An overview of battery research and industry in Norway

By SINTEF

Technology for a better society

Contributors:
Benjamin Synnevåg
Charifa Hakim
Edel Sheridan
Eibar Flores
Francis Kinyanjui
Fride Vullum-Bruer
Ingeborg Kaus
Killian Stokes
Magnus Rotan
Margaux Gouis
Ole Martin Løvvik
Paul Inge Dahl
Sidsel Meli Hanetho
Sridevi Krishnamurthi

For questions related to the report or battery research at SINTEF please contact:
Fride Vullum-Bruer
fride.vullum.bruer@sintef.no
Paul Inge Dahl
paulInge.dahl@sintef.no

www.sintef.no/fagomrader/batterier
www.sintef.no/en/sintef-research-areas/batteries/

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Abbreviations

Abbreviation	Meaning
BESS	Battery Energy Storage Systems
BMS	Battery management system
CRM	Critical raw material
DPP	Digital product passport
ENOVA	Norwegian state organisation owned by the Ministry of Climate and Environment, focused on promoting environmentally friendly energy production and consumption.
EU	European Union
EC	European Commission
EV	Electric vehicle
FAIR	Findable, Accessible, Interoperable, and Reusable (in data management)
GHG	Greenhouse gas emissions
GWh/TWh	Gigawatt hours/Terawatt hours
IPN	Innovation Project for the Industrial Sector, funded by the RCN
FME	Centre for Environment-friendly Energy Research, funded by the RCN
IRA	Inflation Reduction Act
KSP	Knowledge-building and collaborative project, funded by the RCN
LFP	Lithium iron phosphate
LIB	Li-ion battery
LMNO	Lithium manganese nickel oxide
LMO	Lithium manganese oxide
LTO	Lithium titanium oxide
SIB	Sodium ion battery
NCA	Nickel cobalt aluminium oxide
NMC	Nickel manganese cobalt oxide
O&G	Oil & Gas
PV	Photovoltaic
R&D&I/R&D	Research, Development and Innovation/Research and Development
RCN	Research Council of Norway
NGU	Geological Survey of Norway
TRL	Technology Readiness Level
EoL	End-of-life
USN	University of South-Eastern Norway
UiO	University of Oslo
UiA	University of Agder
UiS	University of Stavanger
IFE	Institute for Energy Technology
FFI	Norwegian Defence Research Establishment
NTNU	Norwegian University of Science and Technology
KPI	Key performance indicator
DPP	Digital Product Passport
H2020	Horizon 2020, 8th framework program in the EU
HEU	Horizon Europe, 9th framework program in the EU
AI	Artificial Intelligence

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, has 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. 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, focusing on battery technology development, battery manufacturing, and implementation of batteries in different areas.

Although the European battery market (particularly battery cell manufacturing) has recently experienced a negative trend due to bankruptcies by large stakeholders such as NorthVolt, there is still significant European activity along the whole battery value chain. The EU, through the Clean Industrial Deal, is also making efforts to support and strengthen both existing and new initiatives. In Norway, several strong research groups have been involved in battery research for more than a decade. This report provides an overview (although not exhaustive) of current Norwegian R&D&I efforts along the battery value chain with focus on eight main areas. These are raw materials and recycling, new and emerging technologies, advanced materials, digitalisation, 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 this 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 spearheaded the implementation of hybrid and fully electric ships and vessels, which is also evident from the current stakeholders. However, there is a clear tendency towards increased interest in stationary storage applications in houses, 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 organisations, we also now see that Norwegian as well as other European industrial stakeholders realise 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 battery packs was predicted to be worth EUR 600 billion annually in 2050 (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 intellectual property (IP), infrastructure 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, and most of the refining of raw materials still takes place in China.

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 LIBs. In 2024, about 75% 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 synthetic, with more than 90% market share (5). Natural graphite is also considered a critical raw material by the EU (6). The European and global market for electric vehicles (EVs) is thus highly dependent on China, making the European market extremely vulnerable, as shown in Figure 1 (7). For mobility applications, Global EV Outlook 2025 predicts that EV battery demand will reach more than 3 TWh in 2030 (8). 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.

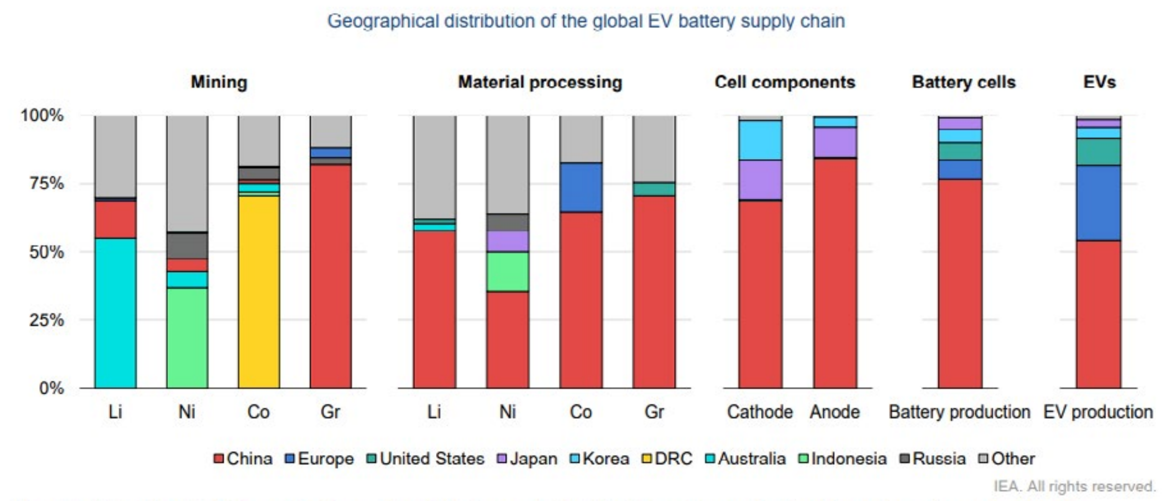


Figure 1: Geographical distribution of the global EV battery supply chain (7).

The cumulative installed stationary battery capacity in the EU was 16 GWh in 2024, which is around 12 % of the global installed capacity (9).
The use of utility-scale batteries is predicted by Bloomberg NEF to reach 1000 GWh by 2030 (10).

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 securty. 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 transportation but also provides a way for consumers to adapt their energy consumption to prices and their needs. According to the ETC CE report (11) 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 in 2019, which is mainly caused by energy consumption for heating, hot water and lighting.

In response to the European and global market trends, the Norwegian Government launched its own battery strategy (Norges batteristrategi) in 2022 (12). 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 on 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 keeping 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 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 energy technology.
The Energi21 strategy was launched in 2022 with a vision of further developing Europe's best energy system (13). The report identifies specifically eight areas of strategic importance for a successful green transition, including hydropower, offshore wind, solar energy, hydrogen, batteries, and CO_2 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 utilisation according to application, safety, reuse and recycling, and digitalisation.

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 University of Stavanger (UiS) and University of Agder (UiA). UiA is conveniently located next door to Morrow Batteries and benefit from their interest in collaboration with the research and education development. The Norwegian Catapult Centre Future Materials, which offers test facilities, competence and network to develop new innovative materials for batteries, is also located close by. Altogether, the Norwegian research community are actively involved in research along the whole battery value chain. 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) (14). 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), silicon (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 mainly originates from the Democratic Republic of Congo, from which 63% of EU's cobalt needs are covered (6). 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 mainly come from Australia, Chile, and Argentina. McKinsey & company have also studied the raw material supply and demand for the battery cell electrode materials (15) as shown in Figure 3.

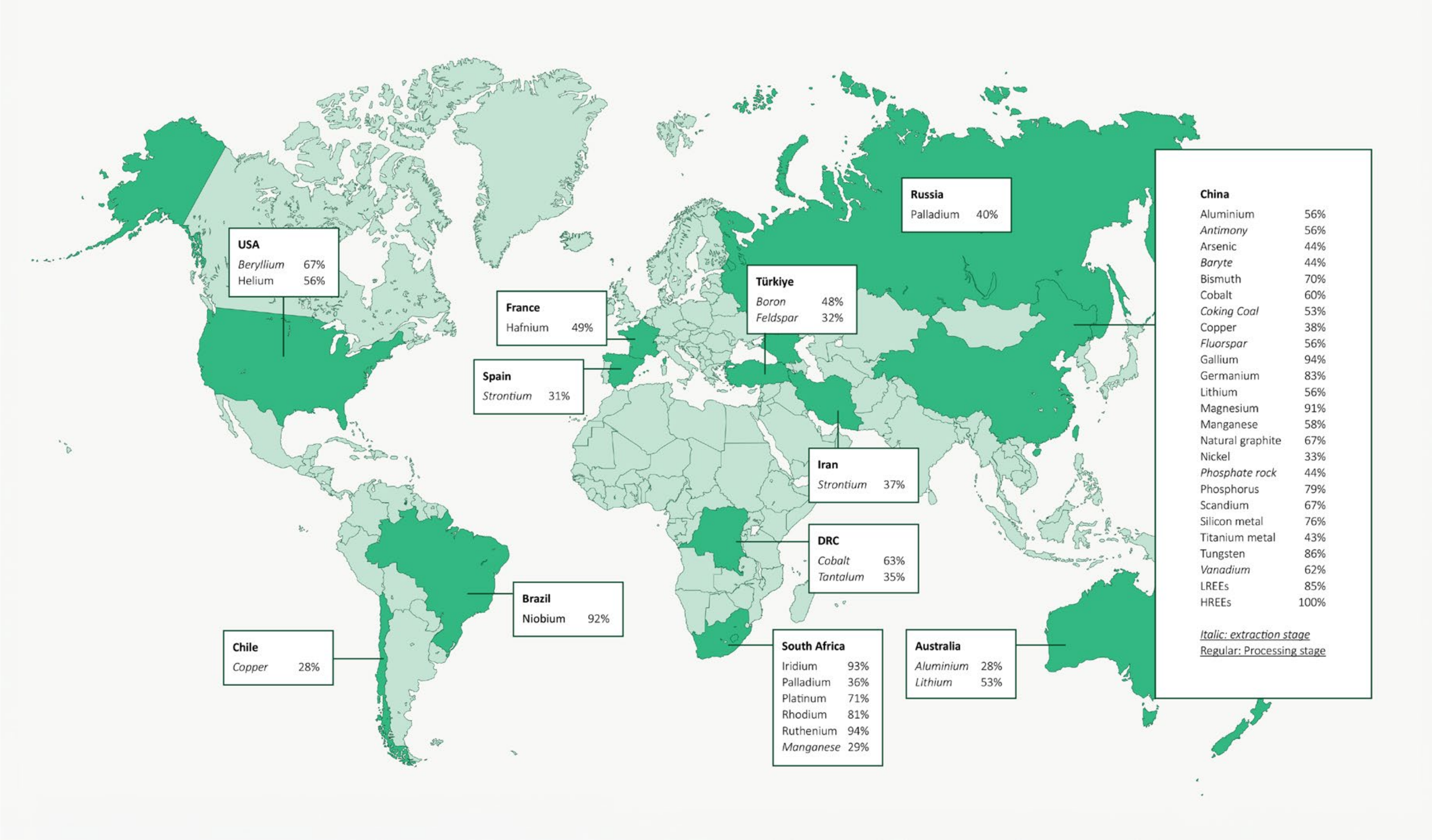
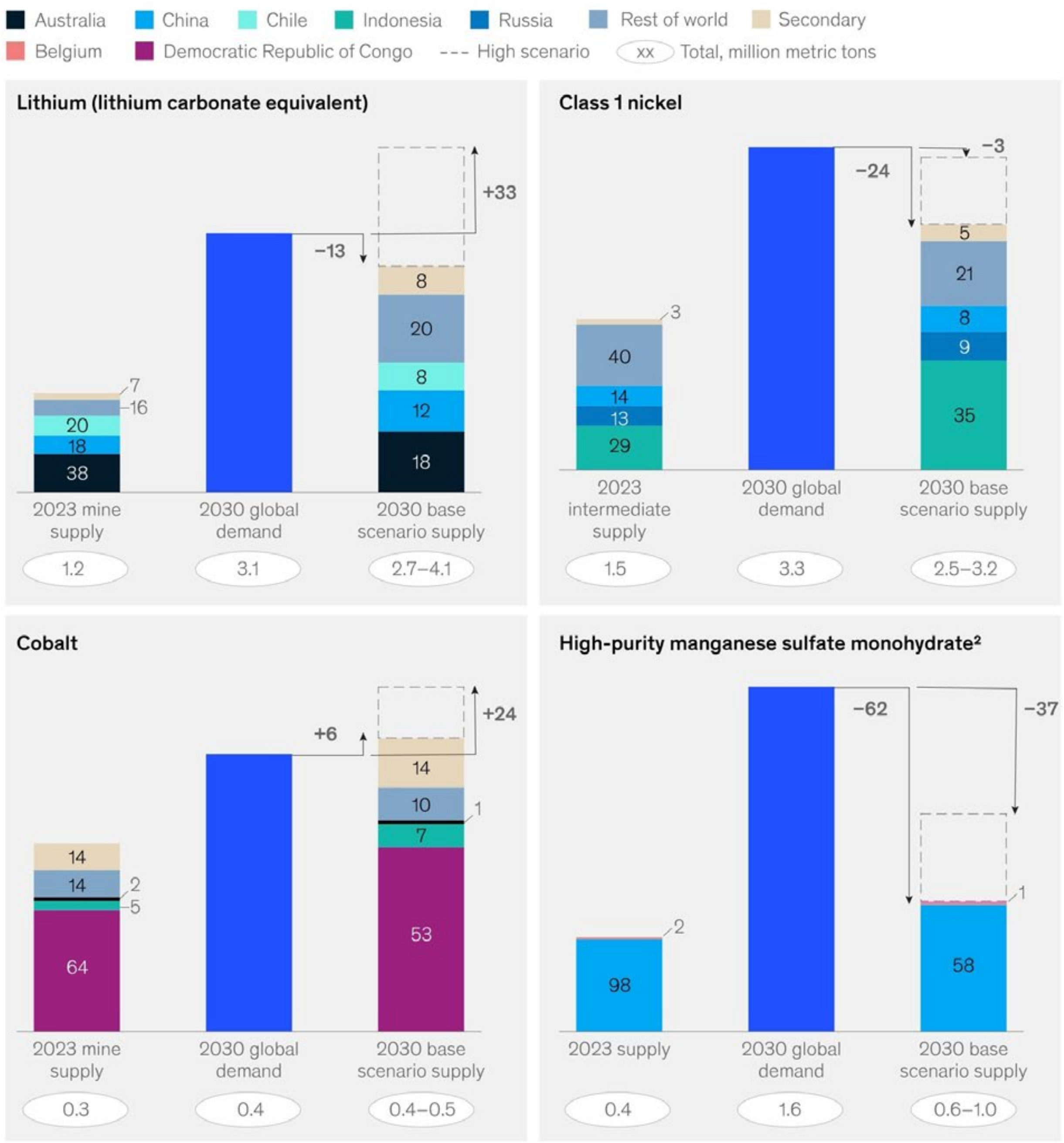


Figure 2: Countries accounting for largest share of global supply of CRMs (6)

Battery manufacturers may have challenges securing some essential raw materials through 2030.

Raw material supply and demand,[1] Q4 2024 data, %



Note: Figures may not sum to 100%, because of rounding.
[1]The base-case scenario for raw-material availability in 2030 considers both existing capacity and new sources under development that will likely be available, while the high-case scenario considers the breadth of possible outcomes.
[2]Includes data for South Africa of less than 1%.

Figure 3: Supply challenges expected for battery raw materials (15).

Since battery production requires high-purity materials, refining of raw extracted materials is also of great importance. 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 must move from a linear to a circular system by improving re-use, recycling, and integration of secondary raw materials. A 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.

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 (16).

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

Norway's position

The current geopolitical game has induced rising concerns regarding security of supply 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. 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 (17). Norway has no production of lithium, as deposits with economic potential have so far not been discovered (18). 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 tons of potential yearly production of battery grade lithium hydroxy mono hydrate (19).
The deposits are among the most significant in Europe and is being developed through the Keliber OY project. Nordic Mining ASA, a Norwegian company with their main activity allocated to mining of titanium oxide, has been involved in the project (20). Kuniko is an Australian company that aims to extract various battery-relevant minerals, nickel, copper, cobalt and zinc, from several sites around Norway. Their plan is to start operations in 2030 (21).

The deposits of minerals in Norway are far less mapped compared to the neighbouring countries Sweden and Finland. Considerable exploration has been conducted by the 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, for Norway, having complementary experience from geoscience and subsea operations from oil and gas exploration, efforts are being made by the government to investigate the potential of deep ocean minerals. The activity is controversial due to rising concerns for loss of biodiversity and degradation of ecosystems, which may put excavation and realisation of these resources at a halt indefinitely (22). Permits for commercial exploration have not yet been granted.

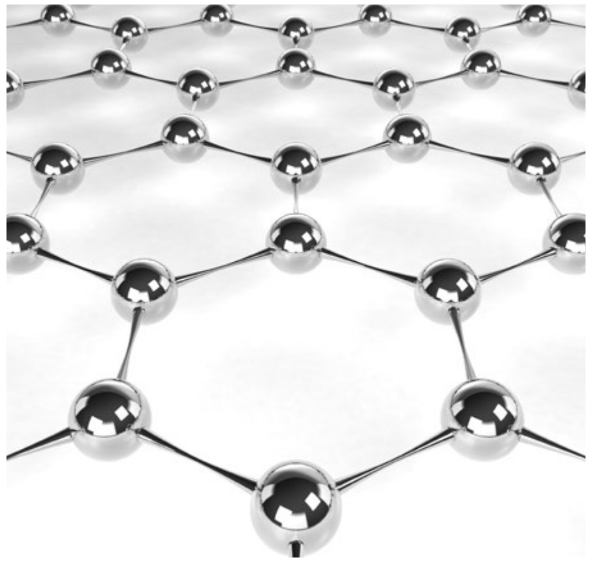
Two Norwegian companies, Green Minerals and Adepth Minerals, are seeking to extract valuable deep ocean minerals for the green shift. In addition to exploration on the Norwegian continental shelf, Green Minerals has obtained licenses in the Clarion-Clipperton Zone at the seabed of the Pacific Ocean where substantial resources of nickel, cobalt, copper and manganese have been indicated (23).

Mining and raw material production in Norway dates back more than 150 years, and around 1870 there were 40 mines and 7 smelting plants operational, which had a ~70% share of the global nickel production. Today there is no mining activity, however the original Kristiansand's Nikkelraffineringsverk (now Nikkelverk – a Glencore company) is still producing more than 90.000 tons of nickel pr year, mainly from ores shipped from Canada (24). In addition to nickel, large amounts of cobalt and copper are produced both from raw materials and recycling.

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 (25). 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 Hydro branch, Hydro Rolling, has however been sold in 2021, and now goes under the name Speira. Speira produces battery cell connectors and casings. The final aluminium product is one of the key components in LIB and is also commonly found as the current collector for the cathode.

Alcoa is an American company with several aluminium production locations globally. Two smelting plants are established in Norway, producing aluminium for a variety of applications including batteries (26).

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 (27). According to Geological Survey of Norway (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% graphitic carbon (28). In October 2019, the company was acquired 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 (29). As of 2024, the company was bought by Norge Mineraler Holding AS, a subsidiary of Norge Mining Limited (30). Norge Mining 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.



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 Norway 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 (31).

Cenate AS is a Norwegian company that develops silicon nano particles for the global LIB industry (32). 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.

TioTech AS is a Norwegian manufacturer of titania (titanium dioxide) nanomaterials for Li-ion battery anodes (33). Their product TitanBTM improves the charging, lifetime, safety and temperature robustness of the battery compared to currently used lithium-titanate based batteries.

Elkem has traditionally produced both graphite and silicon for anodes and also silicone solutions for battery packs and modules. They are still producing these materials, but they no longer have R&D&I activities related to use of these materials in LIB. The current focus for Elkem is within the areas of silicon for tomorrow's anodes and silicone solutions for battery packs and modules and various other applications in electric vehicles (34).

The development and production of graphite for LIB is taken over by Vianode, originally a spin-off company from Elkem. Vianode offers a range of anode graphite products with supreme performance characteristics and is produced with 90% lower CO_2 emissions than today's standard materials. They target producing battery materials for 3 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 (35).

Bergen Carbon Solutions was established in 2016 and is making CO_2 a valuable resource, using renewable energy to turn the excessive greenhouse gas into solid carbon (36). The company has developed a clean process for capturing CO_2 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 specialises in the green shift through processing of critical raw minerals and recycling of valuable materials from the process industry including battery manufacturing (37). 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.

NORSIRK is a company which collects and handles electrical and electronic products, batteries and packaging waste all across Norway (38). Through one of their subsidiary companies, Batterigjenvinning, they offer collection and recycling of batteries.

Hydrovolt was established as a joint venture between the Swedish company Northvolt and Norwegian Hydro on EV battery recycling (39). 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 hydrometallurgical treatment. Northvolt filed for bankruptcy in 2025, and as a consequence Hydro has acquired Northvolt's share of Hydrovolt. Northvolt's battery recycling plant, Revolt, and Hydrovolt plan to continue their commercial partnership, building on their positions as two of the earliest and most complementary players in Europe's battery recycling value chain (40). Although recycling of black mass from Hydrovolt 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 (41). Lithium is currently not recovered from end-of-life LIBs and is 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 (42). In 2014 Batteriretur Høyenergi AS was established for handling of batteries from EVs and the maritime sector. Through this company they have also contributed to developing solutions for safe handling, disassembly, reuse and recycling of EV batteries.

Glencore is a major recycler of end-of-life electronics, lithium-ion batteries, and other critical metal-containing products (43). They recycle critical metals like copper, nickel, cobalt, zinc and precious metals. In Norway, Glencore Nikkelverk, which was also mentioned above as a main producer of nickel, copper and cobalt, also works with recycling and is one of the largest producers of recycled nickel and cobalt-containing materials (24).

Norwegian stakeholders on second life repurposing

Evyon, established in 2020 and based in Oslo, provides large scale battery packs for stationary storage based on second life batteries provided from a German car manufacturer (44). 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 and world-leading in energy storage solutions in 2030.

Eco Stor is another Norwegian company that specialises in giving second life to batteries from electric vehicles (45). 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 customer's needs. 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 provides solutions for a range of outputs scaling from domestic solar panel PV production to grid balancing and fast frequency balancing, in the Nordic countries. When the batteries no longer fulfil the output requirements, Eco Stor removes 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.

Stena Recycling, based at Ausenfjellet outside Oslo, has established a collaboration with Nissan to establish a second life value chain for EV batteries from Nissan Leaf EVs (46). Stena Recycling have developed competence and technology for battery cell diagnostics to accommodate a circular economy for these types of batteries.

The reuse of batteries is also a cornerstone in Hagal´s strategy and technology, pushing large-scale deployment of new and used batteries (47). 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 (48). They provide solutions for private homes as well as larger battery systems for office buildings and industrial use.

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. Thus, materials development, production and refining has been a major area within LIB research for years. Additionally, the Norwegian research institutes and universities have in recent years also been more involved in projects 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 raw materials and different recycling and re-use projects across the different research institutes in Norway. The list below is not exhaustive but includes some of the most relevant ongoing or previous projects on the topic.

Project Name	Project Description	Norwegian Participants
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, Equinor, Hydro, Batteriretur, Eco-Stor, Corvus
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 this project coordinated by the Spanish research centre Tecnalia, these innovative solutions will be tested and demonstrated in industrially relevant environments.	UiA
Classification of lithium-ion cells for safe reuse	In this IPN 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. Single cell testing differs from the typical approach of testing the entire battery packs, and has the potential to improve performance and safety of reused battery packs as well as the fraction of second-life cells certified for reuse. The methodology will consist of a set of non-destructive tests performed in a test rig, and a cloud side classification model. The system will be scaled for a throughput of 400-4000 cells/day. More exhaustive destructive tests will be used to label non-destructive test data to build and improve on the classification model. A selection of the cells will be put to use in Hagal's RebelCore systems which allows for a wide variation of battery chemistry form factor and state of health within a single battery pack. Real-time monitoring of the battery cells ensures a feedback loop for continuous improvement of the classification methodology through additional labels on the data as well as providing data to improve models of battery degradation.	IFE, Hagal
Non-destructive evaluation and mod-elling 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, maximising the value of critical raw materials present in each battery becomes crucial.	NTNU, Evyon

Project Name	Project Description	Norwegian Participants
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 without 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
CE-RISE	EU-funded CE-RISE project will design and test an integrated framework to effectively reuse, recover and recycle materials. The project coordinated by NILU will define criteria to assess reusable products and embedded components. Information about the reuse criteria and material composition of products will be collected and stored in a digital product passport, along with information on the environmental footprint of products and the socio-economic and environmental impacts of reuse, recovery and recycling processes.	NILU, UiO, Eyde-Klyngen: Vianode AS, Morrow Batteries, Hydro, Glencore Nikkelverk AS, Aludyne
Revitalise	REVITALISE (REcycling of low Value components using high purity pre-treatment, dIrecT recycling And green hydrometallurgical approaches for recycling of Lithium Ion and Sodium Ion BatteriEs) aims to revolutionise battery recycling, in particular for NMC, LFP and Na-ion batteries where traditional recycling methods are inadequate. Revitalise will introduce an innovation solution, utilising cutting-edge techniques like electrohydraulic fragmentation and ultrasonication for material purity.	NTNU, Hydro
RESTORE	The EU-funded project RESTORE (Automated soRting and safE pre-procesSing of EoL BaTteries with nOvel smart and fast dismantling, and sepaRation technolgies for direct reuse of high purity materials in Energy storage application) will develop a holistic, scalable battery recycling process. The project, led by the technology centre LEITAT in Spain, aims to revolutionise battery waste handling, with a focus on safely pre-processing End-of-Life electric vehicles and domestic batteries. RESTORE will unlock the recovery of valuable resources like electrolyte salts, graphite, and cathode materials, which are often lost in traditional methods. The project will contribute to meeting EU recycling targets.	UiA, Vianode AS

Project Name	Project Description	Norwegian Participants
BeyondBattRec	BeyondBattRec (Beyond state-of-the-art battery recycling by increasing the selectivity and specificity of efficient pre-processing technologies) is an EU-funded project that aims to improve battery recycling methods, in order recover a larger quantity of valuable materials. This inefficiency increases the need for new raw materials, which is costly and unsustainable. As Europe aims for climate neutrality by 2050, improving battery recycling is crucial. In this context, the project coordinated by Aalborg university in Danmark tackles this problem by integrating new technologies and digital tools to enhance recycling rates. With a 13-partner team across seven EU countries, the project focuses on recovering key materials like cobalt, copper, lithium, and nickel. BeyondBattRec will help Europe meet its recycling targets while strengthening its battery industry's global competitiveness.	Shift Materials AS
STREAMS	The EU-funded STREAMS (Sustainable Technologies for Reducing Europe's bAttery raw MaterialS dependence) project aims to showcase, develop, and validate 12 scalable and adaptable technologies focused on the sustainable production of battery-grade precursors and corresponding anode and cathode active materials. Led by the Austrian Institute of Technology (AIT), the project will demonstrate these solutions using primary, secondary, and recycled materials, with the outcomes poised to substantially enhance European competitiveness.	SIPOW AS, Nanopow AS
RESPECT	The EU-funded project RESPECT (Flexible, Safe and efficient REcycling of Li-ion batterieS for a comPetitive, circular, and sustainable European battery manufaCTuring industry) will develop a global process encompassing a process-chain flexible enough to treat all kinds of batteries in closed loop. Let by Orano Mining in France, it will specifically address two recycling routes: full hydrometallurgy and direct recycling and an improved life cycle assessment of each recycling segment. RESPECT will also ensure knowledge sharing on Li-ion battery green recycling processes through engagement with international stakeholders and experts.	Morrow Batteries, Vianode AS

Project Name	Project Description	Norwegian Participants
METALLICO	Electric mobility is driving the battery sector, which is a key strategic sector for the EU. However, electric vehicles run on lithium-ion batteries. Lithium, like other rare earth elements, is scarce. In this context, the EU-funded METALLICO project (Demonstration of battery metals recovery from primary and secondary resources through a sustainable processing methodology) led by IDENER research and development, in Spain, will develop a new opportunity for the EU. Bringing together representatives from the entire value chain (including mining and industrial sites) with primary and secondary sources of critical and battery metals (lithium, cobalt, copper, manganese, nickel), the project will test new processes for producing battery grade materials. Worldwide, these battery metals are predominantly in Australia, Chile, China, the Democratic Republic of the Congo, and South Africa, making it difficult to ensure supply. METALLICO will design sustainable upstream and downstream processes.	Glencore Nikkelverk AS
ENICON	Electric vehicles are expected to dramatically increase the demand for nickel (Ni) and cobalt (Co) over the next two decades. Europe is expected to face difficulties in securing a reliable, affordable and sustainable supply chain as the concentration of such minerals in the continent is scarce. The EU-funded ENICON project (Sustainable processing of Europe's low-grade sulphidic and lateritic nickel/cobalt ores and tailings into battery-grade metals) led by KU Leuven in Belgium, aims to improve the refining capacity of domestic and imported low-grade Ni/Co. ENICON's metal recovery route using hydrochloric acid dispenses with the old-school hydro-based approach that involves continuously precipitating and redissolving metals. Thus, it reduces the amount of chemicals needed for metal dissolution, which result in the production of potentially harmful waste streams.	Glencore Nikkelverk AS

Project Name	Project Description	Norwegian Participants
EMINENT	EMINENT (Energy MINErals for the Netzero Transition) is a Green platform project led by Adepth Minerals, that will establish the basis for an integrated value chain for deep sea minerals. The goal is an 80 percent reduction in the environmental footprint compared to current land-based mining. Initial analyses show that deep sea minerals contain 5 to 10 times higher concentrations of critical minerals compared to those we find on land. The project will develop and demonstrate world-leading technology and methodology for environmental and resource mapping and environmentally friendly production and processing. They will develop tools with a full focus on minimising the environmental impact at all stages. Solutions will be demonstrated in the deep sea and contribute to increased knowledge and expertise on environmental and mineral resources. The project has been established by a broad consortium of 15 companies and research environments with complementary and leading expertise along the entire value chain.	Adepth Minerals, Aanderaa, Aker BP, Akvaplan-niva, DeepOcean, GCE Ocean Technology, Geoprovider, NTNU, Norce, Seabed Solutions, UiT, UiB
ESSENTIAL	The availability of materials crucial for the green transition and sustainable development faces challenges from import dependency, increasing demand, and their energy-intensive production comes with significant greenhouse gas emissions and waste generation. Addressing these challenges requires new technologies, yet there is a lack of mature options and the necessary knowledge. In response, ESSENTIAL (Minerals and metals for sustainable and circular growth), a groundbreaking pre-project initiative, aims to design a new centre in Norway that will revolutionise sustainable mineral and metal processing. Guided by green chemistry principles, this centre will promote lower emissions, digitalised tools, zero-waste mining approach and climate change mitigation actions. ESSENTIAL Minerals and Metals (MaM) for sustainable and circular growth is a crucial infrastructure node in Southern Norway.	IFE, UiS, NMBU

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 (49). 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 underutilised plastic-waste, bio-based waste and side streams, and end-of-life electric vehicle batteries in the Nordics and Baltic Sea Region. 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 (50; 51). Based on the findings from this work a set of policies recommendations which may accelerate 2nd life battery implementation will be proposed towards the end of the project.

LiCORNE: Another EU project funded through the Horizon Europe funding programme, is Lithium recovery and battery-grade materials production from European resources, referred to as LiCORNE (52). 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 utilisation in high-end markets) is an EU project coordinated by SINTEF (53). 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 utilise 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.

COLIBRI (Characterisation of Lithium-Ion Batteries for improved Recycling efficiency) is an IPN project funded by the RCN (54). Partners in the Colibri project are Hydrovolt (lead), SINTEF and IFE.
The COLIBRI project will develop a novel approach and establish a toolbox for the characterisation and categorisation of end-of-life (EoL) LIBs for recycling, enabling a recycling process with high reliability and predictability, maximising material recovery rates and capacity utilisation. This will be achieved by utilising IFE and SINTEF's combined materials expertise and advanced materials characterisation infrastructure.

CICERO (MSA-based circular hydrometallurgy for sustainable, cost-effective production of NMC cathode materials) is an HEU project (55). Europe's ambitious energy and climate goals are heavily dependent on critical and strategic raw materials such as those used in the manufacture of NMC cathodes in lithium-ion batteries, i.e., nickel (Ni), manganese (Mn), and cobalt (Co), as this cathode type of chemistry is likely to prevail for a long time due to its high energy density and charging speeds. Hence, there is already a strong demand for high-purity Ni, Co and Mn, and these are expected to increase by 21, 19 and 8 times, respectively, over the next 20 years. Given the shift towards more Ni-rich NMC chemistries, the demand for Ni is of particular concern. To face this challenge, the CICERO project will focus on the domestic refining of Ni, Co and Mn, by developing sustainable and cost-effective processing and refining processes based on a unique and innovative approach which integrates the Twelve Principles of Circular Hydrometallurgy established by the Coordinator KU Leuven, with the smart use of methanesulphonic acid (MSA). SINTEF will contribute with the establishment of suitable electrowinning processes to recover Ni, Mn and Co from MSA-based electrolytes. Moreover, SINTEF is leading the activities focused on the reagent regeneration and iron recovery by electrowinning from the MSA electrolyte.

HalMan The EU-funded project HalMan (Sustainable Hydrogen and Aluminothermic Reduction Process for Manganese, its alloys and Critical Raw Materials Production), coordinated by NTNU, will develop an integrated process to mine manganese metal and alloys from ores and manganese-containing waste by using hydrogen and secondary aluminium sources as reductants (56). Aluminium-containing scrap and waste from the ferromanganese industry will be valorised to produce new aluminium-manganese master alloys for the aluminium and steel industries. Furthermore, HalMan will demonstrate manganese dioxide for lithium-ion battery applications.

SUMBAT KSP (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 (57). SUMBAT KSP is 1 out of 8 sub-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, see Figure 4. 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.

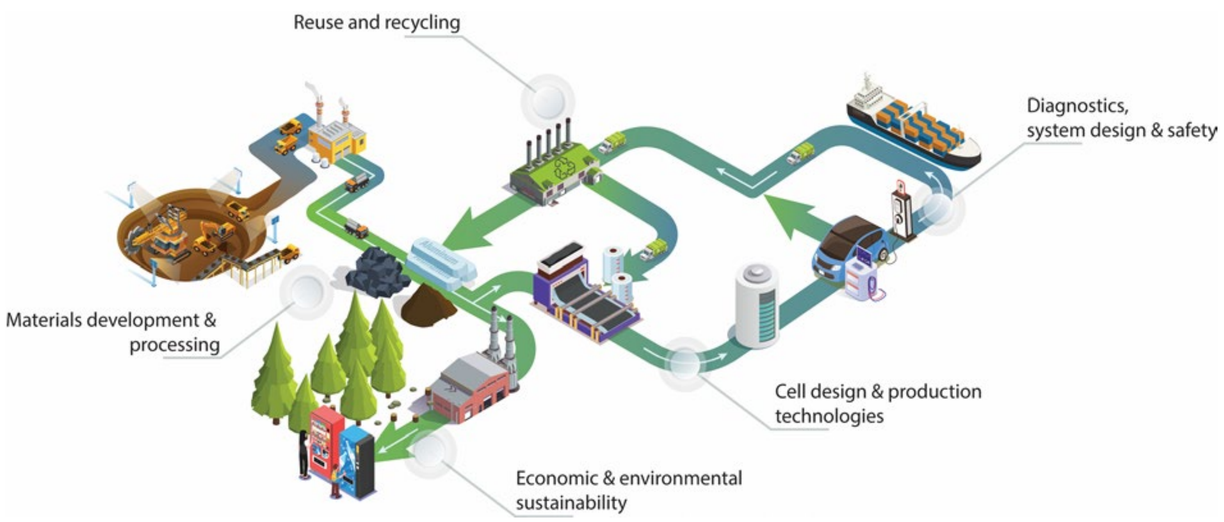


Figure 4: Overview of the main activities within the SUMBAT KSP project (Illustration: IFE)

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 (58), "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.

Na-ion Batteries
Na-ion batteries store energy via sodium-ion intercalation and are well-suited for stationary storage and short-range EVs due to their enhanced safety, low-temperature stability, and abundant, globally available raw materials (59). Unlike lithium sources, which are concentrated in a just few countries, the wide availability of Na-ion battery raw materials has the potential to reduce supply chain risks.

Solid-State Batteries
Solid state batteries use solid electrolytes instead of liquid electrolytes, resulting in potentially higher energy density, improved safety, and faster charging (60). 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 (61). 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.

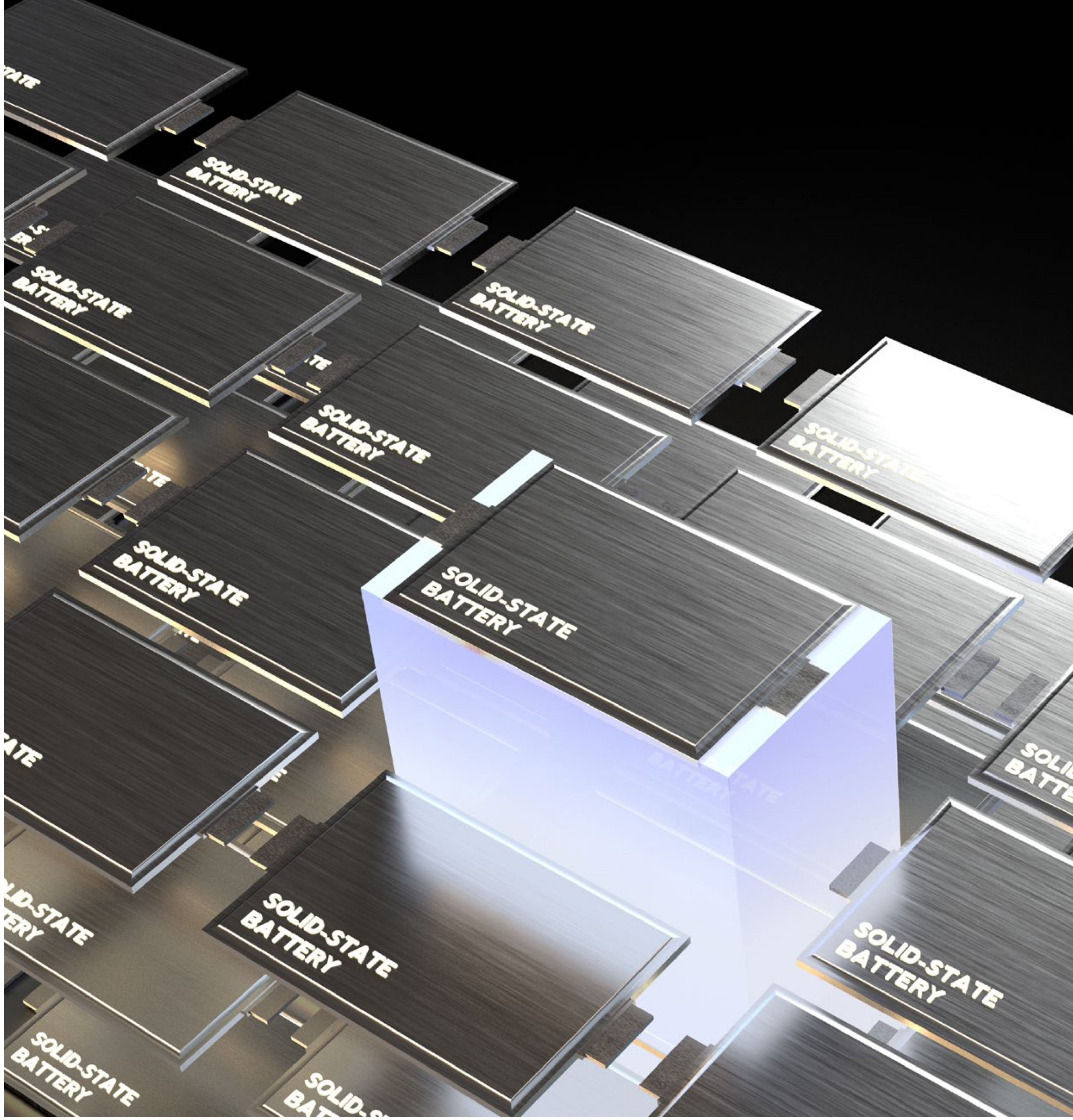
Metal-Air Batteries
Metal-air batteries have 3-30 times greater theoretical energy density compared to conventional Li-ion batteries, as they use oxygen from the air as a cathode material. However, practical challenges related to stability, efficiency, and cycle life still need to be overcome (62).

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 (63). Their challenges are related to complexity in managing multiple electrolyte solutions, stability, and toxicity of electrolytes.

Norway's position

Emerging technologies related to new battery chemistries is mostly on a research stage, and, as such is mainly 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 commercialisation or just started production.

nanoCaps is a leading research group for supercapacitors emerged from University of South-Eastern Norway (USN) (64). They base their new products on 15 years of research at USN and have a series of strong patents. They are currently commercialising their technology by developing a first portfolio of unique products with record high sheet capacitance, low series resistance and high energy density. By partnering with GMCC, a world leading Chinese producer of supercapacitors, they are all set to commercialise their product.



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	Norwegian Participants
SEAMLESS	"Screening of Emerging Anode Materials for Li-based Energy Storage Systems" is a researcher project recently awarded by the RCN under the NANO2021 program. SEAMLESS aims to build a platform for materials' discovery for the batteries of the future by creating a library of silicon-based nanomaterials for the next generation of Li-ion batteries (LIBs).	IFE, UiO
SALAMANDER	The EU funded project SALAMANDER (Smart sensors and self-healing functionalities embedded for battery longevity with manufacturability and economical recyclability), led by IFE, offers a groundbreaking solution to the limited lifetime of Li-ion batteries and the carbon emissions associated with their production. Specifically, it aims to embed advanced sensors and self-healing capabilities within LIBs, creating smart batteries that can autonomously detect and repair damage. This innovative approach not only promises longer-lasting, more reliable batteries but also aligns with the goal of a sustainable European battery value chain and a greener future.	IFE, UiO
BetaBatt	Long-life and maintenance-free energy sources for Micro-Electro-Mechanical Systems (MEMS) in extreme environments is a research challenge in the field of micro-energy worldwide. One of the most promising solutions to this challenge is the development of micro-energy batteries that utilise isotope decay energy. BetaBatt intends to use software simulation to guide experimental research methods, develop long-life and high-efficiency micro-power sources. The objective is to achieve an ECE of no less than 20%, an output power density of no less than 5 µW/cm3, and continuous power supply for no less than 10 years, thereby, eliminating obstacles for the practical engineering application of MEMS across multiple environmental conditions.	USN

Project Name	Project Description	Norwegian Participants
Nanocarbon	Zinc ion hybrid capacitors (ZIHCs) integrate two energy storage mechanisms of battery-type electrode and capacitive electrode, bearing the advantages in energy density, power density, and safety. Until now, the cycle retention rate of ZIHC's capacity reported is still not more than 80%, restricting its development and commercial application severely. Focusing on the issue, Nanocarbon aims at overcoming the limitation of traditional electrode materials and re-defining the designing concept to construct Carbon Quantum Dots (C-QDs) for ZIHCs.	USN
OScAR	The goal of the OScAR (Operando Screening of emerging Anodes for Na-based stationary storage of Renewable energy) project is to advance state-of-the-art SIBs and facilitate future commercial deployment, through the development of new anode materials, capable of delivering higher performance compared to the materials used today. Hard carbon is the only material that has been demonstrated in industrially relevant prototypes so far. The project will focus on the development of more promising Sn-based anodes that -along with Sn being abundant, low-cost, and non-toxic- have been proposed to deliver a substantially higher capacity. OScAR will conduct a comparative compositional screening of Sn oxides and chalcogenides (SnX) by employing state–of–the–art operando methods. An advanced multidisciplinary scheme will be followed in 3 directions: (1) fundamental materials science, (2) methodological expansion of operando methods, (3) demonstration of a full SIB with SnX-anode.	UiO

SINTEF's research

On-going research projects related to new and emerging technologies where SINTEF is either coordinator or partner, are described below.

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 (65). NTNU is involved as a partner contributing with electrochemical characterisation of the produced hard carbon materials and evaluating suitability as sodium-ion battery (SIB) 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 SIBs, 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 owner, highlight the project's significance in light of prevalent lithium-ion batteries containing environmentally hazardous elements. They conclude that Na-ion batteries are better and safer (66).

ZABAT (Next generation rechargeable and sustainable Zinc-Air batteries) is the beneficiary of funding from the M-ERA.NET materials engineering research competition (67). 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 utilisation 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 (68). 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 emphasises 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, utilising 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 characterisation of the membranes. SINTEF will also perform experiments at the Norwegian Fuel Cell and Hydrogen Centre.

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 (69). 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. 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 utilisation 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 electrolyte 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 (70). 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 minimising environmental impacts throughout the entire lifecycle of the batteries. To achieve this, SIBERIA suggests the use of aqueous processing methods and the exclusion of

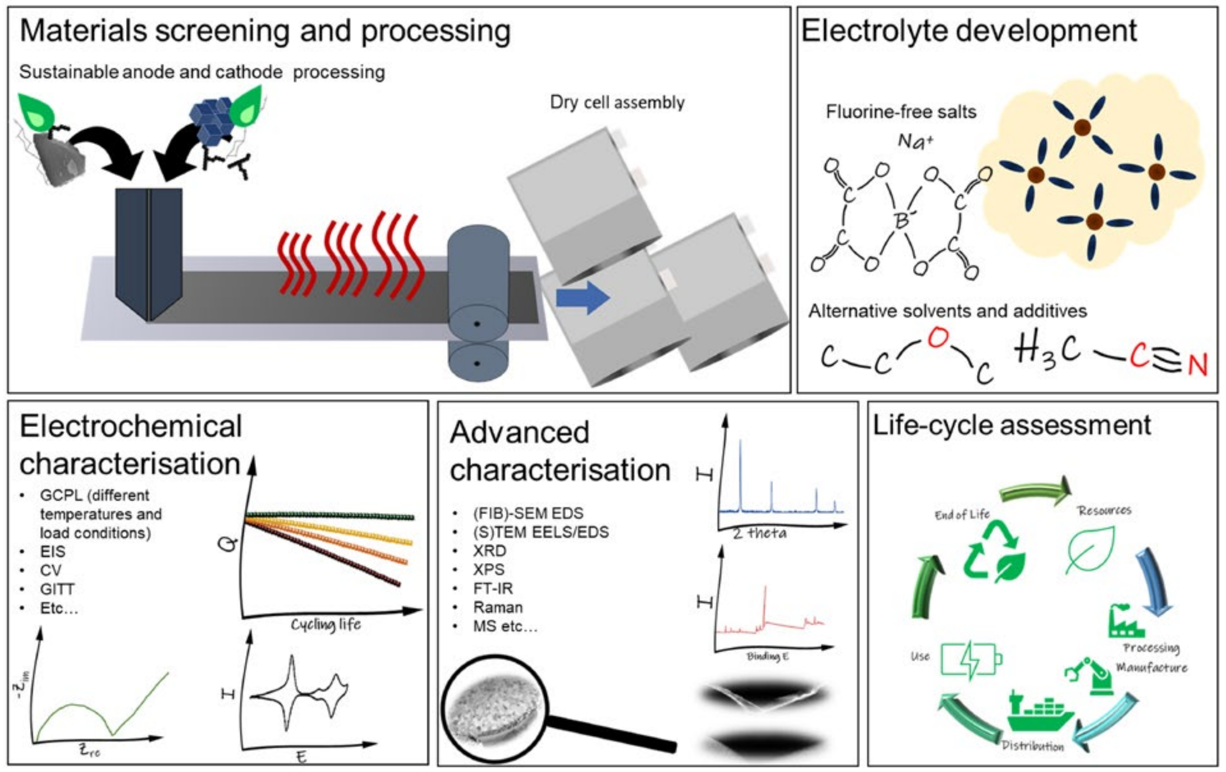


Figure 5. Schematic overview of the SIBERIA project (Illustration: SINTEF).

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 synthesise them within the project. Furthermore, the project involves characterising 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 the sodium-ion cells operating under Nordic climate conditions, offering a full characterisation 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 (71). 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 emphasises 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 commercialisation, 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 utilises ZnO/Zn as a storage vector and incorporates electrochemical 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 (72). 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.

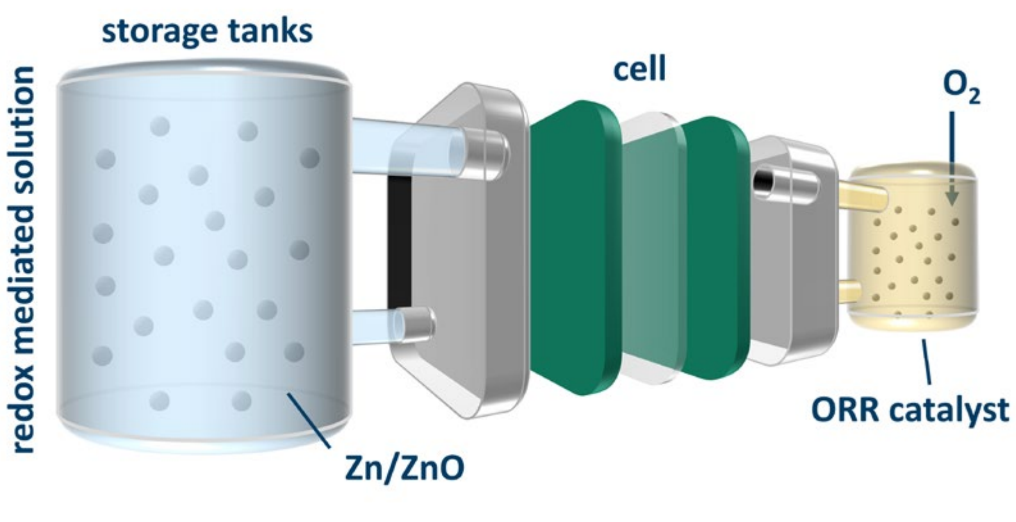


Figure 6: Illustration of a zinc-air battery (not to scale) (Illustration: SINTEF).

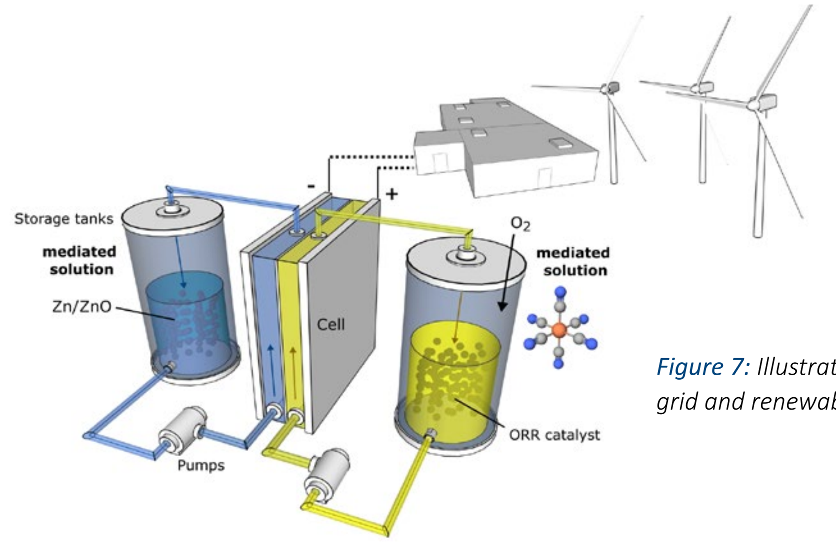


Figure 7: Illustration of a flow battery connected to grid and renewable energy (Illustration: SINTEF).

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 lifetime 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 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.

REWAMP (Repurposing coke waste for scalable battery electrode material production) is a two-year innovation project launched in 2025, jointly led by SINTEF and Vianode (73). The project focuses on transforming graphite production waste–particularly low-grade coke and coke fines–into high-value materials for battery applications. The primary objective of REWAMP is to develop sustainable processes for producing hard carbon materials from low-grade coke waste for use in sodium-ion (Na-ion) battery anodes. Additionally, the project aims to repurpose coke fines as feedstock in the production of graphite for lithium-ion (Li-ion) battery anodes. A key innovation in REWAMP lies in replacing fossil-based pitch with bio-based raw materials for the surface modification of both hard carbon and synthetic graphite. This aligns with the project's broader ambition to reduce reliance on petroleum-based inputs and improve the circularity of battery material value chains. REWAMP seeks to address both environmental and supply chain challenges in the battery industry by introducing scalable and greener approaches to anode material production. By valorising waste streams from graphite and coke-based production lines, the project aims to contribute to a more sustainable and resource-efficient battery ecosystem.

ALCBATT (Aluminium Carbon Battery as Next Generation Battery) is funded by the RCN as a Collaborative and Knowledge-Building Project (KSP) where NTNU and SINTEF are the research partners, and Beyonder, Equinor and Vianode are project partners (74). Within the project, the aim is to develop a battery with aluminium and carbon electrodes which can demonstrate 300+ charge-discharge cycles. On the carbon electrode, several graphite qualities are studied, various qualities of aluminium are considered and eventually the electrolyte composition is also under evaluation. Ultimately, the goal is to demonstrate a battery concept based on abundant, low-cost, and recyclable materials.

Sosoba (Solid-state sodium batteries: Screening for electrolyte materials) is a researcher project funded by the RCN (75). The scope of this project is to develop new electrolyte materials for solid-state sodium-ion batteries. The goal is to discover materials with an unprecedented combination of beneficial properties: high ionic conductivity, high thermodynamic stability, adequate stability for different voltages, tolerance for air, coexistence with a Na-rich anode, low electrical conductivity, and adequate mechanical properties. Partners in this research project funded by the RCN SINTEF (lead) and UiO.

3. Advanced materials

In the category advanced materials there is a certain overlap with topics listed under New and emerging technologies. However, this section will focuse 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 1990 (76) 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.

Although the electrolyte is a vital part of the battery and its properties, in this chapter the focus is on anode and cathode 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 (high-Ni NMC) are examples of progressive work although challenges are still to be overcome (77). For cathode materials, there are additionally a variety of chemistries on the market, including NCA, LMO, LMNO and variations of these. Recently, LiFePO4 (LFP) and LFP-based cathodes have seen a new spring and is starting to dominate the EV battery market in China.

Norway's position

NanoPow AS is a Norwegian company established in Oslo in 2016 providing crystalline silicon nano-powder (78). 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 (79).
By leveraging the potential of graphene-based nanomaterials, they are working to enhance the performance and safety of LIB electrodes.
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 (80).
The company is rooted on 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 energy storage systems.
They claim to hold expertise and knowledge enabling them to create tailored system solutions using highly efficient materials. They develop technology to optimise materials for higher performance, longer life cycles and safe and more sustainable energy storage systems (81).

Morrow Batteries is a European company founded in 2020 and located in Arendal in Southern Norway (82). Their newly inaugurated (in August 2024) giga-factory is set to produce up to three million battery cells annually, or 1 GWh capacity (83). With the industrial standard cathode material lithium iron phosphate (LFP), Morrow will become one of the very first battery cell suppliers in Europe.
They recently signed a letter of intent with the Finnish Proventia regarding LFP development for heavy-duty machinery electrification (84). Advancing through lithium nickel manganese cobalt oxide (NMC) they aim to revolutionise 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. Despite 1.5 billion NOK from Innovation Norway granted in the end of 2024, Morrow was forced to let about 20% of their employees go in the start of 2025 to secure a safe financial future (85).

The recently established Shift Materials is another technology-driven company headquartered in Norway (86). The company is focusing on LFP cathode material production for the European battery industry.

Cenate (32) and TioTech (33), 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 the material's degradation during use has been hampering widespread implementation in the LIB anode. Cenate now claims 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 pulverise during charging and discharging (87). 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 (88).

Baldur Coatings AS is a small spin-off company from the University in Oslo (UiO) (89). 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.

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.

Project Name	Project Description	Norwegian Participants
MoreIsLess	The objective of the MoreIsLess (Design of electrodes for Li-ion batteries with optimised balance of energy and power) 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, Freyr/T1, Equinor, Morrow Batteries, Norsk Hydro and Cenate.
SPRINT	The EU-funded project SPRINT (Sustainable European sodium-ion batteries for stationary applications featuring improved PRocesses, Inherently safe and Non-Toxic materials) will optimise and demonstrate two safe, sustainable, and cost-effective quasi-solid-state sodium-ion batteries tailored for stationary applications. SPRINT will harness abundant materials, such as novel NFP cathode and hard-carbon materials, alongside advanced electrolytes, to enhance energy density, cycle life, and cost-efficiency. The project will engage international use cases and bring these innovations closer to commercialisation.	IFE, WAI Environmental Solutions AS
FLUFFY	The FLUFFY project (Fluoride-based Na-ion battery cathodes for stationary storage) will focus on identifying fluoride-derived materials as cathode materials that maximise the electrochemical performance, lifetime and minimise the environmental footprint of sodium-ion batteries. The high electronegativity of fluorine enhances the electrochemical performances and chemical stability, making these materials ideal for battery applications. Our mixed-anion approach will further modify the fluoride chemistry to increase ionic and electronic conductivity.	UiO
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

SINTEF's research

SUSTBATT (Scalable Sustainable Anodes for Li-ion Batteries by Structural Design) is a collaborative three-year project with a budget of 12 MNOK funded through M-ERA.NET (90). 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 essential. 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 oxide (SiO_2), which is abundant in the Earth's crust. Silicon oxides occur naturally in various forms, such as diatom frustules. Diatom frustules, or shells, are present in both fresh and sea water and exhibit the capability of consuming CO_2 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, which will be converted into usable Li-ion battery materials by magnesiothermic reduction into SiO_x ($0<x<2$). SINTEF contributes with advanced characterisation using advanced electron microscopy techniques. In addition to lab scale testing of the materials, SUSTBATT will assess these materials through pilot-scale production.

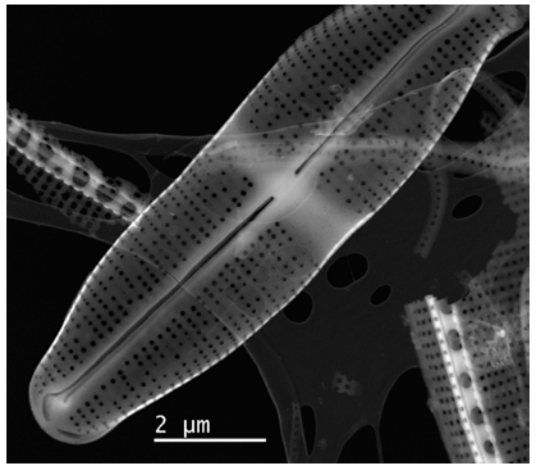


Figure 8: Microscopy image of a diatom frustule (Image: SINTEF).

IntelLiGent (Innovative and sustainable high-voltage Li-ion cells for the next generation (EV) batteries) is another EU-project coordinated by SINTEF (91). The project duration is 4 years, the budget is 6.8 M€, and it is funded through the HORIZON EU.

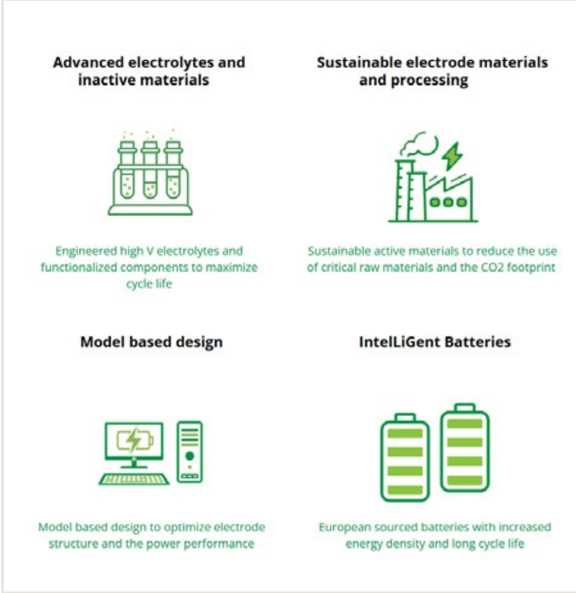


Figure 9. Goals of the IntelLiGent project (Illustration: SINTEF).

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 optimisation 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 (92). The total project funding is around 8 M€. 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 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.

LiTIA (Li transport and interface reactions in advanced battery materials) is a competence building project funded by the RCN (93). Partners in the LiTiA KSP project are SINTEF (lead), UiO, Cenate, and Vianode. The LiTIA project will develop new knowledge on lithium transport and interface reactions in advanced battery materials. Utilising cutting-edge materials characterisation techniques such as dynamic and operando NMR/TEM/XPS, LiTIA seeks to bridge the gap between fundamental science and commercial battery material optimisation.

Longlife (In situ conversion alloying anode materials for long lifetime, high-energy density batteries) is a competence building project funded by the RCN (94). LongLife aims to develop a new class of Si-based materials which operate on a principle of in situ conversion. Such materials having formula of SiE_x (E= N, C) will be prepared by a scalable method of pyrolysis (to be tested in two different reactor architectures). Such approach will ensure a quick adoption of the materials by relevant industries. Partners in Longlife are IFE (lead), SINTEF, UiO, Hydro, Equinor, Morrow, Elkem and Cenate.

ASAP-Recycling (Avansert Silisium-Anode-Produkt med Resirkulering) is an IPN with Cenate (lead), SINTEF and IFE (95). ASAP-Recycling is a project that will contribute to the fastest possible progress towards the goal of recyclable, silicon-based anode materials for Li-ion batteries.

Additional previously described projects

SUMBAT KSP (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 (57). The SUMBAT project spans several of the topics of this report and was described under Chapter 1. Raw materials and recycling- SINTEF projects.

4. Digitalisation

Digitalisation is a wide topic covering many aspects of the battery value chain. It covers topics from modelling of materials on atomic and molecular scale, to simulation and modelling of battery cells, systems and manufacturing processes. Additionally, artificial intelligence (AI) and machine learning are being integrated into battery management systems to optimise charging, discharging, and battery health monitoring. This improves overall performance, safety, and longevity. Batteries are also 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. Digital tools are also used in the search for new materials and optimisation of chemical processes. Here, quantum computing holds potential for simulating and optimising new materials and processes without the need to perform large matrices of materials synthesis and characterisation, accelerating the discovery of novel battery materials and designs (96).

Norway's position

The Norwegian Government lists digitalisation as one of the priorities when developing the battery value chain in the Norwegian Battery Strategy from 2022 (12). This Battery Strategy states that "Batteries and battery production often interact with digital autonomous technologies, enabling "smart" solutions in a range of fields. There is considerable potential in using automated/autonomous production technology with control/digitalisation, robots, unmanned autonomous vehicles (UAV) and track systems in connection with battery production". Furthermore, there is a general trend that the industry becomes more digitalised, and it's important to understand and operate advanced autonomous machines. Capgemini lists digitalisation as one of the seven challenges and opportunities for the Norwegian battery industry, "digitalisation is key to scaling up and optimising Norway's battery manufacturing processes" (97). Furthermore, the Capgemini report stresses the importance of using AI for both accuracy and cost as well as time effectiveness for Norwegian companies. An important part of the digitalisation efforts is the implementation of Digital Product Passports (DPP) for batteries, to which Norwegian stakeholders, including SINTEF, have been actively participating in the development (98). Life-cycle analysis (LCA) and related methods are integrated in DPPs, but are also actively implemented through-out various projects and activities in industries and research organisations in Norway. Norwegian research organisations, particularly SINTEF, have also been central in the development of battery-related ontologies (see below), which are instrumental in digitalisation across scales and methods. The Norwegian activities in the H2020 project BIG-MAP established Norway and SINTEF as important actors within the field of high-throughput screening for new materials using digital tools ranging from ab-initio atomistic simulations to AI-based machine learning techniques, and there are several projects and initiatives in the research sector on this topic (99).

Norway's research and research funding potential

The Norwegian research community has strengthened their competence and efforts into the digital field tremendously in the past decade, also joining forces with scientists with a background in computer science, cybernetics and robotics.

Project Name	Project Description	Norwegian Participants
BatCAT	The global demand for advanced batteries is surging, driven by the EVs revolution and renewable energy storage needs. However, traditional manufacturing methods struggle to keep pace, facing challenges in efficiency, quality, and trustworthiness. The BatCAT project (Battery Cell Assembly Twin) led by NMBU is pioneering a transformative solution, aligning with the BATTERY 2030+ Roadmap to construct a Digital Twin for battery manufacturing, merging data-driven and physics-based methods. It tackles the triple challenge of design, operation, and trust, enhancing product quality and process efficiency. BatCAT is a research and innovation project funded by the EU's "Horizon Europe" programme. The project is a collaboration between 18 partner organisations from 9 European countries, including IndiScale GmbH. The project aims to create a digital twin for battery manufacturing by developing a cross-chemistry data space for two technologies: Li-ion and Li-S coin cells and redox flow batteries. The project will also address three challenges in digital manufacturing: Design, operation, and trust. BatCAT is closely connected to the finished BIG-MAP project and BATTERY 2030+, EOSC, EMMC, and OntoCommons, ensuring a community and industry uptake of the results.	NMBU, Simula AS
NANOPOWER	The Internet of Things (IoT) offers great potential to monitor and manage complex systems, yet remains hindered by excessive use, size, and replacement of batteries in IoT nodes. Decreasing power use is essential. With EIC support, Nanopower will address the IoT battery bottleneck and become a Europe-based, world-leading ultra-low-power specialist, using it's unique Intelligent Power-Management Integrated Circuit (IPMIC) using silicon-proven subthreshold technology that can autonomously manage any sensor, microcontroller, wireless chip, or peripheral to reduce energy consumption by ~50-99%.	NanoPower semiconductor AS

Project Name	Project Description	Norwegian Participants
OptHyMob	The industrial project OptHyMob (Optimized Hydrogen Powered Maritime Mobility) is a combined KSP/IPN funded by the RCN. The project aims to significantly improve hydrogen fuel economy and extend system lifetime for maritime fuel cell-battery hybrid systems. The project will combine experimental and full-scale operational data with knowledge of degradation mechanisms in maritime fuel cells and batteries to develop a cost-optimisation system for optimal load distribution between fuel cells and batteries applied for ship propulsion. The system will be based on physics-based and data-driven models and implemented in an industrial clustered edge computing infrastructure. To succeed with the innovation, research is needed to gain knowledge about degradation mechanisms in batteries and FC systems used in maritime applications, how they affect each other and how they best can be used in combination to limit system degradation and extend system lifetime.	Corvus Energy, NORCE, Topeka, SinOceanic Shipping and SEAM
SPEED	The IPN project SPEED (Let's speed up battery analytics) aims to significantly advance open-source data analytics tools for battery cell analysis, enabling battery researchers, both in academia and industry, to faster implement new diagnostics routines, analyse larger data sets and implement best practices in both cell testing and data handling.	Morrow Batteries

Project Name	Project Description	Norwegian Participants
HeaLiSelf	Being able to quantitatively monitor the state of health of batteries non-destructively and during usage is essential to both further improvement and better understanding of their limitations and performance. X-ray computed tomography is well-suited for in-situ/operando studies of battery related processes and assemblies, however, it is expensive, and unsuitable for battery health monitoring on a commercial scale. Optical fibres, notably fibre Bragg gratings, constitute a complementary low-cost and light-weight technology, enabling temperature, chemical environment, and mechanical strain to be measured in small form factor batteries. For the HeaLiSelf (Self-healing lithium-ion batteries enabled by fibre/nano optic sensing and convergent data-driven analytics) project, the working hypothesis is that data collected from fibre Bragg grating sensors will serve as a highly efficient proxy for X-ray computed tomography observations. The strategy of HeaLiSelf relies on the convergence of fibre optic sensing, nanoscale material characterisation, and advanced data analytics.	NTNU, FFI, IFE
DREAMS	DREAMS (Diagnostic Requirements for Evaluating and Advancing Module Safety) will develop time and cost-efficient methods to detect safety-critical degradation mechanisms in battery cells and modules during operation. DREAMS will expand and improve a well-known technique applied for SoC estimation as an independent diagnostic technique for battery health. The technique involves finding a battery's state of health as well as unveiling how the battery has lost its capacity through identifying ageing modes and possibly ageing mechanisms. The technique will also be applicable as an on-line diagnostic tool on most real battery operational data to increase the overall safety of Li-ion battery systems.	IFE, FFI, NTNU

SINTEF's research

On-going research activities and projects related to digitalisation where SINTEF is either coordinator or partner, are described below.

Digital frameworks and platforms

SINTEF has developed several frameworks and platforms for development of the battery field, from cell to systems level.

Battery cell development

BattMo - A Continuum-Scale Simulation Software for Electrochemical Systems

BattMo (100) is an open-source framework implemented in both MATLAB and Julia. The framework is currently capable of modelling Lithium-ion battery cells, using the Doyle-Fuller-Newman model, and can be extended to include other battery chemistries and hydrogen systems. BattMo is well-suited for typical design engineering workflows, especially those involving 3D modelling. It delivers efficient performance in cases where simulation runtimes of a few seconds per cycle are acceptable, making it ideal for long-term cycling studies and iterative design using gradient-based optimisation. BattMo also supports advanced degradation models, including SEI growth and lithium plating, and can incorporate thermal effects for more comprehensive simulations.

In addition to the MATLAB and Julia environments, we also offer the BattMo App a user-friendly, web-based tool designed to simplify pseudo-two-dimensional (P2D) simulations for those with no programming experience. The app makes it exceptionally easy to run simulations, thanks to its graphical user interface and seamless workflow. Users can quickly access a comprehensive default parameter library for various materials, customize simulation settings, and take advantage of interactive visualisation tools to analyse and interpret results with ease.

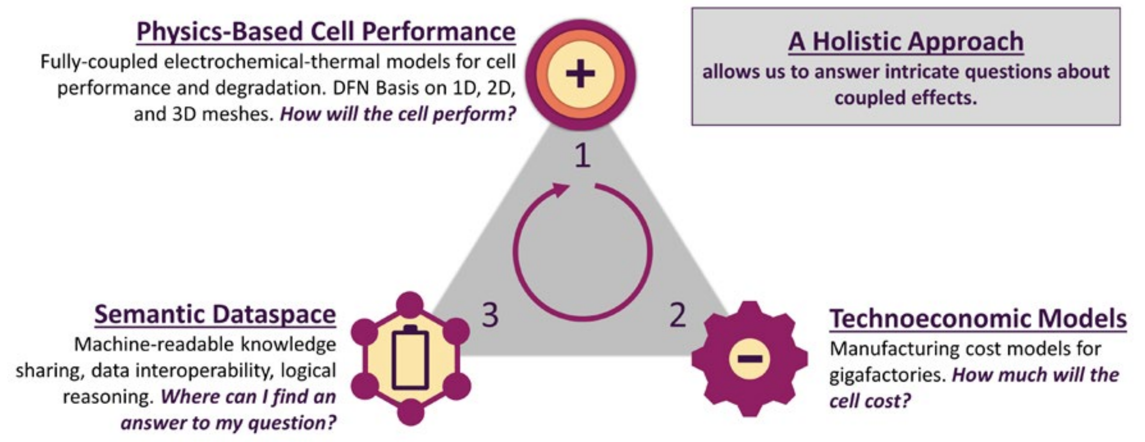


Figure 10: *A cutting-edge, open-source battery modelling and simulation framework (Illustration: SINTEF).*

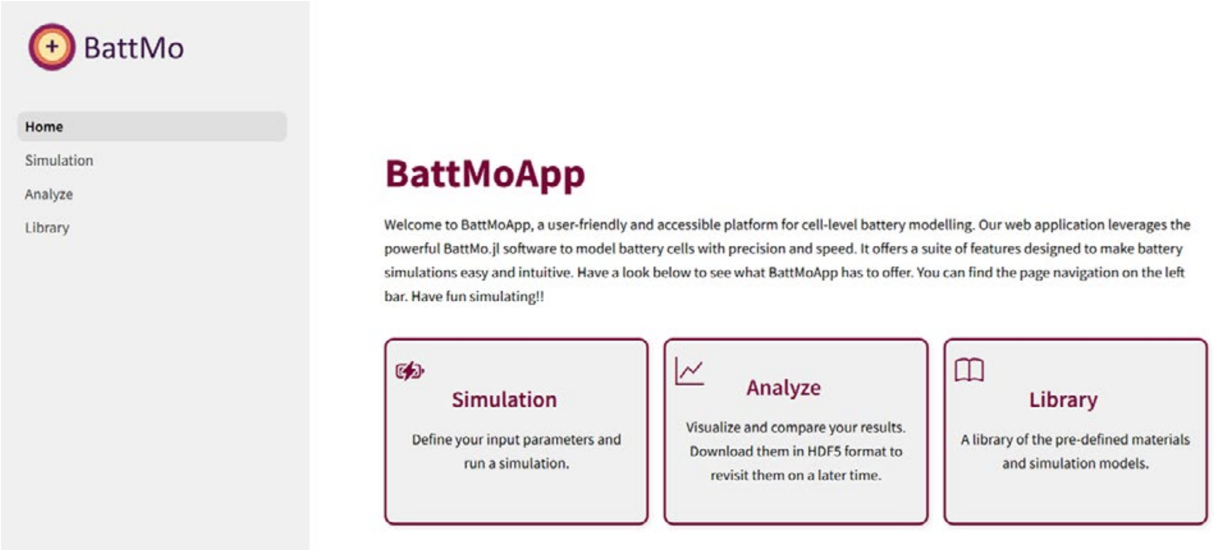


Figure 11: The BattMo GUI app (Illustration: SINTEF).

BattINFO - A semantic Framework for Battery Data
The Battery Interface Ontology (BattINFO) is a semantic framework designed to describe and interlink the full ecosystem of battery data: materials, design specifications, tests, equipment, processes, and results (101). In essence, BattINFO describes concepts related to batteries and their relationships between them, in a machine-readable format.
The concepts become an unambiguous, universal vocabulary that enables standardised, machine-readable descriptions of both virtual and real research workflows related to battery cells and stacks. By turning unstructured battery data into connected, queryable knowledge, BattINFO reduces overhead, improves interoperability, and lays the groundwork for digital twins, automated workflows, and AI-driven insights.

Digital Twin Framework
A battery digital twin enables real-time monitoring and actuation over battery performance and behaviour. It also integrates diagnostics to detect faults and prognostics to predict future performance, degradation, and remaining useful life under various usage conditions. The design of the digital twin framework integrates well-structured battery metamodels with dynamic and static data sources to build digital representations of physical battery systems. To achieve this, the digital twin framework brings together three distinct tools:
COLD, GLEANED, and ECHOED, each playing a specific role in the digital twin architecture.

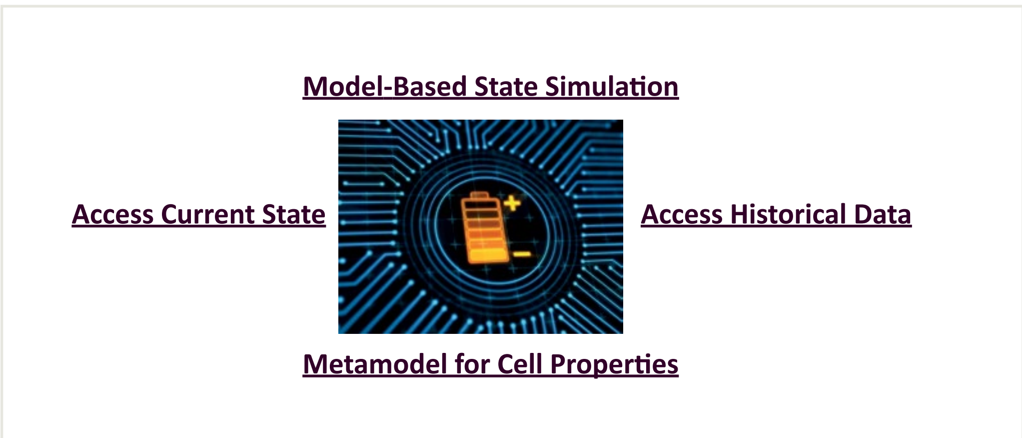


Figure 12: A schematic representation of the battery digital twin framework (Illustration: SINTEF).

Creating Ontology-Based Linked Data (COLD)
The COLD framework serves as the foundational layer for creating standardised and semantically rich battery metamodels. The goal of COLD is to provide a consistent and flexible mechanism for describing batteries, enabling interoperability and accurate digital representation. What makes COLD particularly powerful is its automated generation of these data models from BattINFO. This approach eliminates manual errors, ensures semantic accuracy, and allows the framework to evolve alongside updates to the ontology.

Electrochemical Ontology-Enhanced Digital Twin (ECHOED)
The ECHOED framework ties together the battery metamodel from COLD and the data collected from battery testers to create a fully functional digital twin. ECHOED provides a high-level interface for instantiating and interacting with digital twins, making it possible to monitor live performance, analyse historical data, and connect with simulations or optimisation tools.

Energy systems modelling

ZESES
In the internally funded ZESES project, SINTEF has developed models to optimise the design and operation of zero emission MW scale hybrid electrical energy systems of ships, such as ferries in Norwegian fjords. The models account for the route and operating profile, timetable, access to grid for battery charging and hydrogen production and re-fuelling. The model results include optimal dimensions of the components in the energy system (battery or fuel cell size), onboard hydrogen storage, required charging and hydrogen infrastructure, as well as degradation of system or components. The optimisation is done with regards to the lowest TCO (total cost of ownership) for a chosen time perspective.

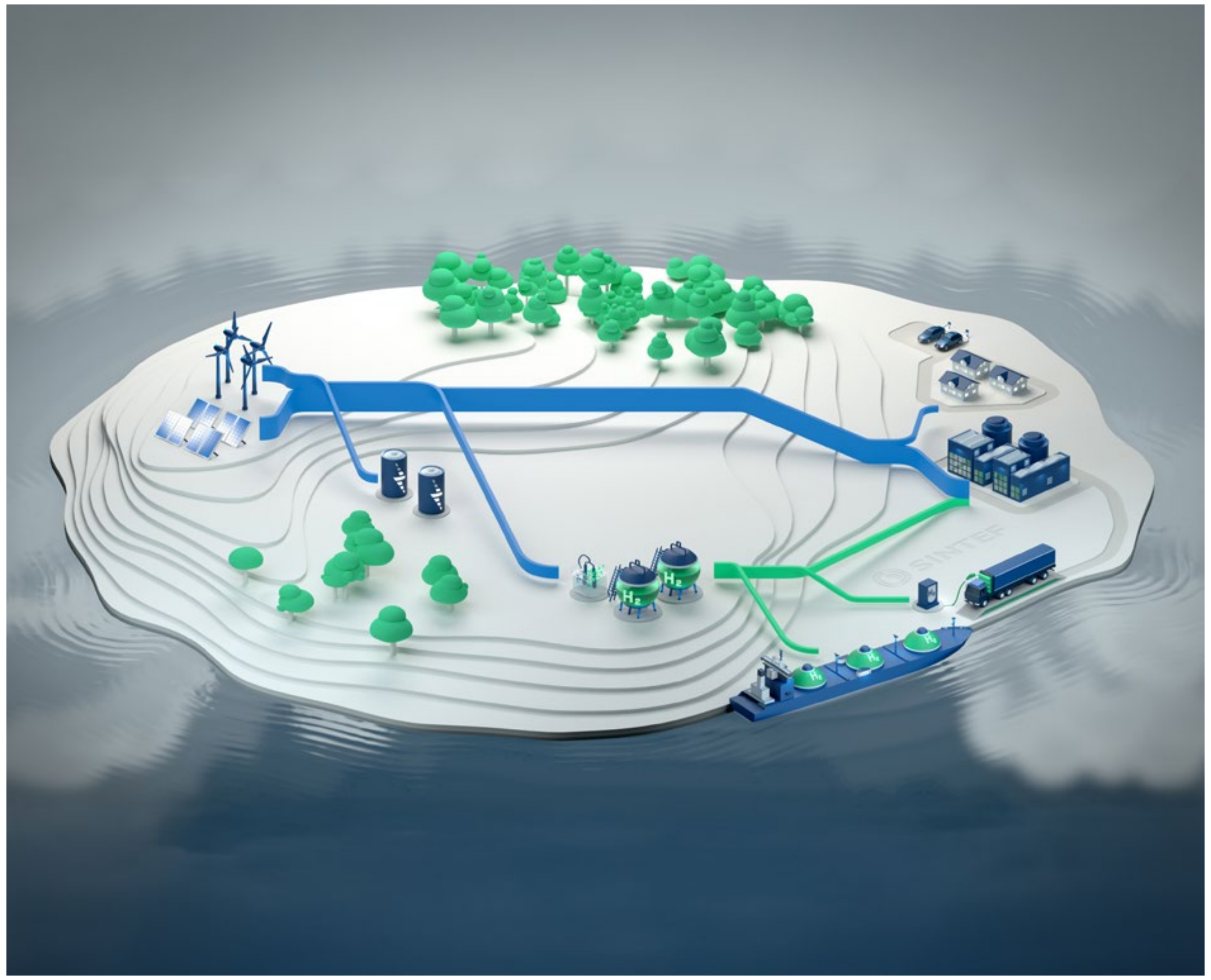


Figure 13: Remote island showing an off-grid, stand-alone energy system (Illustration: © SINTEF).

Virtual FCS
VirtualFCS is a Modelica library for hybrid fuel cell-battery system modelling developed through the EU H2020 research project Virtual-FCS (102). The objective of the open-source modelling library is to enable the design, simulation and performance assessment of hybrid systems of different architectures, for researchers, hobbyists, and industry actors. VFCS include data-driven degradation models depending on operational modes, capable of predicting the system lifetime. While the library was designed with transport applications in focus, it remains reliable for other stationary applications as well. While the library is focused on the hybrid fuel cell-battery system, it is extendable to other technologies via either model interfaces or hardware-in-loop capabilities, which are included in the library.

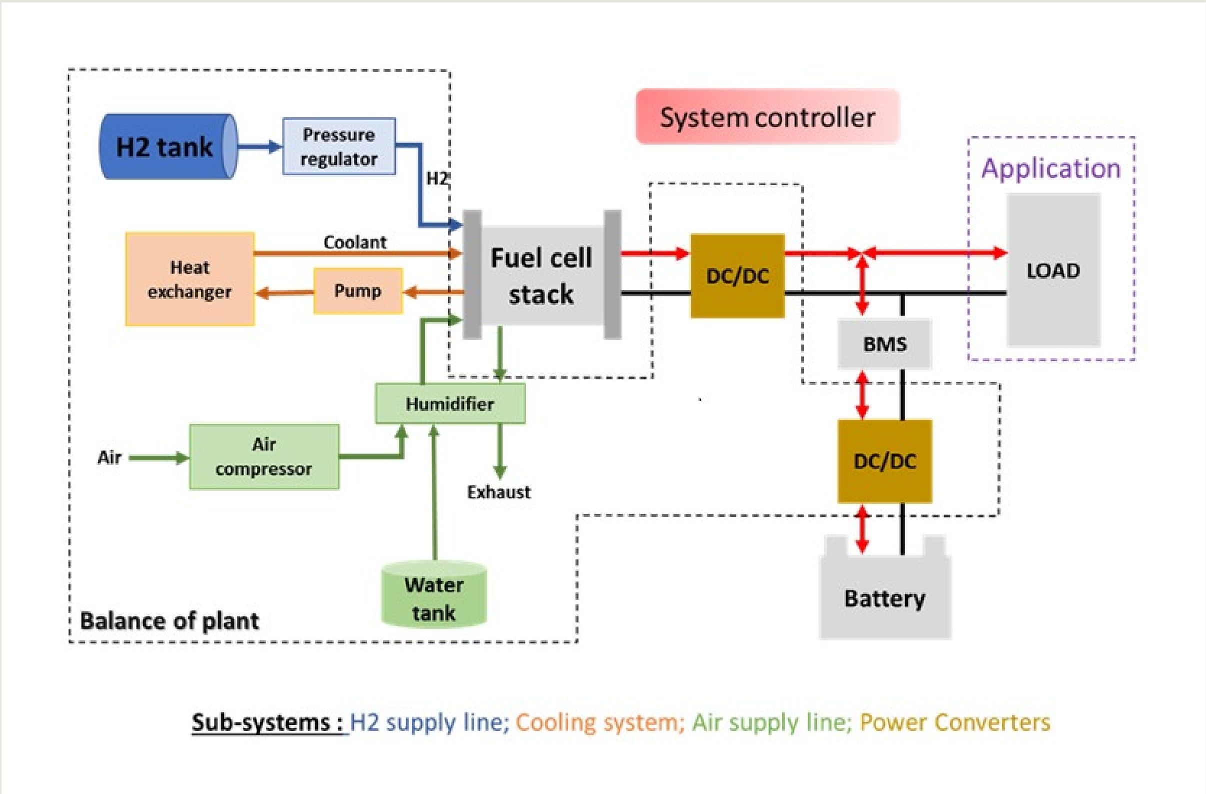


Figure 14: System of fuel cell and battery used in the Virtual FCS model (103) (Illustration: SINTEF).

Integrate (previously eTransport)
Integrate is a software system developed by SINTEF for the optimisation of integrated energy systems. In the energy system optimisation process it takes into account the projections in energy demand and the different technological possibilities for energy supply, conversion between energy carriers, distribution, storage, end-use measures and restrictions on CO_2 emissions (104). The solution methodology is a combination of linear programming (LP) and dynamic programming (DP / SDP). The end result from the model is a cost-effective development plan, as well as a model of the operation of the system hour by hour in different seasons.

Research activities

Pilot line insights and research data management at the battery lab
Research data management is central for tracking the provenance and lineage of samples generated in our pilot line laboratory. To support this, customised digital tools are being developed to manage samples and data across the battery manufacturing workflow. Built on top of existing research data management systems, these tools are designed to adapt to various workflows and support the creation of a comprehensive database by tracking metadata at every stage of the battery manufacturing process in our pilot line. This initiative showcases our growing digital capabilities and underscores our commitment to FAIR (Findable, Accessible, Interoperable, and Reusable) data principles. By enabling seamless access to manufacturing data, we deliver added value and transparency for our clients.
By integrating this framework with the tools developed in the BATMACHINE project, which focuses on standardised digital machine interfaces, we enable seamless data exchange across equipment and material management systems.

Scientific machine learning to predict battery lifetimes and degradation
Predicting battery lifetime and degradation behaviour remains a significant challenge. Traditional approaches rely on either pure machine learning (ML) models, which require large datasets to be effective, or physics-based models, which are applicable when the underlying physical principles are well understood. However, many real-world research challenges fall between these extremes, involving systems that are expensive to probe for data, and are governed by partially-known physics. We develop and explore Scientific Machine Learning models that exploit both scarce data and physical principles to make data-efficient, transparent and accurate predictions of key battery phenomena. Our efforts focus on understanding battery degradation and predicting battery lifespan. By integrating AI into battery research, SINTEF is enhancing its expertise in hybrid modelling techniques, leveraging domain experts' knowledge to drive innovation and accelerate the development of more efficient and reliable battery technologies.

Data analysis tools from battery testers
Battery test data is notoriously challenging to analyse, as different test equipment manufacturers often use proprietary data formats, custom column names, and inconsistent definitions for cycle numbers. This lack of standardisation complicates data integration and comparison across systems. The battery test data analysis activities focus on the automatic extraction of parameters from battery tests. Starting from only raw time series of current and voltage, our software identifies the type of test applied, such as Galvanostatic Intermittent Titration Technique (GITT), High Power Pulse Characterization (HPPC), Intermittent current interruption (ICI), or Constant Current Constant Voltage (CCCV), and extracts key parameters like diffusion coefficient, internal resistance and pseudo-open circuit potentials. These parameters can then be utilised in P2D simulation tools, such as BattMo, for further analysis and modelling. Additionally, the project involves scraping publicly available data from Zenodo, processing it, storing the extracted information, and generating visualisations to support experimental researchers.

Research projects

FME Battery (Centre for next generation and improved circular sustainable battery technology value chain) is a centre for environment-friendly energy research, started in 2025 and ends in 2032 (105). The centre is hosted by NTNU and includes numerous R&D and industrial partners. Battery technology represents one of the most significant business opportunities of this decade and it is important to gather the key actors of Norway and to position our competence in an international environment. By jointly emphasising research, innovation and education across different value chain elements, we can create a more sustainable future. Figure 15 illustrates the work packages constituting FME Battery, showing the value chain approach from materials processing to integration and recycling. SINTEF's main contributions to the FME Battery are in WP6 Digitalisation, WP4 Manufacturing, WP5 Diagnostics & System Integration, in addition to leading WP7 Innovation and Prospects.

Figure 15: FME work packages (Illustration: NTNU)

DigiBatt (Innovative digital solutions for fast battery testing) is a three-year EU project in collaboration with Corvus, and also research and industry partners from Germany, Austria, Belgium and England (106). The project aims to address the current slow paradigm for battery testing, that is fragmented, time-consuming, and expensive. To fully characterise the performance of a battery cell, a wide variety of both destructive and non-destructive tests are required, some of which can last for months or years.
The goals of DigiBatt are to standardise, automate and accelerate the battery testing process. This will be achieved through several novel approaches.

Key new developments in the project will be:

- Standard semantic data models for battery testing, which can be read and understood by both humans and machines
- A digital-twin infrastructure linking experimental testing rigs with simulation-based virtual testing workflows and allowing for automatic triggering of tests
- Data-driven approaches to support intelligent design of experiments and tailored testing workflows
- Reliable new models for predicting battery lifetime and safety within system-level infrastructure.

Delivering publicly available, open-source solutions will also be a key objective of the project. These developments are expected to streamline testing workflows, enhance the quality of results, and make digital battery testing accessible to the broader battery community.

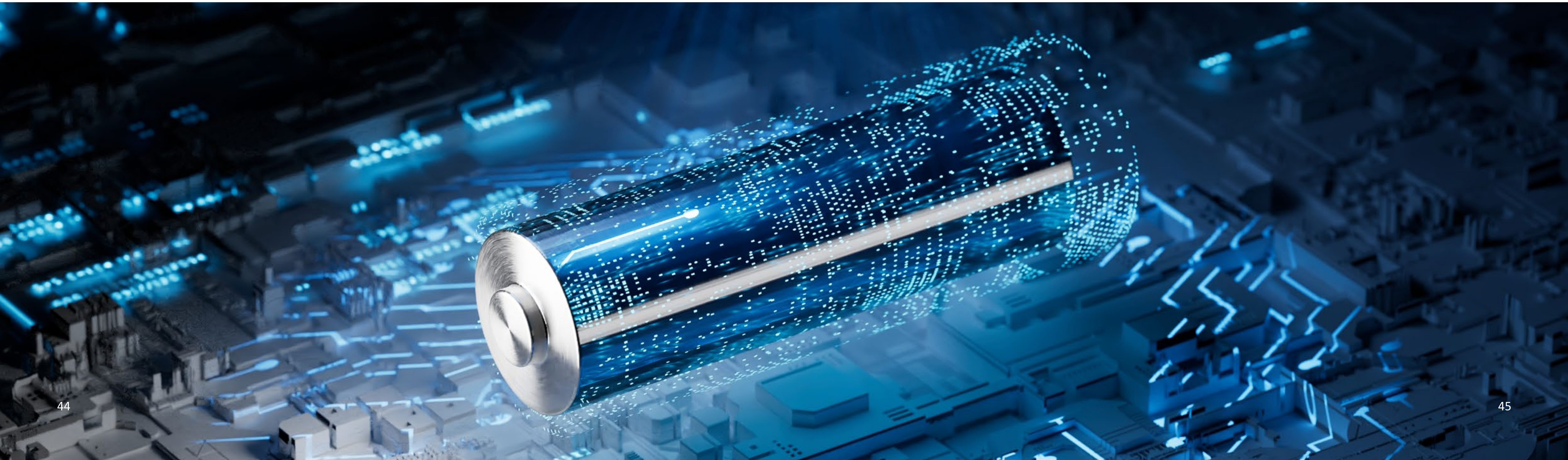
BATMAX (Battery Management by Multi-Domain Digital Twins) is an EU project funded under the HORIZON Europe program (107). The project spans a duration of four years and has a budget of 5 M€. Coordinated by the Finnish research institute VTT, it boasts a consortium of strong industry partners and renowned 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 parameterising physics-based models. This process will play a crucial role in reducing the cost of model development and, in turn, increase the utilisation 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.

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 an EU project coordinated by Vrije Universiteit Brussel and funded through HORIZON EU with a total cost of 7.2 M€ (108). 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.

SINTEF's main role is the digitalisation and data collection and management using data from our pilot lab. We contribute to the development of Intelligent control processes and Industry 4.0 which will be integrated through the creation of a collaborative and FAIR (Findable, Accessible, Interoperable, Reusable) data space for battery production. Digital interfaces between battery manufacturing equipment, control systems and engineers will be developed with the aim of creating universal digitalisation tools to improve battery production and create a battery passport.

Additional previously described projects

IntelLiGent (Innovative and sustainable high-voltage Li-ion cells for the next generation (EV) batteries) is EU-project coordinated by SINTEF funded in the Horizon Europe funding programme. The IntelLiGent project was described under Chapter 3. Advanced materials- SINTEF projects.



5. 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 (109). If all sectors needing batteries are included, such as heavy machinery, transportation or stationary storage, the number of battery production plants with GWh capacity would surpass a roughly estimated 400 on a global scale. In November 2024, global Li-ion battery demand surpassed 1 TWh according to RhoMotion (110). This corresponded to a 26% increase in demand since the previous year. The majority of the growth was from the BESS market, while the EV market still has the highest demand for LIBs. Demand from stationary storage applications doubled to 15% in 2024 compared to 2020.
As mentioned in the previous chapter, Li-ion battery cell manufacturing has been dominated by Asian stakeholders. Thus, knowledge and competence on manufacturing processes as well as equipment needed for battery cell manufacturing are centred in three main countries, namely China, Japan, and South-Korea (111 p. 74). A comprehensive list of battery cell manufacturing plants, and planned initiatives was published by Teknisk Ukeblad in September 2023 (112), including also the Norwegian initiatives FREYR, Morrow, Elinor Batteries and Beyonder. Since then, FREYR has changed name to T1 Energy and is no longer pursuing battery cell manufacturing (113), while Morrow, Beyonder and Elinor Batteries are still in planning to establish GWh production in Norway. 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 not-for-profit association that aims to create a unique European ecosystem of actors in the equipment and machinery segment (114). The battery manufacturing industry can then grow stronger together, and they are aiming to give Europe a leading position in this field. They currently have 115 members and are growing, showing the great interest for this field in Europe.

A significant downturn in the European manufacturing industry has been witnessed with the collapse of Northvolt and CustomCells, downscaling of operations or ambitions or pause by the likes of NOVO Energy, ACC (Automotive cells company), PowerCo among others. This is due to high cash burn rates on ramp-up, cost pressures, rapid cell format developments, lack of sufficient experienced talent for ramp-up phase, and lower European EV demand (111 p. 33). In parallel, there are joint venture announcements by CATL-Stellantis (50:50 , LFP,50 GWh) in Spain, CALB investments (15 GWh, $2 Billion) in Portugal and the "friend-shoring" of the Chinese LFP, pCAM and graphite supply chains in Morocco as supply chains jostle to stay ahead and in compliance of legislation and policy while locking-in market shares, and as car makers strive to secure a timely supply of cells for their launch schedules (115-120).

Battery cell manufacturing

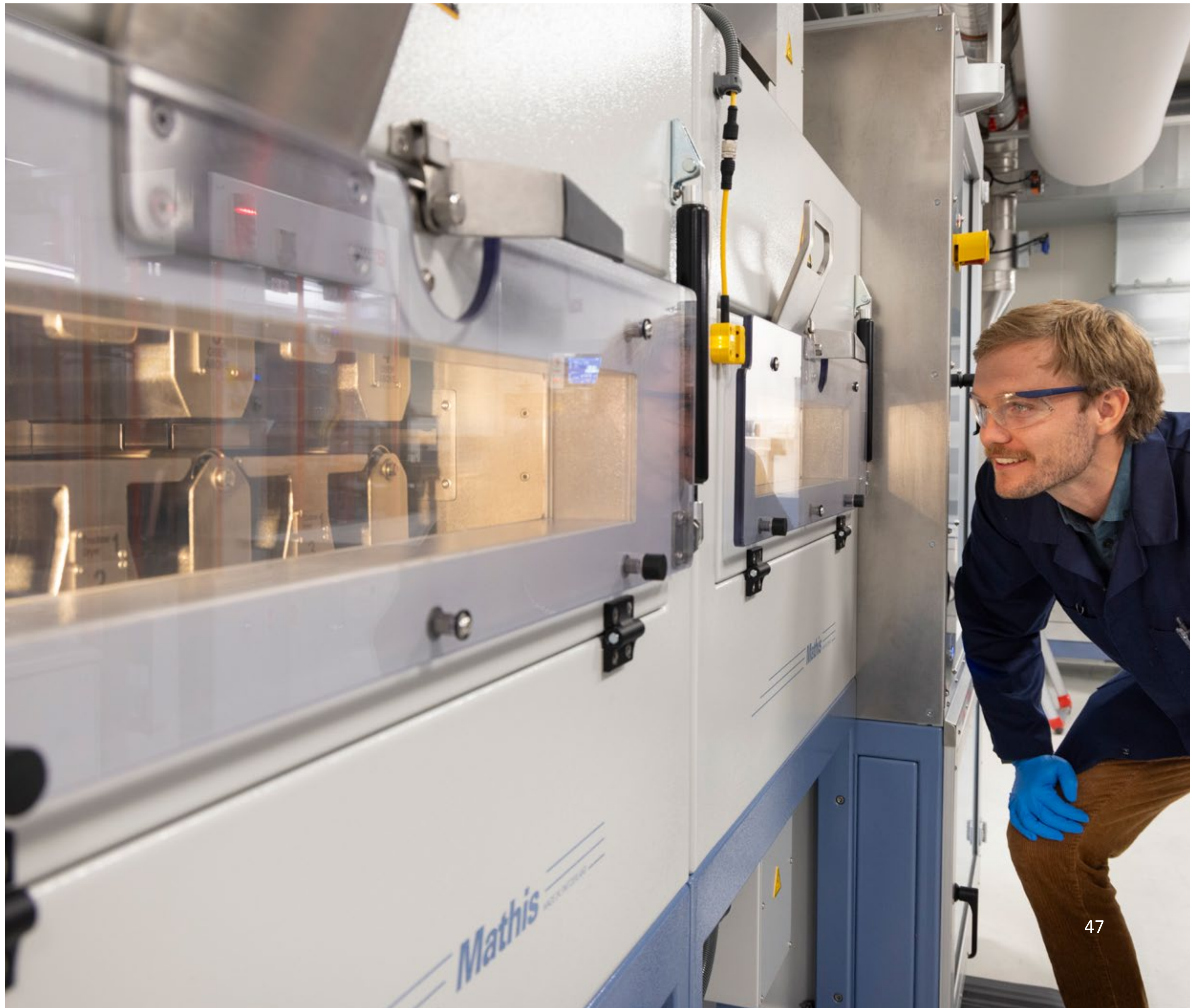
A standard lithium ion consists of the following components:

- Anode: Typically graphite, sometimes with an addition of silicon. Stores the Li ions when the battery is charged.
- Cathode: Consist of metals like nickel, cobalt, iron and manganese. Stores the Li ions when the battery is discharged.
- Electrolyte: A liquid, gel or solid that transports lithium ions between the anode and the cathode.
- Separator: A thin membrane physically separating anode and cathode to prevent short circuiting but allowing ionic transport.
- Current collectors: The back side of the electrodes (copper foil on the anode and aluminium foil on the cathode in Li-ion batteries) transports the current to and from the electrodes.
- Cell housing: Protects the battery cell.

During a standard manufacturing process, the anode material and the cathode material are both mixed with binder and solvent, and slurries are produced. The slurry is then tape cast onto the appropriate current collector and dried into electrode casts.
The cast electrodes are then cut into the appropriate shape and stacked with the separator. This assembly is encapsulated in the cell housing and the electrolyte (if liquid) is poured into the cell pouch, filling all voids in the pouch. The cell is then sealed and prepared electrochemically through a process called formation.

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 (121). Planning production through use of digital twins is also being deployed to minimise commissioning time, increase efficiency and reduce scrap, energy and costs. Robotisation, automation and digitalisation of the battery manufacturing process is also a crucial development for the battery cell production industry. Battery cell production is a complex process with over 150 more or less interdependent parameters and understanding and control over all these parameters is crucial in order to reproducibly produce battery cells of sufficient quality.



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 assembly of cells and adaption of modules to specific applications.

A potential game changer for Norwegian battery manufacturing appeared when the Inflation Reduction Act (IRA) was adopted into US law in 2022 (122). 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 foreign investors. 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 (123). 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% tariff 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 (124).

Although there are some political, financial and administrative hindrances for battery production in Norway, it seems that some of the initiatives are keeping with their plans for producing LIB cells in Norway. It remains to be seen, however, how potential financial barriers, better incentives in other countries and the "Trump 2.0" administration policies will affect the Norwegian battery production in the next few years.

Battery cell manufacturing

As of July 2025, three Norwegian companies, Morrow, Beyonder and Elinor are still active in their ambitions to manufacture cells in Norway. HREINN entered bankruptcy proceedings and ceased operations while FREYR has completely exited battery production, switched its headquarters to the USA and refocussed on solar panel manufacturing rebranding to T1 Energy.

Morrow's strategy is to focus on industrial standard production of LFP before maturing into LNMO technology, which is a cobalt-free cathode. Morrow is focussed on securing start of production at its Morrow Cell Factory (1 GWh/annum LFP BEV2 cells) in Arendal and advancing its proprietary LNMO-XNO battery technology at its Grimstad based R&D centre. They have ramped up their sales activities and target commercial LFP cell production in Q3 2025. They have not escaped the challenges faced by other European factories; namely high cash burn rate and delayed work permits for its Korean ramp up experts from its equipment suppliers. This has caused staff downsizing and delayed start of production (4 months) costing the company 100 million NOK and delayed revenue streams (85). For the LNMO materials, Morrow has entered into a collaboration with the Danish company Topsoe, with the aim to establish a pilot facility for LNMO production in the south of Norway (125). As of 2025 Morrow is the company closest to commercial production in Norway. Their target markets are BESS, commercial mobility, industry, and offroad and passenger vehicles. Morrow secured IPCEI European Battery Innovation program funding of 345 MNOK in 2024 (126).

Beyonder, the second 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 a Li-ion battery. This results in high charge and discharge rate capabilities suitable for applications with high power requirements. Their cathode is also based on wood derived activated carbon making the production more sustainable (127).Their pouch cells, 33 Ah with an energy density of 120 Wh/kg, have managed more than 12000 cycles at 5C/5C, 25 °C with 70 % capacity retention, and they are capable of a 15C constant power discharge (128). Cells are manufactured via an outsourcing model to utilise overcapacity at select partners in China, namely GangfengLi Energy and Farasis (including modules) to quickly achieve production scale as well as remain CAPEX light. This offers Beyonder access to highly experienced scale-up teams and facilities and rapid cell development while keeping customer management and R&D in-house. They also have signed an MOU with Leclanché towards European production and plan for a small-scale production line for the defence market. The targeted market applications include bus/heavy duty, data centres and 12V/48V batteries for low voltage systems in cars (129). Beyonder secured IPCEI European Battery Innovation program funding of 75 MNOK in 2024 (126).

Elinor Batteries is an initiative owned by the Norwegian investment company Valinor (130). They are currently developing plans for a giga-scale battery factory in Orkland, Norway. Elinor is planning to build the factory in modules to limit financial and technological risk. At full capacity, the goal is to produce batteries equivalent to 40 GWh per year. Elinor targets the stationary battery market (BESS) via LFP-based batteries. In 2024, Elinor entered a technology partnership with Morlus Technology, a Chinese cell and BESS producer led by an ex-BYD team. This will result in alignment of Elinor's product roadmap and production line concepts with Morlus', benefiting both from the experience and competence of Morlus while customising for the European market and Norwegian standards. The agreement enables Elinor to gain an early market entry with cells and BESS DC Blocks currently produced by Morlus. Consequently, it has made a market debut of its flagship 6.7/7.2 MWh Orkan DC Block (fits in a 20ft container) at the 2025 London Energy Storage Summit. Elinor expects an investment decision to be made in 2025.

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 robotised and digitalised battery module factory in Trondheim early 2019 basing their production on imported cells (131). 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 (132). 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 (133). Their headquarters is located at Høvik in Oslo.

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 (134). They engineer, design, build and test batteries for optimum performance for any required application. SCHIVE is also located in Oslo.

Hagal is a company providing Smart BMS solutions enabling individual cell monitoring and balancing in a pack ensuring that a single cell does not degrade the performance of the whole pack. Their product is known as the Hagal Rebel Core™ BMS (135).

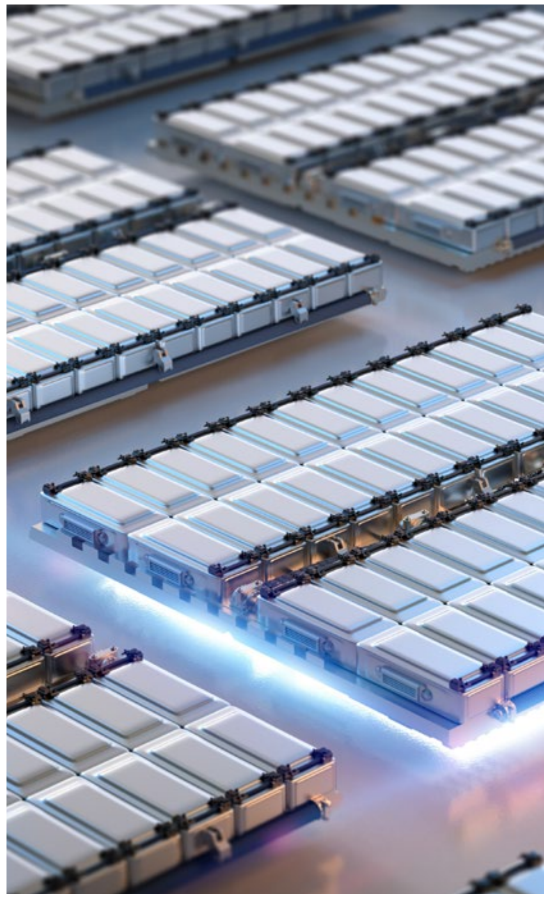
VersaPowr is a company assembling battery energy storage systems of 200 kWh for the C&I market and also provides energy management systems (EMS) for management of distributed energy assets (136).

Pixii produces modular BESS systems based on LFP and NMC battery technologies for energy storage (137). Nordic Booster has developed a portable fast-charging station and are also producing modular systems for stationary applications (138). As previously mentioned, Elinor is currently marketing several BESS container solutions for stationary storage (139).

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	Norwegian Participants
BatteryCoast	The project at UiA aims to strengthens 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 optimisation.	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 (140).

The infrastructure is led by IFE with 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, characterisation, 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 laboratories that may give major national advancement in a highly competitive and accelerating field.

GigaGreen (Towards the Sustainable Giga-Factory: Developing Green Cell Manufacturing Process) is an EU initiative coordinated by Politecnico Di Torino (141). 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 prioritises 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 minimising 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.

BATNET (Norwegian Battery Packing Network) is a large project funded through Green Platform with Kongsbergklyngen as coordinator (142). 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). 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.

Additional previously described projects:

SUMBAT KSP (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 (57). The SUMBAT project spans several of the topics of this report and was described under Chapter 1. Raw materials and recycling- SINTEF projects.

IntelLiGent (Innovative and sustainable high-voltage Li-ion cells for the next generation (EV) batteries) is EU-project coordinated by SINTEF funded through the Horizon Europe funding programme. The IntelLiGent project was described under Chapter 3. Advanced materials- SINTEF projects.

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 funded through the Horizon Europe funding programme. The IntelLiGent project was described under Chapter 4. Digitalisation- SINTEF projects.

FME Battery (Centre for next generation and improved circular sustainable battery technology value chain) is a Centre for environment-friendly energy research, funded by the Research Council of Norway. The FME Battery was described under Chapter 4. Digitalisation- SINTEF projects.

6. Battery application – transport

Norway's position

The transport sector is responsible for over 1/3 of Norway's emissions of greenhouse gases (143). As part of the Norwegian government's plan to achieve the climate goals a set of means of action was first implemented in the national transport plan for 2018-2029 and is now being carried forward for the 2025-2036 period (144). The initial aim was 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. These objectives are not fully met, as the share of zero-emission of first-time registered vehicles was at 88 % for private cars, 28 % for light duty vehicles, 27 % for long distance busses and 12 % for trucks in 2024 (145). New policies are in place to increase the share of low emission transportation, including an increase of the CO_2-fee on greenhouse gas (GHG) emissions not covered by the European emission trading system (ETS). The transport sector should increase its emission by 30% by 2030 (compared to 2005 levels) and 100% of new heavy-duty vehicles should now be zero-emissions or use biogas by 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, reaching near-total electrification of sales, with 88% of car sales being battery electric in 2024, and 92% as of May 2025 (145), (146). 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. They also have several hybridised vehicles and the two most trafficked ferry-connections operating in the Trondheimsfjord are also hybridised. These ferries had by 2024 reduced their emissions by a factor of 6 compared to 2018 (147). However, while plans were initiated in 2022 to fully electrify the entire fleet of ferryboats in the fjord, they are currently facing technical challenges and may ultimately be abandoned to the profit of diesel-powered boats (148). 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 (149). Also, in the regions outside the largest cities, operators have started investing in electric public transportation as exemplified by Nobina in Østfold county (150). Tide AS is also participating in this effort, announcing the start of operation of 235 electric buses in Vestfold county (151).

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 transportation 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, with newer, more powerful and longer-range trucks from Scania soon to be seen driving in Østfold (152). 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 (153).

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 (154).

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 30 % of all passenger and ferry-connections is as of June 2025 running partially or fully electric (155). 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 (156). 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.

Figure 16: The world's first large electric car ferry, MF Ampere, launched 10 years ago by Norled (Source: Norled AS)

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 (now Eikefjord Slipp AS after a bankruptcy process in Brødrene Aa) constructs and rebuilds high speed passenger ferries exemplified by MS Baronen and Baronessen (157) and Fiskerstrand Verft offers solutions for rebuilding from diesel and LNG to battery operation (158). Selfa Arctic is another company whose main occupancy is maintenance and repair of recreational- and profession boats, but they also construct new coastal fishing vessels equipped with battery propulsion (159). Evoy also provides electric boats, both for recreational purposes as well as vessels for the fish farming industry (160). The company is expanding, receiving recently 190 MNOK from the EU's innovation fund for producing electric boat motors, shortly after merging with the British producer Vita to become Europe's leader in high/power electric propulsion (161; 162). 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 (163). One of the companies who also provide battery systems for large ships is ABB. They started offering containerised energy storage systems in 2021, which are tailored for container ships, offshore supply vessels, and ferries (164).

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	Norwegian 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
STEESMAT	With large vessels accounting for a significant portion of the maritime industry's emissions, the need for energy-efficient solutions is urgent. Current power systems on ships are inefficient, hindering the transition to sustainable transport. The EU-funded STEESMAT (Smart Transformer for Enhanced Efficiency and Sustainability in Maritime Transportation) project led by Maritime CleanTech aims to develop advanced technologies for onboard DC grids on large vessels. STEESMAT focuses on creating a plug-and-play power electronic system based on solid-state transformer technology. The project will integrate fuel cells, batteries, and AI-driven smart management systems to boost energy efficiency. Through testing in laboratory and real-world conditions, STEESMAT will pave the way for greener maritime transport.	Maritime CleanTech

SINTEF's research

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 (165). 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 commercialisation 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 (166). 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) optimising route patterns and charging infrastructure.

eWAVE is an Horizon EU project with a consortium of 18 partners, including SINTEF (167). The project has received a total of € 7.5 million over 4 years, staring in 2025. The project focuses on research and development of high-voltage technology for battery powered vessels. By developing high-energy-density batteries, scalable modular systems, and an integrated safety concept, eWAVE aims to enhance the sustainability, safety, and efficiency of maritime transport. The project will also explore circularity through bio-based materials and recycling, supporting the EU's goal of reducing the environmental footprint of shipping.

FME MarTrans is an eight-year collaborative project with 65 partners within maritime industry and research, funded by the Research Council of Norway under the Research Centre for Environment-friendly Energy (FME) program (168). The focus is on research, innovation and education to accelerate the energy transition within the shipping industry, while increasing value creation and exports for the Norwegian maritime industry. With total funding from the Research Council of Norway and the industrial partners of over NOK 300 million, this is the world's largest maritime research program of its kind. The main objective of the centre is to accelerate the maritime energy transition and reduce emissions from ships through R&D for innovation and value creation within the Norwegian maritime and energy industries.

SafeLiMAR is a recently granted KSP project with SINTEF, FFI and Høgskulen på Vestlandet as research partners. Additionally, 6 industrial partners, the industrial cluster RENERGY as well as Norwegian Maritime Authorities and Norwegian Directorate for Civil Protection (DSB) will contribute with funding and expertise in the project. SafeLiMAR's primary objective is to enhance the safety of Li-ion battery systems by developing better design solutions, improving operational practices, and increasing expertise in managing Li-ion batteries in maritime environments. The project will last for 4 years and has a total funding of 13.24 MNOK.

Additional previously described projects

SUMBAT KSP (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 (57). The SUMBAT project spans several of the topics of this report and was described under Chapter 1. Raw materials and recycling- SINTEF projects.

7. 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 CO_2 emissions incurred by the fossil-fuel based power and heat generation. To cover all needs related to stationary energy storage, hybridisation of systems and technologies is also considered for certain applications. Combining different types of energy storage technologies, such as batteries and supercapacitors (169), can provide complementary advantages in terms of power and energy capabilities.

Many Norwegian grid- and power companies are 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 (170). 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 (171). Another ENOVA supported project is NORFLEX in which a stationary battery is installed at the new energy station at Kongsbergporten. Here, Å Energi and Circle K are investigating how a stationary battery together with solar power can support the grid during periods with high load (172). 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 (173). Å Energi is also one of the main stakeholders for the Morrow Battery factory described in Section 3.

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 organises a network of qualified solar installers which together with suppliers offers complete solutions for the private market. One of these companies is Solcelle-spesialisten, who uses Pixii as one of their sub-contractors 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 the 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 (174).

Another Norwegian substantial stakeholder in the stationary battery market is Eltek (175). Head-quartered 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. 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 (176). These are containerised battery systems on wheels which can be moved from site to site. Nordic Booster provides similar solutions with mobile high-power charging systems with integrated battery technology and energy management systems on wheels (138).

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 and Evyon deliver battery systems for the stationary energy market. Examples of buildings with battery systems delivered by Eco Stor are Holmlia Skole (177), Tiller videregående skole (178), and Skipet (179), while Eaton has delivered the battery system located at Bislett Stadium (180).

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	Norwegian Participants
Smart Platform	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 offshore wind integration into the platform's electric network. Smart Platform will investigate how to mini-mise 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 Garder-moen 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, Equinor

SINTEF's research

SafeBESS (Technology and building design for safe operation of battery energy storage systems) is a competence and knowledge building project funded by the RCN and industry partners and spans a duration of four years (181). 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.

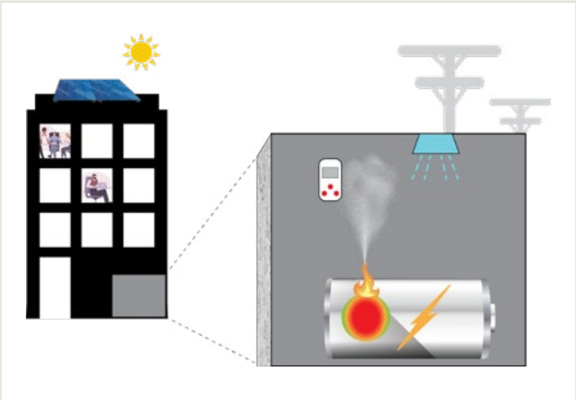


Figure 17. SafeBESS aims take an in-depth look at battery fires, how they should be handled and how they can be safely installed in both large and small buildings (Illustration: SINTEF).

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 minimise 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.

FME SecurEL is one of 8 newly funded centres for environment-friendly research with the objective to continue research activities carried out in FME CINELDI (2016-2024) (182). SecurEL, led by SINTEF, aims to facilitate research and innovation that contributes to a secure, resilient and sustainable electricity distribution network, ensuring both security of electricity supply and contributing to the transition to a zero-emission society. The research in SecurEL will focus on the new needs for knowledge, innovation and solutions arising from the fundamental changes in the distribution network driven by the electrification of society. The centre will develop new solutions to increase grid capacity in a cost-effective and socio-economic way while promoting value creation in business, public administration and society.

SecurEL has the following ambitions:

- Develop innovative concepts to enhance security of electricity supply
- Integrate resilience as a core element in the design and operation of distribution systems to ensure security of electricity supply
- Develop a risk-based operational planning frame work for increased utilisation of the grid, incorporating the interactions between grids-users and DSOs/TSO
- Incorporate models of component degradation, failure, and risk in power system models, enabling analyses of system-components interactions and their impact on security of electricity supply
- Quantify the role of electricity distribution grids in achieving climate goals SecurEL has received 180MNOK from the RCN, and will span its activities over 8 years, until 2032.

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) (183). 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. Recognising 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, fostering collaboration and the development 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. Among its most significant achievements to date, StoRIES has officially published its Strategic Research and Innovation Agenda (SRIA) 2025, with a focus on Hybrid Energy Storage (184). Developed in close collaboration with EERA and EASE, the SRIA outlines how flexible, scalable storage technologies can be integrated into hybrid energy storage systems (HESS) to advance Europe's goals for climate neutrality, energy resilience, and industrial leadership. It identifies four strategic research areas—ecosystem development, digitalisation, sector integration, and system resiliency—accompanied by targeted recommendations on workforce, funding, and policy alignment. Complementing this milestone, StoRIES has also supported the publication of the open access book Hybrid Energy Storage: Case Studies for the Energy Transition (Lecture Notes in Energy, Vol. 47) (185), due for release by Springer Nature in October 2025. The volume features practical case studies across sectors such as industry, transport, buildings, and grid systems, showcasing real-world applications of hybrid energy storage. Developed in cooperation with the EERA Joint Programme on Energy Storage, the book gathers insights from leading experts and will be freely accessible, further contributing to knowledge sharing and education in the field.
In summary, StoRIES is a forward-looking project that recognises 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 (Multi-storage systems for multi-markets under multi-time horizons) 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 maximising their socio-economic benefits to further facilitate more VRES in the power grid (186). 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 (187). 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 utilising 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 utilising 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.

LowEmission (Research Centre for a Low-Emission Petroleum Industry on the Norwegian Continental Shelf) is a Petroleum Centre that aims to develop new technology and concepts for offshore energy systems, energy efficiency and integration with renewable power production technologies for application on the Norwegian Continental Shelf (NCS) (188). LowEmission gathers leading energy companies, operators and vendors, who have joined forces with globally recognised research groups at SINTEF and NTNU. The strong interaction within the Centre will accelerate development and implementation of low-emission offshore technologies and make it a platform for innovation. The main scientific focus in the Centre is on power and heat generation with lower emissions, on reduced energy demand, and on energy systems and management. The latter includes the development of digitalised solutions and concepts for integrating renewable power production technologies in the offshore energy system.

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 (189). 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 organised 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.

Additional previously described projects

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. The TREASoURCE project was described under Chapter 1. Raw materials and recycling- SINTEF projects.

8. 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 decarbonisation 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 that 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 that research and innovation provides Europe with the competitive and sustainable batteries needed to succeed in the energy transition.

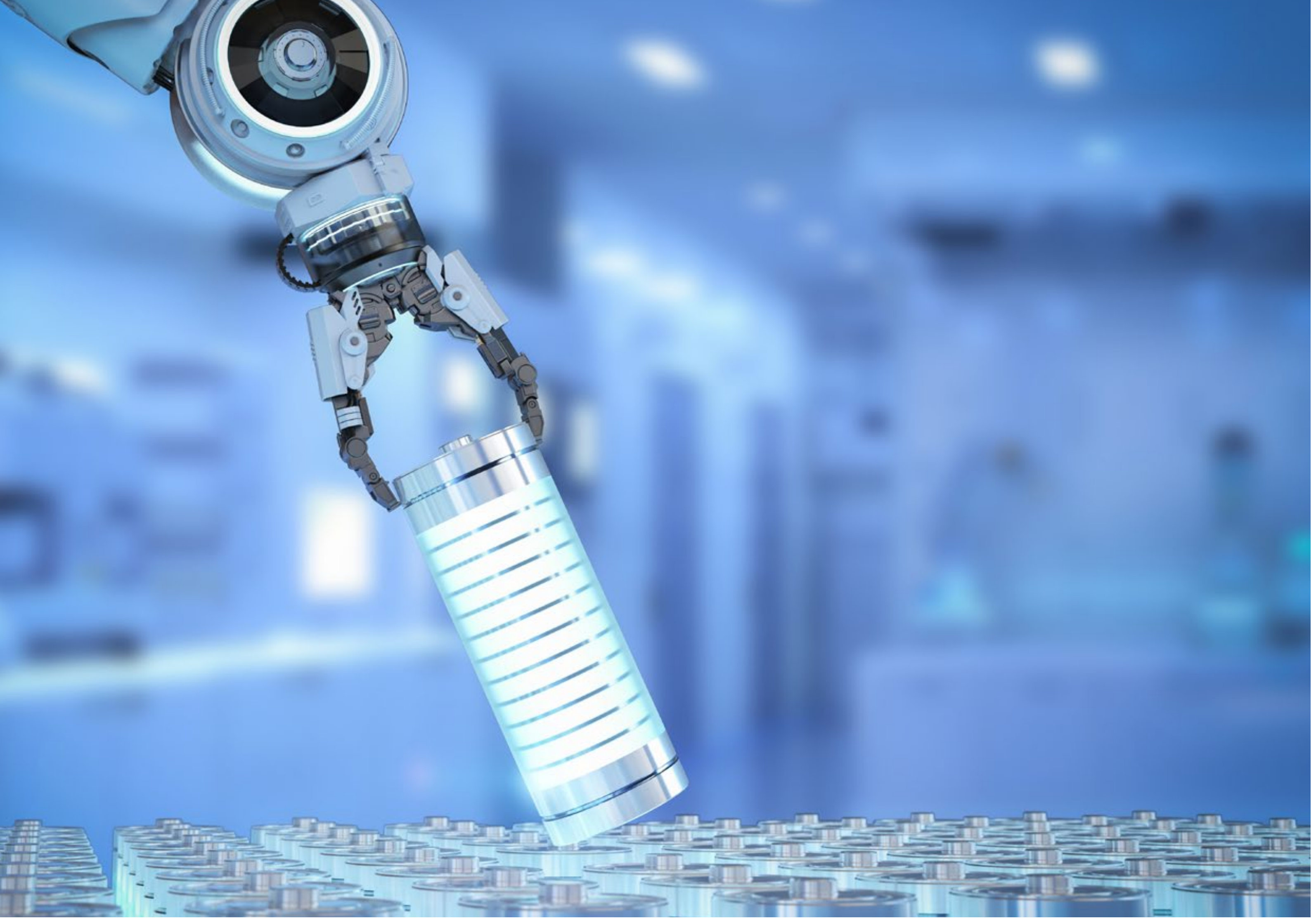
There are concerted efforts made by the leaders of the battery R&I initiatives to communicate, collaborate and avoid duplication. This effort ensures that all parts of the battery value chain and cross cutting issues are addressed from education to new business models and from fundamental interface modelling 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** (190): 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 Europe ETIP is in its final year in 2025, and a new call for a Coordination and Support Action (CSA) is opened with deadline in the fall of 2025.
- **Batteries European Partnership Association - BEPA** (191): 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 and Innovation 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.
- **Batteries Europe** (192): This European technology and innovation platform (ETIP) brings together all relevant stakeholders in the European batteries research and innovation ecosystem in order to develop and support a competitive battery value chain in Europe. The Batteries Europe Secretariat (BEST) in which SINTEF contributes, aims to enrich, strengthen and extend the key role of Batteries Europe by gathering academia, industry and research expertise within the Secretariat to consolidate the Battery R&I community and assist the



existing platform in the achievement of their ambitious goals by forging synergies and consolidating the workflow among the initiatives.
- **Battery 2030+** (193): 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 bold novel concepts in battery technology from direct recycling to materials and interface design.
- **The European Battery Alliance** (194): 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** (195): 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 (114) which is a not-for-profit European battery manufacturing alliance striving to create a unique European ecosystem of actors in the equipment and machinery segment for battery manufacturing industry, aiming to give Europe a leading position in this field.

9. 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 (140). The primary goal for NABLA is to provide a national infrastructure dedicated to the battery research and development to Norwegian research and industrial organisation. 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 (196) 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.

Figure 18. Cell assembly line in SINTEF Battery Lab (Photo: SINTEF).

Another part of the NABLA infrastructure hosted by SINTEF is a new **high-voltage and high-power battery tester, which is co-located with the Machinery Laboratory (M-lab)**, a 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 (197) 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 (198) 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.

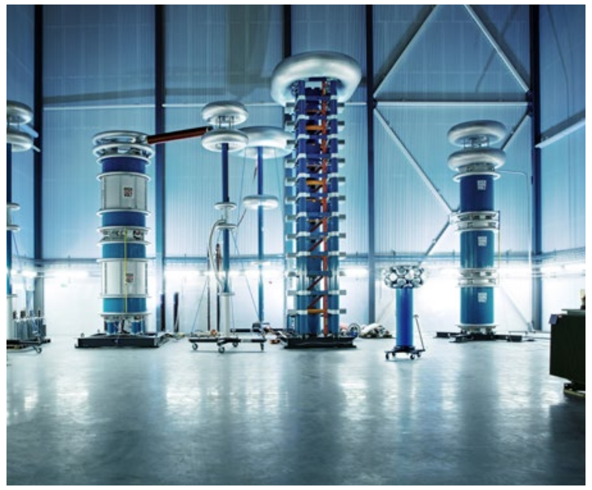


Figure 19. High voltage facilities at SINTEF Energy Lab (Photo: SINTEF).

SINTEF Pore Imaging Laboratory (199) is an advanced national and European research infrastructure comprised of multifaceted X-ray imaging facilities, with advanced analysis tools, and fast computing power. It has been applied for scanning of batteries, from small cylindrical cells to large pouch cells with sufficient resolution to get details of the battery architecture, e.g. electrode thickness, number of layers, position of tabs, defects.

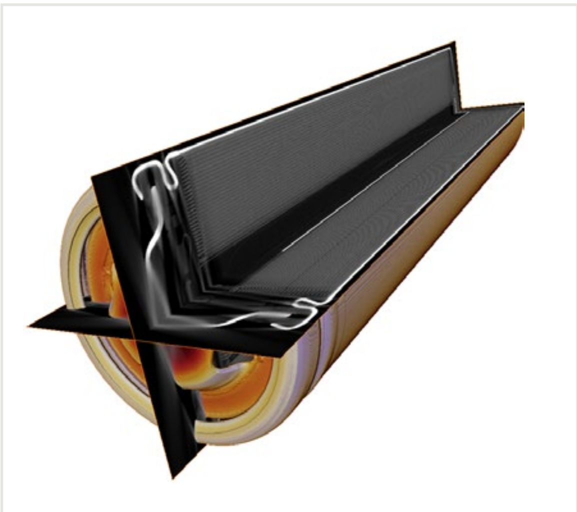


Figure 20. X-ray CT of 18650 cylindrical cells (Image: SINTEF).

Battery Innovation Lab at SINTEF Energy AS was established in 2024. This is a brand-new facility located on the Gløshaugen campus of NTNU, in Trondheim. The laboratory is equipped with both battery cell and module testers, but also a state-of-the-art **flow battery testing** bench allowing 4 flow batteries to be tested at once. The battery cells and module testers are both equipped with 16 channels. 4 cells can be tested in parallel with a current of 240 A in total and voltage up to 5V. The Battery module tester, provided by Neware, allows to test up to 4 modules in parallel with a current of 120 A in total, and a voltage of 3 to 60 V. The laboratory is also equipped with a battery cell characterisation, with 8 channels, for flow battery testing. This device can run tests up to 9V/15A.

Figure 21: Flow battery test set-up for one flow battery cell (Photo: SINTEF).

Combining all of SINTEF's available infrastructures, it is possible to test and characterise 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, as well as flow-batteries.

Independent of, but highly relevant for, batteries, SINTEF hosts and has access to world leading physical characterisation equipment. This includes, but is not limited to, many different microscopic and spectroscopic methods, and SINTEF have employed scientific experts for these.

NORTEM – The Norwegian Centre for Transmission Electron Microscopy (200) 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. 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.

Norwegian Laboratory for Minerals and Materials - The infrastructure project MiMaC aims at establishing a world-leading national laboratory for multi-scale (atomic to micron) and multi-dimensional (from 1D to 3D) structure characterisation and high-sensitivity (down to ppb level) chemical analysis of minerals, metals and advanced nano materials (201). The national laboratory will be based on a further development, upgrading and coordination of the existing laboratories, located at each node of the three consortium members NTNU, NGU and SINTEF. A series of state-of-the-art instruments of national importance will be invested, which include- 3D Atom Probe Tomography (APT) for 3D chemical and structural analysis at the nm scale.-Field Emission Electron Probe Micro-Analyser (FE–EPMA), for µm-level chemical and structural analysis.-Automated Mineralogy System (AMS) for efficient mineral characterisation.-Two sets of complementary Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA–SS–ICP–MS and LA–QqQ–ICP–MS/MS) for chemical and isotopic mineral analysis and mapping, and inorganic and hybrid organic-inorganic materials analysis. The total budget for the proposed infrastructure is 84.827 MNOK (with 54.942 MNOK in RCN support). Such a national infrastructure is highly complementary to the existing micro/nano structure characterisation infrastructures in Norway, e.g. NorTEM, NanoLab, NorFab and RECX. MiMaC will strengthen the fundamental and applied research environments of academic institutions and the innovation in mineral and metallurgical industries. It will also facilitate the research fields of nano and advanced materials in Norway. The value-chain approach from minerals to materials will open for new cross-disciplinary research opportunities.

Other national infrastructures which are important for SINTEF's battery research are **NTNU NanoLab** (202) and **RECX** (203). 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 characterisation 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 characterisation.

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