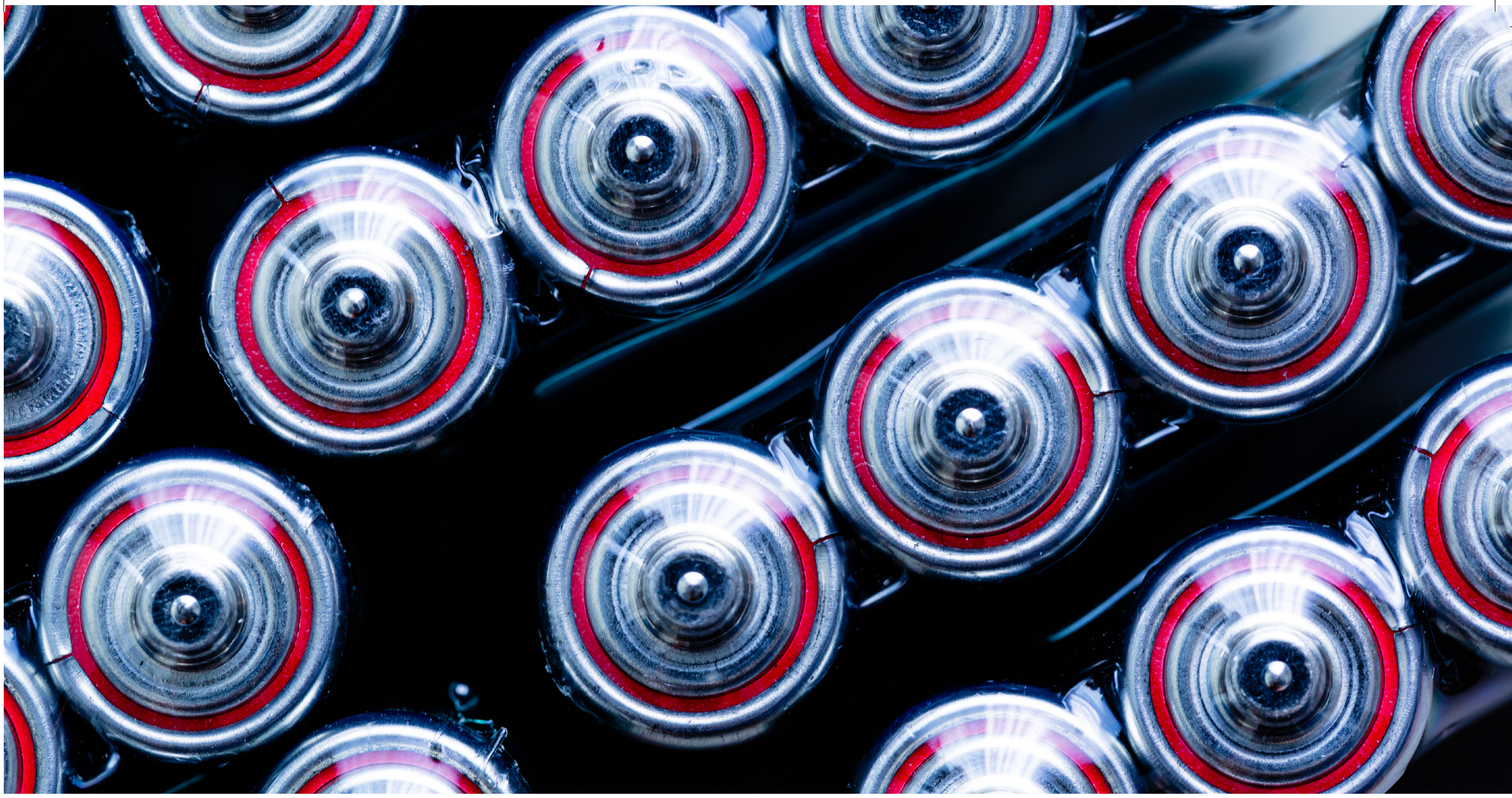
NABLA is an important establishment that ensures that Norwegian R&D has access to highly valuable laboratory that may give major national advancement in a highly competitive and accelerating field.

NorGiBatF (The Norwegian Giga Battery Factories) is a competence project that receives funding from the Research Council of Norway and collaborates with various Norwegian industry partners (108). The project is led by NTNU and involves scientific partners from IFE, SINTEF, and the Technical University of Braunschweig. Notable industry collaborators include FREYR, BEYONDER, NORSIRK, Nordic Mining, and Hydro. Norwegian industries are in the early planning stages of establishing large-scale (GWh) battery cell factories, with the aim of producing batteries for export. This endeavour holds the potential to create new industries in Norway. The core objective of the NorGiBatF project is to support these industries by cultivating expertise in energy-efficient battery cell production. It also seeks to develop a world-leading research environment for industrial battery production within Norway. The project is structured into five distinct work packages, each with a primary focus on aspects related to battery production and factory development:

1. *Life-cycle assessments:* This work package centres on assessing the environmental and sustainability impacts of battery production across its entire life cycle.
2. *Aspects of solvents in electrode fabrication:* It explores the role of solvents in the fabrication of battery electrodes, considering factors related to efficiency and sustainability.
3. *Electrolyte treatment and filling:* This package concentrates on the treatment and filling of battery electrolytes, a critical component in the manufacturing process.
4. *Cell production developments:* It encompasses advancements and innovations in the production of battery cells, a fundamental aspect of battery manufacturing.
5. *Factory building analysis:* This work package is dedicated to the analysis of the infrastructure and facilities required for large-scale battery production.

The NorGiBatF project aims to contribute to the growth and development of the battery manufacturing industry in Norway, fostering expertise, sustainability, and efficiency in battery cell production.

GigaGreen (Towards the Sustainable Giga-Factory: Developing Green Cell Manufacturing Process) is an EU initiative coordinated by Politecnico Di Torino (109). This project is allocated a budget of 4.7 M€ and spans a duration of five years. Its overarching mission is to drive a new era of 3b generation lithium-ion cell manufacturing that prioritizes sustainability and efficiency. GigaGreen introduces a structured research plan aimed at the development and scaling of novel manufacturing processes for electrodes and cell components. This plan employs a “design to manufacture” approach, aligning with the European objective of establishing leadership in the global Li-ion battery value chain. The project places a strong emphasis on minimizing environmental impact and energy consumption while creating cell designs that facilitate re-use and disassembly. By doing so,



GigaGreen seeks to enhance cost-efficiency and reduce greenhouse gas emissions throughout the entire value chain. The project is driven by scalability and automation, aligning with the concepts of Industry 4.0 and 5.0, which are associated with gigafactories. By the project's conclusion, GigaGreen intends to introduce a set of novel materials, encompassing binders, electrolytes, separators, cathodes, and anode active materials. These materials are developed in conjunction with innovative dry and wet electrode processing techniques. Additionally, the project incorporates data-driven digital twins to enhance the understanding and control of the manufacturing processes. GigaGreen represents a significant effort to advance the sustainability and efficiency of lithium-ion cell manufacturing, contributing to the global transition toward greener and more responsible energy storage solutions.

BATMACHINE (Boosting Europe's sustainable battery cell industrial manufacturing value chain by developing an optimised machinery with intelligent control processes to minimise costs, scrap and energy consumption) is and EU project coordinated by Vrije Universiteit Brussel and funded through HORIZON EU with a total cost of 7.2 M€ (110). The main goal for BATMACHINE is to strengthen Europe's battery cell industrial manufacturing value chain by developing new battery cell manufacturing machinery. Increasing energy efficiency in production, reducing scrap rates, and enhancing plant efficiency rates will be achieved through development and implementation of an optimised and energy-efficient process chain. Parts of the battery manufacturing process that will be considered are slurry mixing, electrode coating and drying, as well as calendaring. Additionally, intelligent control processes and Industry 4.0 will be integrated through the creation of a collaborative and FAIR data space for battery production.

BATNET (Norwegian Battery Packing Network) is a large project funded through Green Platform with Kongsberg Klyngen as coordinator. The total budget for the project is 135 MNOK, while 70 MNOK comes from public funding (Innovation Norway, Norwegian Catapult, Research Council of Norway, and SIVA) (111). SINTEF participates in the project through its branch in Raufoss. The main goal for this large-scale project is to ensure Norwegian's position in the global battery value chain, which will accelerate the national green transition. Expected results from the project includes establishing a full-scale infrastructure for piloting and demonstration of automated production and recycling of complex battery systems, develop state of the art battery packs for the maritime market, and document profitability for Norwegian production of battery packs/systems with transfer of knowledge to other industry sectors.

In addition to the projects described above, the two projects **SUMBAT** and **BronzeTitan** also have elements of battery cell manufacturing. These two projects are described in more detail in a previous section.

5. Battery application – transport

Norway's position

The transport sector is responsible for almost 1/3 of the Norway's emissions of greenhouse gases (112). As part of the Norwegian government's plan to achieve the climate goals a set of means of action was implemented in the national transport plan for 2018-2029 and carried forward for the 2022-2033 update (113). The aim is to have all new private and light duty transport vehicles as zero emission vehicles by 2025. All new city buses should have zero emission or running on biofuels by 2025 and within 2030 all new heavy-duty vehicles, 75% of all new long-distance buses and 50% of all new trucks should be zero emission vehicles. For retail and distribution in the largest city centres no emissions should be allowed beyond 2030.

With access to relatively cheap renewable energy, as well as targeted incentives from the government, Norway has been a pioneering country for the electrification of transport. Currently Norway has the largest share of electric vehicles per capita in the world (114). The majority intuitively belongs to the private consumers, but the number of companies aspiring into the green shift taking advantage of the evolving battery market is also accelerating. Adapting to the means set out by the government, the public transport sector in the largest cities has been diligent and particularly in Oslo. Ruter is responsible for the public transit system in Oslo including buses, trams, subway trains and the boats servicing the small islands from the city harbour. By December 2023 virtually all their operational buses are running on batteries just as their passenger boats have been since 2022. Norled is operating the connection between the city harbour and Nesodden and the three ferries Kongen, Dronningen and Prinsen have been rebuilt to run fully on batteries. In Trøndelag, AtB is responsible for the public transportation. Although not fully electrified, more and more of their buses are running 100% electric as well as having several hybridized vehicles. A contract has been signed with Norled to operate the Trondheimsfjord with fully electric passenger boats from 2024 and the two most trafficked ferry-connections operating in the same fjord are hybridized. The ferries have stepwise increased their battery capacity and were in 2022 operating 91% and 69% on electricity, respectively (115). In Bergen DSD AS, the owner of Tide AS, is responsible for the buses in the city centre and more than 80% are running electric (116). Also, in the regions outside the largest cities, operators have started investing in electric public transportation as exemplified by Nobina in the previous Østfold county (117).

Logistics is also a major part of the transport sector and several of the largest actors have implemented electric vehicles in their services. ASKO is one of Norway's largest transport companies and handles groceries for Norgesgruppen as well as being a supplier for many restaurants. They were the first to implement electric trucks for distribution in Norway and have today a significant part of their utilities running on batteries. The company also invested in the world's first autonomous electric sea-drone vessel which is transporting goods across the Oslofjord. The company Posten Bring is a Nordic corporation delivering services within post and logistics. They are currently servicing half of the Norwegian population using electric vans and trucks and are continuously expanding their charging infrastructure to support long distance transport (118).

In aviation electrification appears to be quite a challenge, and further technological development is required before we see significant degree of electrification within aviation. However, there are a few actors trying to find solutions. The Norwegian airline Widerøe and Rolls-Royce Electrical Norway have for several years been working together on a vision to operate battery powered airplanes. Because today's battery technology has limited energy density the possibilities are limited to only short distance flights with very few passengers. Still, Widerøe foresees market possibilities for passengers wanting to access areas that are outside the traditional routes. In 2023 the company signed an option agreement to buy 50 small fully electric "helicopter-planes" and together with the hotel group Strawberry and the innovation company Seabrokers, they plan to provide revolutionary traveling experiences, accessing areas that would otherwise be challenging to reach (119).

As previously mentioned, several of the seaway connections in Norway are operated by hybrid or electric vessels and the major operating companies are Norled, Boreal, Fjord1 and Torghatten. According to Norsk Klimastiftelse approximately 25% of all passenger and ferry-connections is of July 2023 running partially or fully electric (120). Color Line AS is Norway's largest cruise- and transport companies and offers travels and transport to Sweden, Denmark, and Germany. As part of their effort to reduce carbon emissions the plug-in vessel Color Hybrid was put into operation in 2019 and was provided with a 5 MWh battery (121). This is sufficient for the ship to sail fully electric within about 1 hour from the harbours at each side, thus reducing the local emissions near the coast.

Many of the ferries and boats operating in Norway are designed, constructed, or rebuilt by shipyard companies in Norway. Ulstein Verft, Brødrene Aa, and Fiskerstrand Verft are all stakeholders deeply invested in making electrically powered vessels possible. Ulstein provides solutions for hybrid power operations and charging as well as onboard battery feasibility studies. Brødrene Aa constructs and rebuilds high speed passenger ferries exemplified by MS Baronen and Baronessen (122) and Fiskarstrand Verft offers solutions for rebuilding from diesel and LNG to battery operation (123). Selfa Arctic is another company whose main occupancy is maintenance and repair of recreational- and profession boats, but also construct new coastal fishing vessels equipped with battery propulsion (124). Evoy also provides electric boats, both for recreational purposes as well as vessels for the fish farming industry (125). They are in competition with Moen Marine who is one of the world's largest suppliers of vessels for the fish farming industry and uses the before-mentioned ZEM Energy as battery provider (126). One of the companies who also provide battery systems for large ships is ABB. They started offering containerized energy storage systems in 2021, which are tailored for container ships, offshore supply vessels, and ferries (127).

Norway's research and research funding potential

Within application of batteries for transportation, the majority of the research in Norway has been related to the maritime industry. As also outlined above, companies involved in water-born transport have been actively implementing batteries, either as hybrid or fully electric vessels. This has given Norway a world leading position in this field. Naturally, the research has also been focused in that area. With SINTEF Ocean as the spearheads in this sector, with involvement of some other SINTEF institutes, the majority of the research also involves SINTEF to some extent.

↓ Project Name	↓ Project Description	↓ Participants
EMPOWER	Sustainable Batteries in Mobility- (Em)powering a Net-zero Energy Transition is taking interdisciplinary research and education perspectives to investigate the role of electric vehicle (EV) batteries in enabling a sustainable net-zero energy transition in Norway	UiO

SINTEF's research

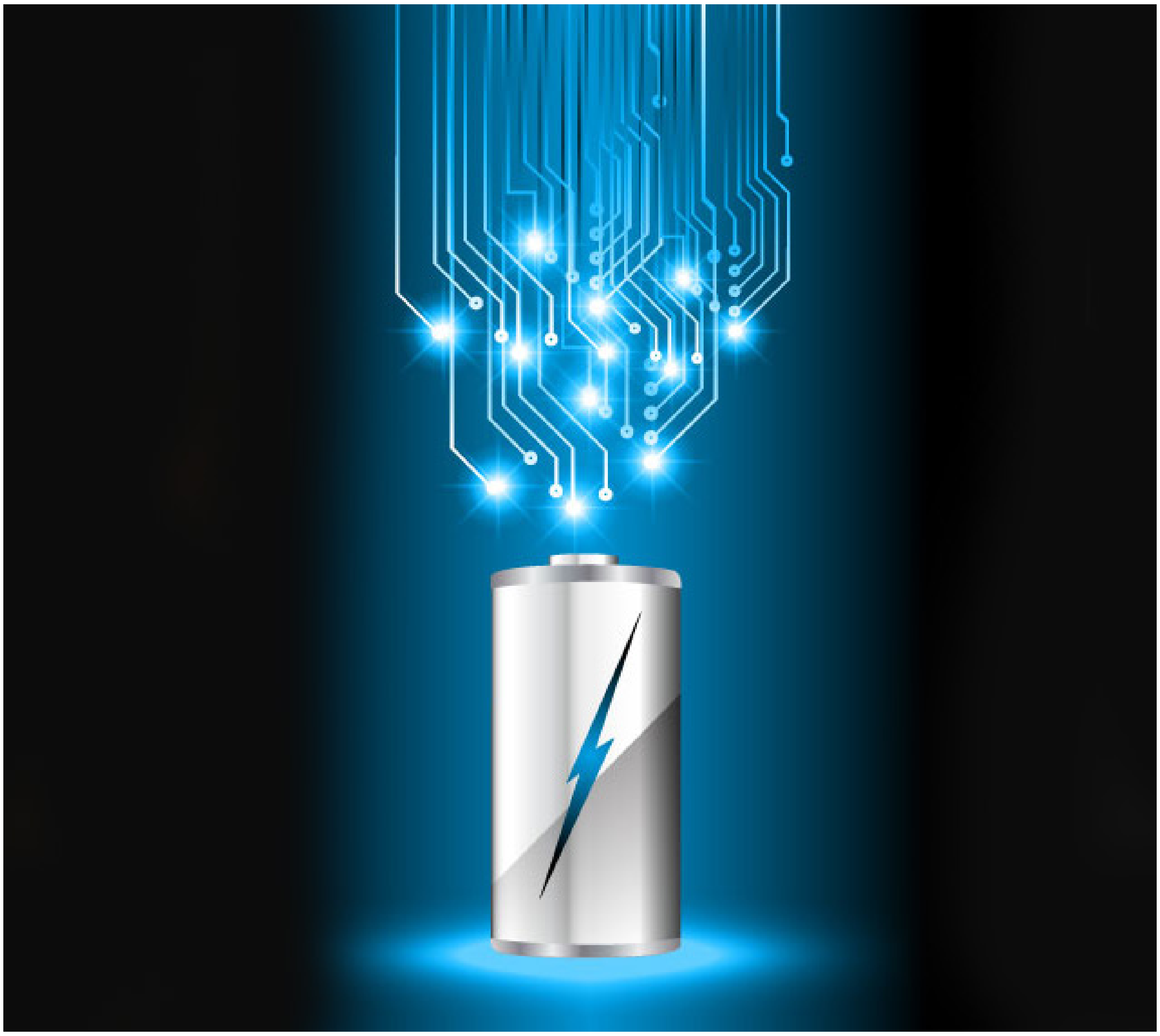
ElMar (Electrification of Maritime Transport and Ports for the Future) is an innovation project partially funded by the Norwegian Research Council under the ownership of the Trondheim Port Authority, with collaborative partnerships spanning various sectors including port authorities, grid companies, energy companies, and ship-owners. The primary objective of ElMar is to thoroughly investigate and chart the challenges associated with electrifying the maritime transport sector. The overarching aim is to reduce emissions by facilitating the adoption of shore power and battery facilities within this domain. The project seeks to assess how integrated energy systems and novel business models impact the attractiveness of developing, operating, and utilizing shore power and battery charging infrastructure. This comprehensive investigation encompasses an understanding of the effects of such facilities on the electrical grid and its components, thereby addressing technical barriers. ElMar, through its robust consortium of relevant stakeholders spanning the entire value chain, is poised to make significant contributions to the holistic electrification of maritime transport. The project is structured around four key research domains: (1) integrated energy systems; (2) component stress analysis; (3) business model innovation; (4) case studies. ElMar emphasises the importance of innovation and knowledge in the maritime industry.

OMB6 (Optimizing marine battery operations), an innovation project partially funded by the Norwegian Research Council and owned by Equinor, involves a consortium including Havila Shipping AS, Corvus Energy, IFE, and SINTEF. Its primary goal is to optimize marine battery operations by leveraging operational data from two currently active battery-powered vessels. In light of the financial pressures faced by numerous Norwegian ship owners during their transition towards environmentally friendly practices, OMB6 seeks to enhance the benefits derived from operating marine battery vessels by achieving a 5-10% improvement. Three main activities are suggested to achieve this: firstly, a new integrated marine battery operation model with three new marine batteries operational modules, are suggested to improve the current operational models. For this activity, large amounts of already existing data are required for analysis to study where most improvements could be made. Marine battery degradation diagnosis and lab testing will also be included in this activity. Secondly, testing of new optimized operational strategies has been planned for two commercially operating offshore supply vessels. Thirdly, roadmaps will be outlined to enhance investors and potential investors confidence in the technology and to facilitate further installations of marine batteries in vessels. This activity will also provide a cost benefit analysis and explore cross sectorial synergies.

EXPECT (Complex extruded aluminium profiles for BEV battery protection system), an industry project with partial funding from the Research Council of Norway, is a collaborative effort led by Benteler Automotive and Hydro, with the participation of NTNU and SINTEF (128). This project is centred on addressing the critical aspect of battery tray protection systems for the electric vehicle market. In the context of electric vehicles, battery protection systems encompass all components surrounding the battery that safeguard it and the surrounding environment in the event of an impact. These systems are becoming increasingly pivotal as the electric automotive industry continues its rapid expansion. The primary objective of the EXPECT project is to develop optimization schemes for aluminium alloys with a focus on three key aspects. Firstly, the project aims to enhance the extrudability of aluminium alloys, making them more amenable to the complex manufacturing processes involved in creating battery protection systems. Secondly, the project endeavours to improve the materials and design to enhance the system's ability to withstand impact and protect the battery effectively. Lastly, the project also concentrates on optimizing the design functionality of complex multi-chamber profiles, ensuring they meet the specific requirements of battery protection systems. The consortium, composed of industry leaders and research institutions, will collaboratively acquire the necessary knowledge and expertise during the project's duration. Subsequently, the project owners, Benteler Automotive and Hydro, plan to commercialize the technology in the coming years by implementing it in specific customer projects.

Ocean Charger - Maritime value chain for offshore energy transfer within offshore wind is an innovation project awarded 38 MNOK from the Research Council of Norway through Green Platform, with a total budget of around 80 MNOK (129). The project is led by Vard Design and have multiple strong industry and R&D partners. The primary objective of Ocean Charger is to conceive, develop, and demonstrate an innovative offshore charging solution tailored for battery-powered maritime vessels. This aligns with the broader goal of enabling zero-emission operations for maritime vessels in offshore wind parks. As a key outcome, the project aims to provide a blueprint for the scaling up and commercialization of large-scale solutions, ultimately expediting the transition toward eco-friendly practices within the maritime sector. In essence, Ocean Charger represents a significant step toward accelerating the green transformation of the maritime industry by pioneering offshore charging solutions for battery-driven vessels, and simultaneously, offering a pathway for the adoption of zero-emission vessel operations in offshore wind parks.

Sea Zero is another project funded through the green platform initiative and was awarded 67 MNOK, with a total budget of around 123 MNOK (130). This project is owned by Hurtigruten Norway and enjoys the participation of a diverse consortium comprising esteemed research institutions and industry partners. The primary mission of the Sea Zero project is to pioneer the development and demonstration of a zero-emission vessel for Hurtigruten by the year 2030. Through this ambitious undertaking, the consortium aims to showcase the feasibility and viability of sustainable passenger and cargo transportation along coastal routes. The project has three main areas to be studied: (1) development of energy efficient design for zero emission large ships; (2) zero-emission energy systems; (3) optimizing route patterns and charging infrastructure.



SEABAT (Solutions for large batteries for waterborne transport) is funded through the HORIZON 2020 programme and has a duration of 4 years (131). The project is coordinated by FLANDERS MAKE and has a budget of 9.6 M€. This initiative is aligned with the global trend in the transport sector, which is actively striving to reduce emissions through electrification. SEABAT draws inspiration from the automobile manufacturing sector, where most suppliers have fully electric vehicles into their portfolios. However, in the context of maritime propulsion, particularly for larger vessels, the battery sector is not yet as mature. To overcome this challenge and expedite the electrification of the maritime industry, SEABAT adopts a novel approach: combining modular high-energy batteries with modular high-power batteries. This combination seeks to provide vessels with the advantages of both worlds in terms of energy and power requirements. One of SEABAT's central research areas is the optimization of battery sizing, tailored specifically to the needs of vessels. The goal is to determine the most efficient configuration and size of battery modules, optimizing operations while minimizing investment costs. Additionally, SEABAT explores innovative converter concepts, including distributed, partial power conversion, and cell-level switching. This includes the development of battery management systems and algorithms for precise control at the module- or cell-level. Overall, the SEABAT project's mission is to expedite the electrification of the maritime sector by addressing crucial aspects such as battery topology and the production process. By integrating modular high-energy and high-power batteries and optimizing battery sizing and conversion techniques, SEABAT aims to drive the adoption of electric propulsion in the maritime industry, contributing to reduced emissions and a more sustainable future for water-borne transport.

BATMAX (Battery Management by Multi-Domain Digital Twins) is an EU project funded under the HORIZON Europe program (132). The project spans a duration of four years and has a budget of 5 M€. Coordinated by VTT, it boasts a consortium of strong industry partners and renowned research institutes, including SINTEF. The primary objective of BATMAX is to enable advanced, adaptable battery management systems for the next generation of batteries, serving the requirements of both mobile and stationary applications. The project's overarching goal is to contribute to the enhancement of battery system performance, safety, reliability, service life, and cost efficiency. To achieve these objectives, BATMAX proposes a comprehensive framework for battery management. This framework integrates extensive data from various sources, including experimental data, operational data, and synthetic data. It leverages adaptable physics-based models and suitable reduced-order models to develop physical battery management system algorithms and multi-scale digital twins. By implementing this framework, BATMAX aims to create an efficient process for parameterizing physics-based models. This process will play a crucial role in reducing the cost of model development and, in turn, increase the utilization of these models within battery management systems. In essence, BATMAX represents a significant step toward improving the management of batteries for various applications, leading to enhanced performance, reliability, and cost-effectiveness.

FME MoZEES (described in a previous section) is also relevant for application. Research areas 1 and 2 mainly focus on the material and key component sector, while research area 3 is working on system integration and applications. For more information on the project, refer to Advanced materials – SINTEFs research.

6. Battery application – stationary

Norway's position

Although the battery revolution is seemingly propelled by the EV market, stationary storage is also gaining momentum. The increased electricity consumption induced by the green shift and the incorporation of renewable energy resources into the electric grid increases the demand for energy storage to ensure reliable power supply, grid resiliency, and reduced costs for both grid operators and customers. Long-duration stationary energy storage enables efficient utilisation of intermittent renewable energy and reduce the CO2 emissions incurred by the fossil-fuel based power and heat generation. Many of the Norwegian grid- and power companies are therefore heavily engaged to find integration pathways for energy storage. In 2023 Tensio, the grid company responsible for the region of Trøndelag, initiated together with Eidsiva Energi and their subsidiary company Peak Shaper a pilot test using a stationary 1 MW battery to support the undersized grid at Jule industrial park in Lierne municipality (133). The installation is first of its kind in Norway and enables stability of production among industry, power access for new consumers as well as saving time and cost for an otherwise grid capacity expansion. The pilot is part of the large-scale demonstration project IDE which is partly funded by ENOVA (134). Another ENOVA supported project is NORFLEX in which a stationary battery is installed at the new energy station at Kongsberg-porten. Here, Glitre Energi (now part of Å Energi) and Circle K are investigating how a stationary battery together with solar power can support the grid during periods with high load (135). TrønderEnergi, Ren Røros, Equinor and Powel also joined forces in a project in 2020 to create a large-scale test arena for new energy and climate technology and innovative energy systems at Røros (136). Late in 2021 Hafslund Eco commissioned their first battery supporting peak shaving for 300 apartments in Sandaker condominium (137). The previous Agder Energi (now also part of Å Energi) is also one of the main stakeholders for the Morrow Battery factory which will provide stationary batteries in the near future.

The installation of solar power from photovoltaics often comes with a solution for energy storage. Several companies in Norway are now providing solutions where the costumer can sell stored energy back to the grid. Otovo is a company that organizes a network of qualified solar installers which together with suppliers offers complete solutions for the private market. One of these companies is Solcellespesialisten who uses Pixii as one of their subcontractors for battery storage. TGN Energy is a company that targets energy management solutions for commercial real estate. Providing the physical microgrid and services for energy storage they give the customer opportunity to trade energy. In 2022 TGN together with partners commissioned a 1 MW battery coupled with 1700 solar panels at Revacs recycling facility in Linnestad (138).

Another Norwegian substantial stakeholder in the stationary battery market is Eltek. Headquartered in Drammen the company has customers in more than 100 countries across a variety of industries including telecom, rail and infrastructure, power generation, power distribution and solar energy (139). Other companies offering large stationary energy storage solutions are Corvus and Siemens Energy. Their target market area is maritime applications. However, they also deliver stationary battery systems. Aneo, a company owned by TrønderEnergi, 19 municipalities in Trøndelag, KLP, and HitecVision, provide stationary battery solutions particularly for construction sites to enable zero-emission construction. These are containerized battery systems on wheels which can be moved from site to site (140). Nordic Booster provides similar solutions to Aneo with mobile high-power charging systems with integrated battery technology and energy management systems on wheels (141).

In the stationary energy storage sector, it should also be mentioned the companies described in a previous section for reuse and repurposing of batteries. Nearly all these companies, including Eaton, Hagal, Eco Stor, Evyon, and Chainpro deliver battery systems for the stationary energy market. Examples of buildings with battery systems delivered by Eco Stor are Holmlia Skole, Tiller videregående skole, and Skipet, while Eaton has delivered the battery system located at Bislett Stadium.

Norway's research and research funding potential

Research within stationary energy storage has only recently gained momentum for LIBs. Previously, other battery technologies and stationary storage solutions have been preferred. However, with the reducing cost of LIB and increased availability and safety, the market has increased several-fold, and so has the R&D&I efforts to go with it. Although, several research groups in Norway are involved in this area, SINTEF is involved in nearly all the projects in the current project portfolio. Relevant projects are described in more detail below.

↓ Project Name	↓ Project Description	↓ Participants
Smart Platform	**Efficiency increase and emissions reduction in offshore O&G platforms by wind generation, storage deployment and cooperative control** Smart Platform will investigate how energy storage and cooperative control strategies can affect energy efficiency and greenhouse gas (GHG) emissions in a typical offshore oil and gas (O&G) platform and identify technical solutions required to mitigate the impact of off-shore wind integration into the platform's electric network. Smart Platform will investigate how to minimize their use by supplying part of the required power by offshore wind turbines, energy storage devices or a combination of both. The project, led by NTNU, will work on realistic test-cases, based on a close synergy between the Norwegian partners (Equinor, ABB, and SAFT) and two leading Brazilian Universities (Sao Paulo State University and Federal University of Minas Gerais).	NTNU
NeX2G	The project will investigate the potential magnitude and economic sustainability of flexibility available to the energy system from long-term parking of electrical vehicles (EVs) and commercial building assets. Bidirectional EV chargers will be installed at Gardermoen airport together with devices to collect real time data on operation and control of chargers and selected building assets. Machine learning algorithms will be used to predict the flexibility based on the collected data and experience with seamless exchange of energy, grid and flexibility services collected.	NMBU, MINA, REALTEK, and industry partners

SINTEF's research

BaSS (Electrochemical battery for voltage support in distribution grid) is an innovation project for the industry sector, which is funded by the Norwegian Research Council and the industry partners and is owned by ENERGI NORGE AS (142). This four-year project aims to facilitate the use of battery energy storage systems as an alternative for voltage support in distribution grids when it is economically and socially viable to do so. One of the primary challenges in achieving this goal is the presence of various voltage support services that could potentially be relevant for the same power grid, a concept known as "value stacking." To address this and related challenges, the BaSS project is organized into four distinct work packages:

1. Battery Energy Storage Systems as Grid Services: This phase focuses on studying the conditions under which BESS can be effectively employed for voltage support and when their value might be limited. The aim is to determine the circumstances in which battery energy storage systems can provide optimal voltage support.
2. Operation Strategies and Communications: This work package involves conducting simulations to investigate operational strategies and communication methods. The findings from this phase will directly inform the first work package, refining the understanding of how battery energy storage systems can be utilized for voltage support.
3. Testing battery energy storage systems for Voltage Support: The project includes real-world testing of battery energy storage systems for voltage support in a Smartgrid-lab. This phase will involve demonstrating voltage support and testing operational strategies for addressing both single and multiple voltage-related issues.
4. Methodology Development: The final work package focuses on developing a methodology for assessing and specifying the use of battery energy storage systems for voltage support. This methodology will be crucial for grid companies in making informed decisions regarding grid upgrades versus utilizing BESS for voltage support.

Ultimately, BaSS seeks to advance the utilization of battery energy storage systems for voltage support in distribution grids, offering an alternative to traditional grid reinforcement. By addressing the complexities of value stacking and developing operational strategies, this project aims to provide valuable insights and tools for grid companies to make informed decisions about optimizing their grid infrastructure.

SafeBESS (Technology and building design for safe operation of battery energy storage systems) is a competence and knowledge building project funded by the Norwegian Research Council and industry partners and spans a duration of four years (143). This project is dedicated to addressing safety concerns associated with large battery energy storage systems coupled with intermittent renewable energy sources, such as Li-ion batteries, to mitigate the risks of thermal events and fires. While such incidents involving Li-ion batteries are infrequent, there exists a knowledge gap concerning the safe and practical implementation of large battery energy storage systems in both small and large buildings. In response to this challenge, SafeBESS seeks to minimize this knowledge gap through a comprehensive study of battery fires, their proper handling, and the secure integration of battery systems. This will be done though fire experiments on cell and module level, and then through numerical simulations, the data from these experiments will be extended up to large systems, without the risk and cost of large-scale experiments. There will also be done testing on construction materials to reveal integrity issues and other weaknesses in current building materials. The accumulation of data and findings from SafeBESS is anticipated to form a solid foundation for the development of guidelines and best practice recommendations for the secure implementation of battery energy storage systems in buildings. Furthermore, the information generated through this project may contribute to the formulation of new regulations and laws governing the installation of these systems, enhancing safety standards across the board. SafeBESS aims to promote the responsible and safe integration of BESS into our energy infrastructure while mitigating potential risks.

FlexBuild (The value of end-use flexibility in the future Norwegian energy system) is a four-year competence building project funded by the Norwegian Research Council in collaboration with industry partners (144). This initiative brings together research and industry experts from the building and energy sectors, along with governmental bodies, to investigate the role of end-use flexibility in the future Norwegian energy system. The core focus of FlexBuild is to analyse the flexibility inherent in building structures and how it impacts the design of future energy systems in the context of Norwegian conditions. Energy systems within buildings can be quite intricate, encompassing aspects such as load flexibility, local heat storage, various heating technologies, panel ovens, remote heating, heat pumps, and bioenergy. The project also delves into the electric flexibility offered by building-integrated photovoltaics and batteries. FlexBuild has emerged from the recognition of the need to model these complex energy systems and understand the interactions between different components. This understanding is crucial for optimizing energy usage, which, in turn, has significant implications for investments in future energy systems and their operational efficiency. These investments may involve various elements such as wind power, building heat pumps, batteries, and more, while the operation of these systems may include aspects like water resource utilization and energy trading with Europe. Within FlexBuild, the project aims to explore the cost-optimal implementation of user flexibility, taking a socio-economic perspective into account. The research will initially focus on individual building-level analysis and will subsequently scale up to a national level, providing insights into how end-use flexibility can be effectively harnessed to optimize energy systems for future Norwegian conditions. This project has the potential to inform the development of more flexible and efficient energy systems, contributing to sustainable energy practices in Norway.

FME CINELDI, a centre for environment-friendly energy research, is a significant initiative dedicated to the exploration and advancement of various aspects of energy distribution systems, particularly in the context of electricity grids. With a substantial budget of 160 MNOK and a duration spanning 8 years, CINELDI is led by SINTEF and comprises a consortium of distinguished research institutions, power grid companies, system operators, power market operators, and technology providers, with authorities also contributing to the collaboration. The primary objectives of CINELDI encompass:

- Studying the Electricity Grid of the Future: CINELDI is committed to investigating and developing concepts, technologies, and solutions that align with the vision of a modern, efficient, and resilient electricity distribution grid.
- Digitalizing and Modernizing the Grid: A core focus of the project is the digitalization and modernization of the electricity distribution grid. This effort seeks to enhance efficiency, flexibility, and resilience within the grid.
- Cost-Efficient Realization: CINELDI aims to facilitate the cost-efficient realization of flexible and robust energy distribution systems, ensuring that the solutions developed are both economically viable and sustainable.

Within the CINELDI framework, numerous research, innovation, and pilot activities are being undertaken. Some notable innovations include the BATTPOWER toolbox, comprehensive classification and characterisation of flexible resources, energy storage and renewable energy system representation in multi-period optimal power flow, EV power share charging system, flexible load analysis, and simulation tool for reliability assessment of modern distribution systems (RELSAD). Additionally, CINELDI has embarked on several noteworthy pilot projects: Utsira: NODES flexibility platform, an islanded grid on an island, batteries as voltage support, optimisation of local balancing with battery, transition to and from island mode, fast frequency reserve, system for use of flexible resources. For more in-depth information about the innovation, research, and pilot projects conducted within CINELDI, interested parties can refer to the FME website (145), where detailed insights into the initiatives can be found. CINELDI represents a significant collaborative effort aimed at shaping the future of energy distribution systems, driving advancements in technology, efficiency, and sustainability.

StoRIES (Storage Research Infrastructure Eco-System) is a four-year project funded through the Horizon 2020 program and led by KIT (Karlsruhe Institute of Technology). With a budget of approximately 70 MNOK, this project places a strong emphasis on energy storage and its pivotal role in the ongoing energy transition. Recognizing that no single technology currently available can fully address the multifaceted challenges of energy storage, StoRIES takes a comprehensive approach. It focuses on exploring the combination and synergies between various energy storage technologies. This includes the development of new materials and the creation of hybrid energy storage solutions that integrate multiple technologies. One of the key objectives of StoRIES is to establish a world-class research infrastructure network that provides users with access to cutting-edge facilities and expertise in the field of energy storage. This collaborative environment will foster the exchange of ideas and knowledge among energy storage experts, facilitating the exploration of innovative solutions. In addition to its research infrastructure network, StoRIES is dedicated to offering training and educational materials for both industry professionals and researchers. This educational component extends beyond technical aspects and covers a wide range of topics, including ecological, legal, economic, and social dimensions related to energy storage. In summary, StoRIES is a forward-looking project that recognizes the vital role of energy storage in the energy transition. By promoting collaboration, research, and the development of new materials and hybrid solutions, StoRIES aims to contribute to the advancement of energy storage technologies and their integration into sustainable energy systems.

MultiStore is a researcher project which aims to develop control and operation strategies for battery energy storage systems (BESS) and hydrogen energy storage systems (HESS) with the aim of maximizing their socio-economic benefits to further facilitate more VRES in the power grid (146). Operation algorithms for both the owners (bottom-up) and the grid operators (top-down) will be developed and used to get a better understanding of the incentives required to deploy and combine different energy storage technologies.

ZEESA (Zero Emission Energy Systems for the Arctic) is a competence and knowledge building project focusing on design and operation of thermal-electrical integrated energy systems in the Arctic (147). These systems should be energy- and cost-efficient at same time as they ensure a high security of supply for arctic settlements, thus accelerating the zero-emission transition of the societies. ZEESA will combine improved meteorological models for available renewable energy resources with well-defined field studies of PV systems and provide beyond state-of-the-art competence on the relationship between weather conditions and the productions potential from PV in the Arctic. The coupling of this competence with identification of new and improved solutions for utilizing the thermal energy generated as waste-heat in the energy system will provide essential input for designing robust and cost-effective energy systems for arctic settlements while maintaining security of supply. The project will also evaluate the potential for utilizing thermal energy produced from energy storage in batteries and hydrogen, and electrochemical batteries will be implemented in the system models. The project is a collaborative effort between SINTEF AS, SINTEF Energy, UNIS and CICERO in addition to Store Norske Energi AS, Statkraft AS and Longyearbyen local municipality.

FRIC – Fire Research & Innovation Centre is a research collaboration between RISE Fire Research, NTNU and SINTEF with partners from the fire and rescue service, the public sector, consultancy engineers, manufacturers of building materials and building installations, as well as within real estate development and management (148). The main objective of the centre is to increase knowledge within the field of fire science in order to support decisions and develop better solutions providing increased fire safety in buildings. FRIC strengthens cooperation and leads to a long-term increase of competence and dissemination of knowledge within the fire safety field. The research is organized into four work packages:

1. Evidence-based decision-making within fire safety
2. Fire dynamics and modelling
3. Building Technology and design
4. Fire safety measures and new technology

A significant activity in FRIC is also evaluating fire safety of battery energy storage systems in buildings, and RISE Fire Research conducts experiments both at their facilities in Trondheim and in collaboration with RISE in Sweden.

eNeuron (Green energy hubs for local integrated energy communities optimization) is a project funded through HORIZON 2020 and coordinated by ENEA, with SINTEF as partner. The total project cost is 6.3 M€, of which 5.7 m€ comes from H2020 funding (149). The main goal of eNeuron is to develop innovative tools for the optimal design and operation of local energy communities (LECs) integrating distributed energy resources and multiple energy carriers at different scales. This goal will be achieved, by having in mind all the potential benefits achievable for the different actors involved and by promoting the Energy Hub concept, as a conceptual model for controlling and managing multi-carrier and integrated energy systems in order to optimize their architecture and operation. The project comprises 17 European partners, including Skagerak Nett AS, which will host a pilot study at its PV installation "Skagerak Energilab".

7. SINTEF in the European battery community

Battery technology is essential to meet Europe and Norway's zero emission targets by 2050 because this will facilitate the decarbonization of the European energy and transport sectors. At SINTEF, we are deeply involved in the development of the European R&I Battery Eco-system with engagements and active contribution to most key networks and projects. This is also evident from the large number of projects that are described in the previous sections, and the European collaborative arenas are vital for SINTEF in all parts of the battery value chain.

The European Battery Value Chain

The European Union has established support tools, mechanisms, and networks to foster the rapid growth and upscaling of the European battery industry across the entire value chain. A value chain expected to directly employ 1.3 million Europeans by 2030. Research and Innovation are a cornerstone of this development, essential to ensure European battery production and usage are both competitive and sustainable. At SINTEF, we have for the last decade, made it a priority to influence and help develop the European R&I agenda for batteries, ensuring research and innovation provides Europe with the competitive and sustainable batteries needed to succeed in the energy transition.

There are concerted efforts made by the leaders of the battery R&I initiatives to communicate, collaborate and avoid duplication. This effort ensures that all parts of the battery value chain and cross cutting issues are addressed from education to new business models and from fundamental interface modelling and digitalisation right through to battery integration and recycling.

At SINTEF we are specifically involved with the following topics:

- Development of the European Strategic Research Agenda for Batteries in Europe
- Contributions to the European and National roadmaps concerning the battery value chain
- Organising collaboration activities between stakeholders e.g. webinars, workshops
- Providing an overview of the R&I opportunities in Norway and in Europe
- Building collaborative projects to serve the industry's research needs

SINTEF has significant roles in the following initiatives, alliances, and organisations:

- **Batteries Europe ETIP** (https://energy.ec.europa.eu/index_en): An EU supported initiative, with the aim to accelerate the establishment of a globally competitive European battery industry, driving the implementation of battery-related research and innovation actions of the Strategic Energy Technology (SET) Plan and the Strategic Transport Research and Innovation Agenda.

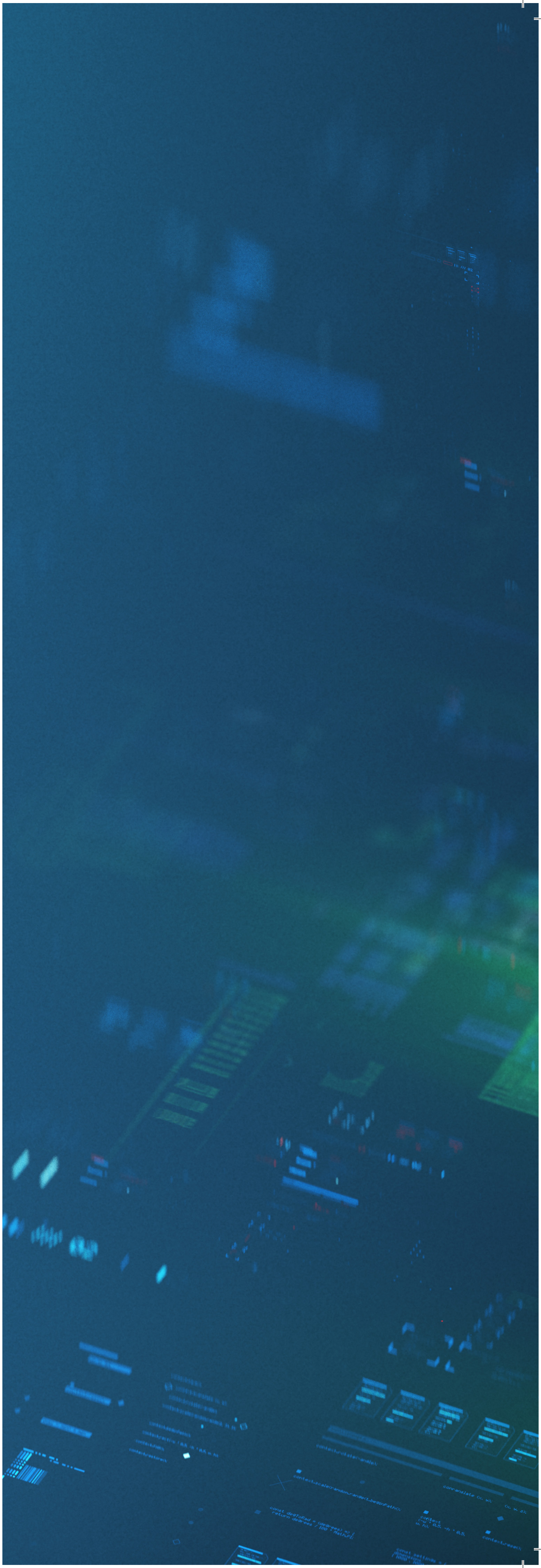
- **Batteries European Partnership Association - BEPA** (https://bepassociation.eu/): This entity is the private side of a public-private partnership called Batt4EU. Batt4EU develops and publishes the Horizon Europe calls. BEPA significantly contributes to the development of the calls and gathers information concerning the development of the sector and progress within ongoing projects. Along with Batteries Europe ETIP, BEPA produces a joint Strategic Research Agenda on Batteries for Europe. BEPA strive towards creating research and development to enable a competitive European industrial battery value chain for e mobility and stationary applications.

- **Battery 2030+** (https://battery2030.eu/): A large-scale research initiative initiating the first phase of inventing the sustainable batteries of the future. Out of this initiative has come the development of several ambitious low TRL projects including development of Battery Interface Genome – Materials Acceleration Platform and several projects on self-healing and sensors for batteries. The Battery 2030+ project has monitored progress on these new initiatives and has been a forerunner in Europe for developing new bold novel concepts in battery technology from direct recycling to materials and interface design.

- **The European Battery Alliance** (https://www.eba250.com/): The purpose is to accelerate the development of the industry establishment in Europe and to provide solid information about the progress of the battery market globally. Their activities also include both financing and providing guidance for companies, in particular for start-ups, across the entire battery value chain. One of the main focus areas for the EBA is to develop a competitive and sustainable battery cell manufacturing value chain in Europe.

- **EERA Energy Storage** (https://eera-es.eu/): EERA is the pan-European programme to bring together all major fields of energy storage research. The Energy Storage working program was established ca 20 years ago. One of the subprograms is focused on Electrochemical energy storage. JPES therefore represents a unique opportunity to align research and development and to develop cross cutting topics such as hybridisation of energy storage.

In addition to those listed above, SINTEF has also recently become involved in the Upcell Alliance (https://upcell.org/) which is a non-for-profit European battery manufacturing alliance striving to create a unique European ecosystem of actors in the equipment and machinery for battery manufacturing industry stronger together, aiming to give Europe a leading position in this field.




///LOCATION///

8. Battery research infrastructure available at SINTEF

All the research, innovation and development that is undertaken at SINTEF would not be possible without extensive research infrastructure. A large part of the infrastructure used in SINTEF's research projects on batteries is owned by SINTEF or acquired in partnership with NTNU and/or other research institutes. The latest addition to SINTEF's battery infrastructure is part of NABLA – Norwegian Advanced Battery Laboratory Infrastructure (www.nablalab.no). The primary goal for NABLA is to provide a national infrastructure dedicated to the battery research and development to Norwegian research and industrial organization. NABLA covers research needs and interests of the battery field and is built upon expertise of six major Norwegian research institutions within battery research: IFE, NTNU, SINTEF, UiA, UiO and FFI.

SINTEF Battery Lab (www.sintef.no/en/all--laboratories/sintef-battery-lab) is realised with financing from SINTEF and The Research Council of Norway and is a part of NABLA. In SINTEF Battery Lab we are further developing our competence and expanding our research activities on materials for different battery technologies. SINTEF Battery Lab also contains an R&D pilot line for manufacturing and testing of battery cells using scalable, industrially applicable equipment.

Another part of the NABLA infrastructure hosted by SINTEF is a new high-voltage and **high-power battery tester**, which will be in place by summer 2024. This battery tester is to be co-located with the **Machinery Laboratory (M-lab)**, which is part of SINTEF's Ocean Technology Centre laboratories. M-lab is a set of laboratories used for research on technology and concepts for energy and propulsion systems on board ships and other vessels such as oil rigs and future aquaculture facilities. M-lab will contain equipment that makes up different parts of the energy system, from fuel supply to exhaust gas purification. This includes internal combustion engines, electric motors, fuel cells, batteries, control systems, internal combustion rigs and setup for the development of exhaust purification technology. The new battery tester will be an addition to already existing equipment with capabilities of testing batteries between 1000 and 1500 V and up to 500 kW.

National Smart Grid Laboratory (https://www.sintef.no/en/all-laboratories/smartgridlaboratory/) is an infrastructure which is a collaboration between SINTEF and NTNU and is located in Trondheim. The laboratory is a system-oriented laboratory providing state-of-the-art infrastructure for R&D, demonstration, verification, and testing over a wide range of Smart grid use cases. This also includes implementation of batteries and part of the laboratory inventory is EV charging infrastructure and energy storage. A battery tester with a climate chamber is available for testing battery modules up to 200 V/960 A/80 kW. The climate chamber can facilitate temperature between-40 and 180 °C and a humidity range between 10 and 98 %.

SINTEF Energy Lab (https://www.sintef.no/en/all-laboratories/sintef-energy-lab/) represents the next generation in energy laboratories and is a vital tool for the development of tomorrow's efficient electrical power systems. The infrastructure includes high-voltage labs, short circuit labs, high current labs, and a power system electronics lab. For battery research these are relevant when testing larger systems at higher voltages, particularly for component compatibility and durability. It is also possible to test systems in saltwater mist, which is highly relevant for maritime applications and has great impact on how batteries and electronic systems behave when exposed to humid conditions containing salt.

Combining all of SINTEF's available infrastructures which will be available by summer 2024, it is possible to test and characterize batteries in all size ranges from laboratory scale coin cells and pouch cells to larger industrial cells and modules, covering the range from a few volts and up to more than 1000 V. A new **flow battery laboratory** is also in the making, where redox flow batteries can be assembled and tested.

NORTEM – The Norwegian Centre for Transmission Electron Microscopy (nortem.no) is a nationally coordinated initiative by the two leading Norwegian TEM groups within the physical sciences supported by the INFRA programme in the Research Council of Norway (RCN). The Centre has two geographic nodes, centrally located at the university campuses in Oslo and Trondheim, with three partners: SINTEF, NTNU and UiO. Here, world class infrastructures for TEM have been established, taking full advantage of recent technical developments. The NORTEM consortium offers access to Norwegian and international researchers seeking to apply state-of-the-art TEM techniques to answer the materials challenges of today and the future.

Other national infrastructures which are important for SINTEF's battery research are **NTNU NanoLab** (https://www.ntnu.edu/nano/nanolab) and **RECX** (http://www.recx.no/). SINTEF are not partners in these two infrastructures but have full access to use them for research and innovation projects. NTNU NanoLab is a clean room facility which is vital in materials characterization for both pristine materials and electrodes from cycled battery cells. This infrastructure is also often used in combination with NORTEM. RECX is the Norwegian Centre for X-ray Diffraction, Scattering and Imaging and is frequently used by SINTEF for materials characterization.

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